Offshore wind farms in the Belgian part of the North Sea

Selected findings from the baseline and targeted monitoring

Edited by
Steven Degraer
Robin Brabant
Bob Rumes

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Royal Belgian Institute of Natural Sciences
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Cover photo:
The first phase of the C-Power wind farm on the Thorntonbank (photo J. Haelters / RBINS / MUMM)

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Phase I of the Belwind wind farm on the Bligh Bank Photo RBINS / MUMM

1.1. Introduction

The new European Climate Plan, launched in 2008, imposes upon each member state a target contribution figure for the production of electricity from renewable energy sources that should be achieved by 2020. For Belgium, this target figure is 13 % of the total energy consumption, part of which will be realised in offshore waters. Since the Royal Decree of 17 May 2004 assigned a zone for the production of electricity in the Belgian part of the North Sea (BPNS), three companies, C-Power (Thorntonbank: 54 turbines, 325 MW), Belwind (Bligh Bank: 110 turbines, 330 MW) and Northwind (formerly: Eldepasco) ("Bank zonder Naam": 72 turbines, 216 MW), were granted a domain concession and an environmental permit to build and exploit an offshore wind farm. In 2009, early 2010, three other companies, Norther, Rentel and Seastar, obtained a concession, but so far only Norther is applying for an environmental permit. Both C-Power and Belwind started their construction phase, with six gravity based foundation (GBF) windmills on the Thorntonbank in 2008 (fully operational early 2009) and with 56 monopile windmills on the Bligh Bank in 2009 (fully operational in 2010), respectively.

To allow for a proper evaluation and auditing of the environmental impacts of offshore wind farms, the environmental permit includes a mandatory monitoring program to ensure (1) the ability to mitigate or even halt the activities in case of extreme damage to the marine ecosystem and (2) an understanding of the environmental impact of offshore wind farms to support policy, management and design of future offshore wind farms. The former objective is basically tackled through the baseline monitoring, focusing on the a posteriori, resultant impact quantification, while the latter monitoring objective is covered by the targeted or process monitoring, focusing on the cause-effect relationships of a priori selected impacts. As such, the baseline monitoring deals with observing rather than understanding impacts and hence leads to area-specific results, which might form a basis adjusting existing activities (or even halting activities, in case of extreme environmental damage). Targeted monitoring on the other hand deals with the understanding of the processes behind the impacts and hence leads to more generic results, which might form a sound basis for impact mitigation. For more details on baseline and targeted monitoring we refer to Degraer & Brabant (2009)[1].

The monitoring program targets physical (i.e. hydro-geomorphology and underwater noise), biological (i.e. hard substratum epifauna, hard substratum fish, soft substratum macrobenthos, soft substratum epibenthos and fish, seabirds and marine mammals), as well as socio-economic (i.e. seascape perception and offshore renewables appreciation) aspects of the marine environment. The Management Unit of the North Sea Mathematical Models (MUMM) of the Royal Belgian Institute of Natural Sciences (RBINS) coordinates the monitoring and specifically covers hydro-geomorphology, underwater noise, hard substratum epifauna, radar detection of seabirds, marine mammals and socio-economic aspects. In 2010, MUMM further collaborated with different institutes to complete the necessary expertise in the following domains: seabirds (Research Institute for Nature and Forest, INBO), soft substratum epibenthos and fish (Institute for Agricultural and Fisheries Research, ILVO-Fisheries), soft substratum macrobenthos and hard substratum fish (Marine Biology Research Group of Ghent University) and atmospheric noise (INTEC of Ghent University).

1.2. This report's focus

The first phase of the monitoring program started the year before the (anticipated) construction of the first wind turbines at the Thorntonbank (i.e. 2005). At the end of this first phase (2005-2012), an overview and discussion of the monitoring activities and outcomes between MUMM, its monitoring

[1] Degraer, S. & Brabant, R., (Eds.) (2009). Offshore wind farms in the Belgian part of the North Sea. State of the art after two years of environmental monitoring. Royal Belgian Institute for Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine Ecosystem Management Unit. 287 pp. + annexes.

partners and the wind farm industry is planned. This workshop will be the first thorough evaluation of possible impacts of marine wind farms in Belgian waters.

Although an exhaustive and thorough evaluation of the observed environmental impacts of offshore wind farms in the BPNS is only expected after this first phase, important monitoring results become available along the monitoring trajectory. These results are published in yearly scientific reports, each focusing on a selection of scientific targets. A first set of scientific reports presented data on the baseline situation at future impact and reference sites[2]. The first integrated report then focused on the appropriateness of the general settings of the monitoring program, e.g. selection of reference sites and conditions, as well as strategic and technical recommendations for future monitoring (Degraer & Brabant, 2009[1]). Last year's report mainly targeted the first scientific results on the evaluation of the early and or localized environmental impacts of the GBF windmills (C-Power) and / or monopiles (Belwind), as well as on the natural spatio-temporal variability (i.e. dynamic equilibrium) of various ecosystem components (Degraer *et al.*, 2010[3]). Finally, this year's report focused on a selection of targeted monitoring results and attempted to construct a hypothesised impact scenario, including presumed cause-effect relationships between the various ecosystem components.

The above mentioned focuses of this year's report by no means preclude the fact that more data have been collected within both the C-Power and Belwind concession areas. These data will however be addressed in one of the upcoming yearly scientific reports.

1.3. Impact assessment: scenario building

Two types of impacts can be discerned: acute impacts and chronic impacts. While the acute impacts might be severe in nature (e.g. marine mammal disturbance by pile driving or soft substrate benthos mortality due to dredging activities), these impacts are of short duration after which (full) recovery will take place, either rapidly or slowly. Chronic impacts however are characterized by their long standing nature and by consequent prolonged changes of the natural environment. They are hence expected to last for the entire lifetime of the wind farms, which will be at least 20 years. Chronic impacts should thus be considered of major importance to the environmental monitoring of offshore wind farms.

While acute impacts of the wind farms in the BPNS were not yet detected, an integration of the monitoring findings obtained so far, already allowed for some speculation on the chronic impact process within the Belgian wind farm zone. It should however be stressed that this truly is a speculation based on preliminary results and should hence be interpreted with care. Further elaboration of the monitoring programme might consequently either confirm or correct the current hypothesis.

This section aims at framing the current findings within an integrated view on the possible chronic impact of Belgian offshore wind farms.

1.3.1. A prolonged organic enrichment of a naturally relatively poor environment?

With the construction of the offshore wind farms, artificial hard substrate is introduced within naturally soft sediment environment. This introduction caused some major environmental changes, of

[2] De Maersschalk, V., Hostens, K., Wittoeck, J., Cooreman, K., Vincx, M. & Degraer, S., (2006). Monitoring van de effecten van het Thornton windmolenpark op de benthische macro-invertebraten en de visfauna van zachte substraten. 88 pp.
Vanermen, N., Stienen, E.W.M., Courtens, W. & Van de Walle, M., (2006). Referentiestudie van de avifauna van de Thortonbank. 131 pp.
Henriet, J-P., Versteeg, W., Staelens, P., Vercruysse, J. & Van Rooij, D., (2006). Monitoring van het onderwatergeluid op de Thorntonbank: Referentieonderzoek van het jaar nul. 53 pp.

[3] Degraer, S., Brabant R. & Rumes B., (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. 2nd Edition. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine Ecosystem Management Section. 184 pp. + annexes.

which biofouling of the hard substrate is considered of high importance, since it might trigger a cascade of environmental impacts. From the previous reports (Kerckhof *et al.*, 2009[4] and 2010[5]), we already learned that many species promptly colonized the newly available hard substrate as soon as these became available. After two years, 74 biofouling species were detected on the foundations, with no less than four species being non-indigenous to the Southern North Sea. Three years after installation of the first windmills (this report), we were now able to demonstrate these new artificial hard substrate to be of particular importance to the obligate intertidal hard substrate species, for which offshore habitat used to be rare to non-existing in the Southern North Sea. Seventeen species, of which eight happen to be non-indigenous (e.g. the pacific oyster *Crassostrea edulis* and the midge *Telmatogeton japonica*) will as such be favoured by the offshore wind farms and hence strengthen their invasive strategic position in the Southern North Sea.

The biofouling organisms of the hard substrates further represent a local increase of benthic productivity, being a major, though local source of organic matter to the water column. The particulate organic matter will take either the form of suspended particulate matter (SPM) or will be deposited onto the sediment surface. As the marine environment, where both actual Belgian wind farms are being developed, is situated in an offshore area, typified by a lower organic matter concentrations in the water column and in the sediment, its organic enrichment is expected to cause a significant environmental impact. This impact could be preliminary confirmed by the lower median grain size of and higher macrobenthic densities within the sandy sediments in the close vicinity of the turbine: the lower median grain size (av. 332.8 ± 15 µm, at 1 and 7m from the scour protection) indicates fine particles (from the water column, SPM) to get mixed with the originally pure medium sandy sediments, while the higher macrobenthic densities (ranging from 955 ind./m² to a maximum of 12407 ind./m²) might indicate organic enrichment of the sandy sediments. This pattern was however not uniformly distributed around the windmill foundation. Higher chlorophyll a concentrations in the sediment (maximum 12.8µg/g) and a lower median grain size (av. 297.9 ± 10.4 µm) together with high densities for *Lanice conchilega* and *Spiophanes bombyx* (up to 1949 ind./m² at seven meters and 1082 ind./m² at seven meters, respectively) were found parallel to the prevailing residual tidal current direction, while perpendicular to the residual tidal current, a median grain size (av. 382.8 ± 46 µm) and a dominance of the tube building amphipod *Monocorophium acherusicum* (2778 ind./m² on the Southeast and 1277 ind./m² on the Northwest gradient, both at one meter from the scour protection) was detected. All three species are known for their preferences for organically enriched sandy sediments as well as for their soft substrate stabilising capabilities and therefore provide a clear indication of a changing macrobenthic community.

1.3.2. Increased food availability for epibenthic and fish predators?

The biofouling organisms on the artificial hard substrates, as well as the enriched sandy sediment macrobenthic communities on their turn, represent an increased food availability for various predators, among which several (commercially important) fish species such as cod *Gadus morhua* and pouting *Trisopterus luscus*. Both species are known to frequent the artificial hard substrates of the Belgian wind farms in seasonally high densities (pouting: up to 30000 ind. close to one single

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[4] Kerckhof, F., Norro, A., Jacques, T.G. & Degraer, S., (2009). Early colonisation of a concrete offshore windmill foundation by marine biofouling on the Thornton Bank (southern North Sea). *In:* Degraer, S. & Brabant, R. (Eds.) (2009) Offshore wind farms in the Belgian part of the North Sea: State of the art after two years of environmental monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. 287 pp. + annexes.

[5] Kerckhof, F., Rumes, B., Norro, A., Jacques, T.G. & Degraer, S., (2010). Seasonal variation and vertical zonation of the marine biofouling on a concrete offshore windmill foundation on the Thornton Bank (southern North Sea). *In:* Degraer, S., Brabant R. & Rumes B. (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. 2nd Edition. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine Ecosystem Management Section. 184 pp. + annexes.

windmill) (Reubens *et al.,* 2010[6]). Whether they thrive in the close vicinity of the windmills or whether they are just attracted to the three dimensional structures (cf. attraction-production hypothesis) is yet to be determined. Their actually observed feeding on dominant hard substrate fouling organisms, e.g. *Jassa herdmani* and *Pisidia longicornis,* however, clearly hints towards the fact that wind farms are major feeding grounds for bentho-pelagic fish species. This study now confirmed cod to be attracted to offshore windmills and their surrounding erosion protection layers, as shown by the high residency (62 – 100 % of the days; max. 85 days) of some tagged cod specimens. Individual cod further profit from the variety of habitat – and hence probably also food resources – as demonstrated by their small-scale spatial distribution patterns nearby the windmills, where they occupy the erosion protection layer with its rich biofouling community, as well as the nearby biologically enriched sandy sediments. These small scale differences in habitat occupation are influenced by the diurnal cycle, with a preference for the sandy sediments during day time and both hard and sandy substrates at night.

The same increased food availability might further have favoured the sandy sediment epibenthos and fish. Whereas the former monitoring results did not allow to detect major and consistent impacts onto the sandy sediment epibenthos and fish, primarily due to the minor extent of the wind farms at that time, major year-to-year and seasonal variability, as well as logistic sampling problems (Derweduwen *et al.*, 2010[7]), this study provided a first glimpse on the possible wind farm impact. Within the wind farm for example, larger individuals of the swimming crab *Liocarcinus holsatus* (dominant size class: 42mm) and the (commercially important) brown shrimp *Crangon crangon* (dominant size class: 50mm) were found compared to outside the wind farm (dominant size class: 30mm and 45mm, respectively). Furthermore, whiting *Merlangius merlangus* was detected in higher densities (19 ind/1000m²) within the wind farm than at the reference stations (av. 10 ind/1000m²), in autumn 2010. The cause-effect relationship between improved food conditions and the observed effects are however less clear here compared to the hard substrate fish mentioned before. Improved feeding conditions, but also altered trophic interactions (e.g. predation pressure), nullified fisheries activities within the wind farms or a combination thereof might all have contributed to the observed changes within the sandy sediment epibenthos and fish. Belgian beam trawl fisheries for example were excluded from the Thorntonbank wind farm and these activities partly (mainly Eurocutters) moved to the gully between the Thorntonbank and the Bank zonder Naam, which may have had a significantly positive impact onto the sandy sediment benthos within the wind farm.

1.3.3. Wind farms as an improved habitat for seabirds and marine mammals?

Whether the same increase of food availability also impacted the seabirds and marine mammals in the area the same way as it influenced the benthic ecosystem components is yet another question to be solved. Both seabirds and marine mammals are highly mobile species, of which the surface area (seasonally) occupied is much larger than the BPNS. The consequently high spatial, but especially temporal variability complicates a correct interpretation of the chronic impacts of offshore wind farms, since any trend observed within the BPNS should be interpreted on a much wider geographical scale.

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[6] Reubens, J., Degraer, S. and Vincx, M., (2010). The importance of marine wind farms, as artificial hard substrata, for the ecology of the ichthyofauna. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. 184 pp. + annexes.

[7] Derweduwen, J., Vandendriessche, S. & Hostens, K., (2010). Monitoring of the effects of the Thorntonbank and Bligh Bank wind farms on the epifauna and demersal fish fauna of soft-bottom sediments: Thorntonbank: status during construction (T2), Bligh Bank: status during construction (T1). *In:* Degraer, S., Brabant, R. & Rumes, B. (Eds.), (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. 184 pp. + annexes.

In seabirds for example, we found that for most species we will be able to detect changes in numbers of 30-70% for most seabird species only after a period of ten years after the impact. This means that only if the wind farm causes a decrease or increase of 30-70% in a species' density, we will be able to statistically underpin this impact, but only after ten years of monitoring. Nevertheless, extremely important in this respect is to realise that not being able to detect a certain change does not mean that there is no effect! A focused monitoring of northern fulmar *Fulmaris glacialis*, northern gannet *Morus bassanus*, great skua *Stercorarius skua*, little gull *Larus minutus*, common gull *Larus canus*, herring gull *Larus argentatus*, lesser black-backed gull *Larus fuscus*, great black-backed gull *Larus marinus*, black-legged kittiwake *Rissa tridactyla*, sandwich tern *Sterna sandvicensis*, common tern *Sterna hirundo*, common guillemot *Uria alga* and razorbill *Alca torda* for example already allowed for deducing some cautious and preliminary trends. More precisely, sandwich and common tern activity increased significantly since the first turbines were built on the Thorntonbank and the same holds true for common and herring gull densities at the Bligh Bank. As for fish, frequenting the offshore wind farms, this enhanced seabird activity inside the wind farms may be induced by mere attraction to artificial structures as a stepping stone, a resting place or a 'reference' in the wide open seascape. The higher seabird densities might however also be caused by the localized organic enrichment and its consequent domino chain throughout the marine food web, as hypothesized above. While this increased seabird occurrence counters the worries of habitat loss due to avoidance or habitat deterioration, increased bird activity increases the risk of collision mortality, stressing the need for seabird radar research, to study flight activity inside the wind farms, and to model collision risks.

In marine mammals, the harbour porpoise is the only (seasonally) common species in Belgian waters (Haelters *et al.*, 2010[8]). Given the high spatio-temporal variability in the distribution of the harbour porpoise and its rather hidden life, especially for this species a wide variety of monitoring techniques are to be used to get a clear picture of the species' actual occurrence in Belgian waters (aerial survey, passive acoustic monitoring and strandings data analysis). While we now know the species is typically abundant (a density of ca. 0.57 animals/km², or in absolute numbers ca. 2.000 individuals in the BPNS in February and March 2010, almost 1% of the North Sea population) in inshore and offshore waters in late winter and early spring and a secondary peak of occurrence might also be encountered in offshore waters in early summer (this study), we still lack confident data to assess any possible chronic impact of offshore wind farms in the BPNS. It should however be noted that because of its seasonal presence in internationally important numbers, the harbour porpoise should receive our continued attention within the monitoring programme. The operational noise from windmills for example, might cause a behavioural response of the harbour porpoises, which are highly sensitive to (excessive) underwater noise. As the operational sound pressure level from the Belgian wind farms (in their current constitution) is however only 20 to 25 dB re 1µ Pa (steel monopiles) and 8 dB re 1µ Pa (gravity based foundation) above the ambient noise levels, no important acute impacts are to be expected here. Nevertheless, operational noise will be emitted throughout the whole life of the wind farm and might hence lead to chronic impacts.

Given the fact that, for both seabirds and marine mammals, the availability of sufficient and accurate data on the spatio-temporal distribution is of utmost importance, an increased attention is needed to collect the appropriate data for impact analysis. Within this aspect, we do not only have to take into account the combination of several monitoring techniques (as done for the marine mammals), but we should perhaps also focus our monitoring effort to those species, that are abundantly present (as done in both ecosystem components), and to those periods and areas when and where impacts are expected. One possible solution is to focus all energy on one wind farm area, which however would be a pity since a monitoring set-up with two (or more) impact and two (or more) control sites clearly is scientifically more consistent.

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[8] Haelters, J., Kerckhof, F., Jacques, T.G. & Degraer, S., (2010). Spatio-temporal patterns of the harbour porpoise *Phocoena phocoena* in the Belgian part of the North Sea. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Brussels, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. 184 pp. + annexes.

As stated before, this hypothesized chronic impact scenario is only based on preliminary observations within wind farms that are still under construction. Its test with reality is hence yet to be performed by a continued monitoring, in which baseline monitoring and targeted monitoring should be comprised. While the future monitoring might increasingly focus on targeted issues, disentangling cause-effect relationships and as such building on the true picture of the integrated impact of offshore wind farms, we should definitely not loose a continued attention for the baseline monitoring, as this will allow for an impact quantification. Both aspects of the monitoring should continue to go hand in hand.

1.3.4. Integrated quality assessment

Although the hypothesized scenario for chronic impact assessment helps identifying the impact's underlying cause-effect relationships, another ultimate objective of environmental monitoring is to assess an eventual change in the environmental quality. Environmental quality is however determined by a mandatory integration of the impacts on all ecosystem components and their interactions. Such integration is consequently highly complex and needs indicators, based on a profound understanding of ecosystem structure and functioning. Next to their integrative capabilities, these indicators further need to be easy to communicate as to assure their applicability in ecosystem management. It needs however to be stressed that all ecosystem quality indicators by definition are a simplification of a complexity of ecosystem characteristics and need further interpretation, based on a detailed knowledge and understanding of the underlying data.

A suite of ecosystem quality indicators can be found in literature, of which the Benthic Ecosystem Quality Index (BEQI) is commonly used in Belgian waters (e.g. in the framework of the EU Water Framework Directive). As such, the use of BEQI was applied to evaluate possible changes in the benthic community characteristics because of the windmill construction activities in the Thorntonbank concession area. This index evaluates the deviation in macrobenthic density, number of species, species composition and biomass between the benthic data collected in the impact area and the control area, both the period before and after the construction of the first windmills.

The index and its parameters showed that the benthic characteristics in the different sub-areas of the Thorntonbank concession area corresponded with those observed in the control areas (Thorntonbank and Goote Bank), except in sub-area A (the impact area) in 2008, which is the moment of the construction of the six windmills. This was not observed with the average BEQI score, because the scores for density and number of species compensated for each other. But, based on the score for number of species in the impact area (2005 autumn: 0.933; 2008 autumn: 0.543; 2009 autumn: 0.767), it can be concluded that the diversity of the benthic community was disrupted in 2008. In 2009, the benthic community characteristics again showed a high correspondence with the characteristics observed in the control areas. This means that, after a single year, the benthic community in subarea A had recovered.

This first and preliminary test of the applicability of the BEQI within a Belgian offshore wind farm impact monitoring context confirmed that the use of a benthic indicator BEQI to evaluate environmental changes is a promising tool to summarize all observed patterns.

Chapter 2. Offshore wind energy development in the Belgian part of the North Sea & anticipated impacts: an update

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Cable laying vessel in the Belwind wind farm

Photo RBINS / MUMM

2.1. Context

The European Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market, imposes upon each Member State a target figure of the contribution of the production of electricity from renewable energy sources that should have been achieved in 2010. For Belgium, this target figure was 6 % of the total energy consumption. In January 2008, the European Commission launched its new Climate Plan, and a new target for Belgium was set at 13 % by 2020. Offshore wind farms in the Belgian part of the North Sea (BPNS) are expected to make an important contribution to achieve that goal.

With the Royal Decree of 17 May 2004 a zone in the Belgian part of the North Sea (BPNS) was reserved for the production of electricity. It is located between two major shipping routes: the north and south traffic separation schemes (TSS). The total surface area of this dedicated zone is 263.7 km² (Figure 1).

Prior to installing a wind farm, a developer must obtain (1) a domain concession in the zone reserved for wind energy development and (2) an environmental permit. Without an environmental permit, a project developer is not allowed to build and exploit a wind farm, even if a domain concession was granted.

When a project developer applies for an environmental permit an administrative procedure, mandatory by law, starts. That procedure has several steps, including a public hearing during which the public can express any objections. Later on during the permit procedure, the Management Unit of the North Sea Mathematical Models (MUMM) of the Royal Belgian Institute of Natural Sciences renders advice on the possible environmental impact of the future project to the Minister responsible for the marine environment. MUMM's advice includes an environmental impact assessment, based on an environmental impact study that is set up by the project developer. The Minister then grants or denies the environmental permit in a duly motivated decree.

The environmental permit includes a number of terms and conditions intended to minimize or mitigate the impact of the project on the marine ecosystem. Furthermore, as required by law, the permit imposes a monitoring programme to assess the effects of the project on the marine environment. The environmental monitoring is a legal obligation and is the responsibility of the federal government. The monitoring has two goals:

- to enable the authorities to mitigate or even halt the activities in case of extreme damage to the marine ecosystem;
- to understand and evaluate the impact of offshore wind farms on the different aspects of the marine environment and consequently support the future policy regarding offshore wind farms.

The monitoring is lead by MUMM, but MUMM collaborates with other institutes that each have their expertise of the marine environment. The costs of the monitoring program are paid by the permit holders.

At present, three companies have been granted a domain concession and an environmental permit to build and exploit an offshore wind farm: C-Power in 2004, Belwind in 2008 and Northwind (formerly Eldepasco) in 2009. C-Power had its permit revised in 2006 and 2008, and the monitoring programme was adapted accordingly (Table 1).

C-Power and Belwind have already started their construction activities at the Thorntonbank and Bligh Bank, respectively, while Northwind's construction activities (72 turbines of 3MW) on the Bank zonder Naam were postponed till September 2012. More detailed information on those three wind farm projects can be found via www.c-power.be, www.belwind.eu & www.eldepasco.be.

Three other projects, Norther, Rentel and Seastar, were granted only a domain concession so far (Figure 1). The Norther project is located in the southern part of the wind energy zone. Rentel, obtained a concession in between C-Power and Northwind (Figure 1). Seastar, in between Belwind and Northwind, was granted a concession in March 2010, but this has been withdrawn. The Norther project recently applied for an environmental permit and that application is currently under consideration (Table 1).

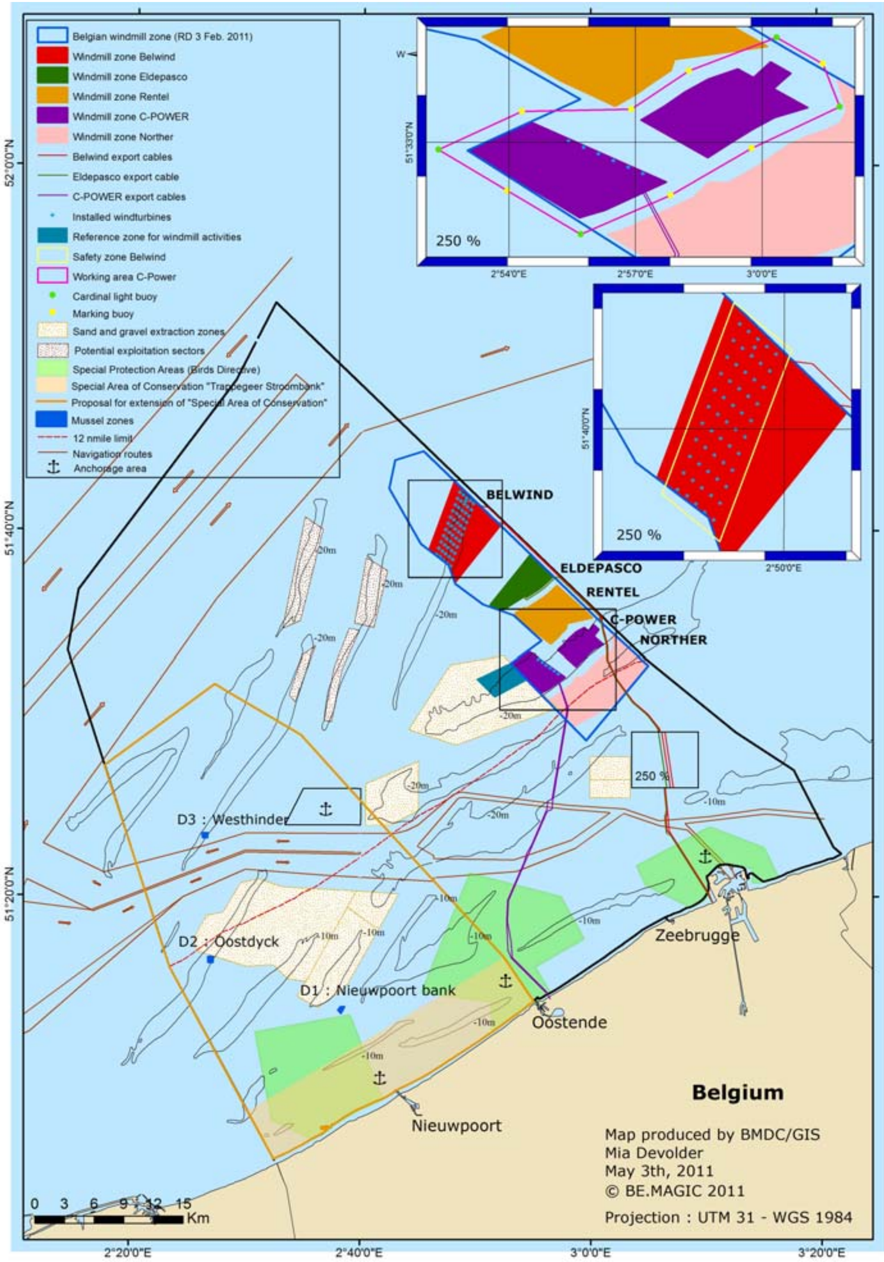

Figure 1. Zone reserved for the production of renewable energy by the Royal Decree of 17 May 2004 (http://www.mumm.ac.be/EN/Management/Atlas)

Table 1.
Overview of the dates when the projects were granted a domain concession and an environmental permit.

Project	Concession obtained	Permit application	Permit obtained
C-Power	27/06/03	17/6/2003 22/9/2005 -	14/04/2004 10/05/2006 25/04/2008
Belwind	5/6/2007	19/6/2007	20/2/2008
Eldepasco	15/5/2006	12/12/2008	19/11/2009
Norther	5/10/2009	10/5/2011	-
Rentel	4/6/2009	No application yet	
Seastar	24/3/2010[1]	No application yet	

[1] The concession of Seastar has been withdrawn.

2.2. Ongoing wind farm projects

2.2.1. C-Power

The C-Power project is located on the Thorntonbank (Figure 1). This is a sandbank located 27 km of the Belgian coast. Water depth in the concession area varies between 18 and 24 m. The sub sea power cable comes ashore near Ostend.

The C-Power concession is divided in two sub-areas (A and B). Across the two sub-areas 54 turbines will be installed. Phase I (30,5 MW), a pilot phase, consists of six turbines that were installed on row D of sub-area A and the first 150 kV offshore cable (Figure 2). The six 5MW Repower turbines are operating since the 10th of May 2009. Phase II and phase III will each consist of 24 turbines of 6.15 MW. The installed capacity of the entire wind farm will be 325 MW.

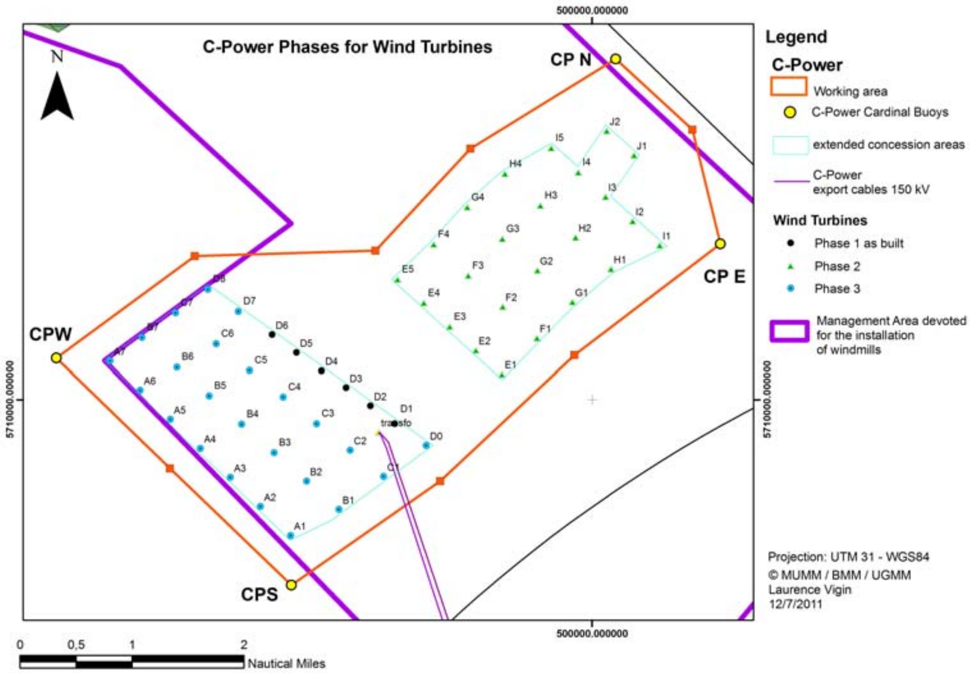

Figure 2. Layout of the C-Power project.

C-Power used gravity based foundations (GBF) for their phase I. These GBFs are hollow, concrete structures that are filled with sand, upon installation on the seabed. More detailed information can be obtained from Peire *et al.* (2009) and Brabant & Degraer (2010).

The foundation type for the phase II and III turbines is different from the pilot phase since jacket foundations, instead of the GBFs, will be installed. These foundations consist of a steel jacket with four legs (Figure 3). The foundations are installed using the pre-piling concept: four pin-piles are driven into the seabed and the legs of the foundation are grouted on the pre-piles. The piles vary in length depending on the water depth at their location and are in the range of 21.0 to 49.5 m.

The phase II of C-Power is located in sub-area B and consists of 24 wind turbines and an offshore high voltage station (OHVS) (Figure 2). C-Power is currently installing the 24 foundations of phase II (area B). Before the pre-piling of the pin piles started, bottom surveys were conducted in 2010 and the seabed needed to be prepared. This seabed preparation consisted of two steps: bulk dredging to remove the loose “sand dunes” and precision dredging, i.e. removal of approximately one meter of the bottom layer to create a flat surface. The total volume to be dredged for the seabed preparation is estimated to be 275.000 m³ for area B (phase II) and 240.000 m³ for area A (phase III), and an additional 4.640 m³ for the OHVS foundation. The dredged sediments are being disposed on three temporary disposal locations in sub-area A of the C-Power concession, situated in the gullies between the large dunes of the Thorntonbank and also used for the disposal of sediments during the construction of the first phase (Van den Eynde *et al.*, 2010).

Pre-piling started on March 30th 2011. Since the weather in the first half of 2011 was very good, piling of Phase II ended on June 12th and pin piles of the phase III turbines are currently being installed. Phase III will consist of 24 turbines and the installation of a second 150 kV export cable. The installation of the phase II turbines, the OHVS, the second export cable and the phase III jacket foundations is scheduled for 2012.

Figure 3. Photo of a jacket foundation of C-Power (Photo RBINS / MUMM).

2.2.2. Belwind

The Belwind project is situated on the Bligh Bank at about 40 km of the Belgian coast (Figure 1 & 4). The water depth in the concession area varies between 15 and 40m. Once finalized, the park will consist of 110 turbines and OHVS, with a total installed capacity of 330 MW. The construction of the park is divided in two phases.

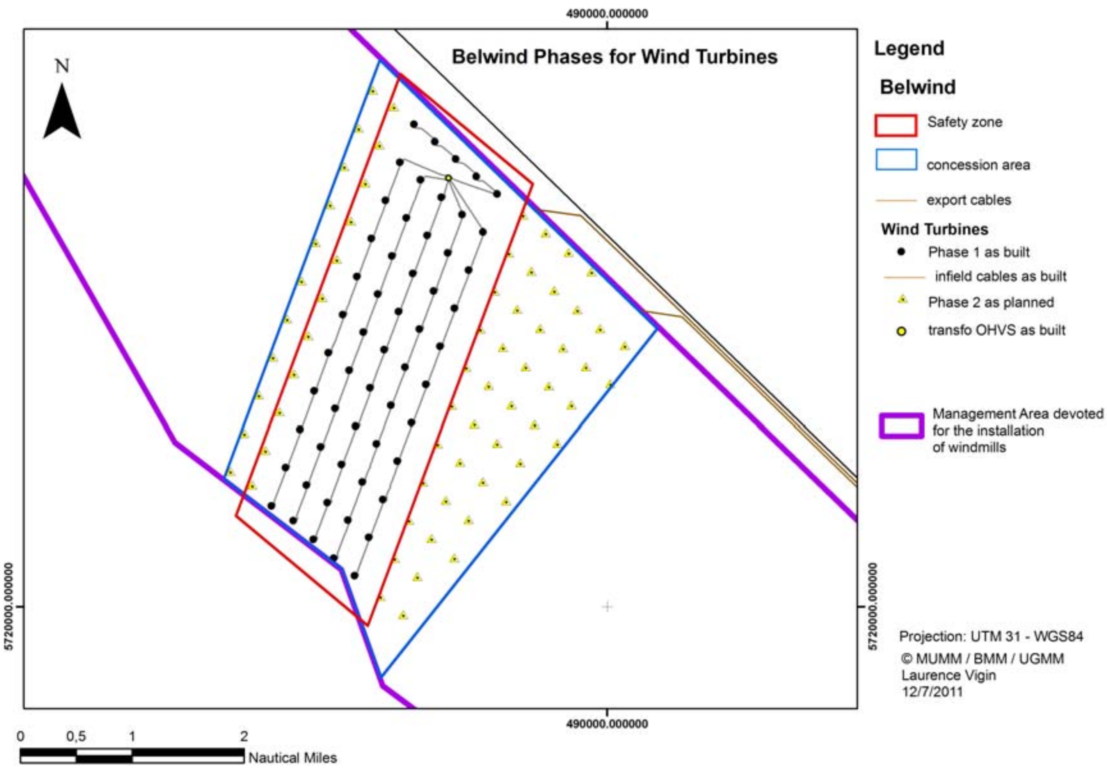

Figure 4. Lay out of the Belwind project.

In 2010, Belwind completed the first phase of their wind farm: 55 Vestas V90-3MW turbines, an OHVS, infield cables and an export cable. The piling of the monopiles (MP) started in September 2009 and the last of the 56 MPs was installed on February 5th 2010. On every monopile a transition piece (TP) was installed. The TP makes the connection between the MP and the wind turbine. All 55 wind turbines and the OHVS were installed in 2010. After they were commissioned, the 55 wind turbines started producing energy on January 13th, 2011 (Figure 5).

Figure 5. Phase I wind turbines on the Bligh Bank (Photo RBINS / MUMM).

The wind turbines are connected with the OHVS by infield cables. The OHVS has five decks, each deck has a surface of 250m² (Figure 6), and has a total weight of about 1150 tons.

Figure 6. Offshore high voltage station (OHVS) on the Bligh Bank (Photo RBINS / MUMM).

The 33 kV generated power is transformed by the OHVS to 150 kV and exported to shore by an export cable. A crucial step during the deployment of the export cable was the crossing of the ‘Scheur’, the main shipping route to Zeebrugge. The total length of the cable is 52km. The sub sea cable comes ashore at Zeebrugge (Figure 7).

Figure 7. Preparation of the beach pull in of the export cable at Zeebrugge (Photo Belwind).

2.3. Anticipated environmental impacts

With the construction and exploitation of the above described projects a new offshore activity started in the BPNS. While offshore wind farms help to achieve the goals set by 2001/77/EC on the promotion of electricity produced from renewable energy and help in the struggle against climate change, the construction and exploitation of offshore wind farms will also have certain impacts on the marine environment, which can be neutral, positive and/or negative for the marine ecosystem.

The environmental impact assessments (MUMM, 2004 & 2007) anticipated a variety of possible impacts. Some of those impacts are already being revealed during the first years of environmental monitoring (Degraer *et al.*, 2010), e.g.:

- Increased erosion of the natural sandy sediments around wind turbine foundations because of accelerating currents next to the foundations;
- Increased turbidity during the construction of the wind farms;
- Increased underwater noise pressure, generated during the construction and exploitation phases and the associated impact on marine mammals and fish;
- Colonisation of the introduced hard substrata (i.e. foundations) by epifouling organisms and its consequent stepping-stone effect on invasive species;
- Attraction of fish by the introduced hard substrata;
- Changes within the soft-substratum macro- and epibenthos and fish as a result of e.g. fisheries displacement, altered sediment characteristics and organic enrichment of the sandy sediments by (local) deposition of organic matter produces by the hard substrate epifauna;
- Altered spatio-temporal distribution, densities and migration routes of seabirds and marine mammals;
- Altered public perception of offshore wind farms.

With the monitoring programme, MUMM and its partners (1) assess the extent of the anticipated impacts on the different aspects of the marine ecosystem and (2) aim at revealing the processes behind the impacts. The first objective is basically tackled through the baseline monitoring, focusing on the a *posteriori*, resultant impact quantification, while the second monitoring objective is covered by the targeted or process monitoring, focusing on the cause-effect relationships of a priori selected impacts. As such, the baseline monitoring deals with observing rather than understanding impacts and hence leads to area-specific results, which might form a basis for halting activities. Targeted monitoring on the other hand deals with the understanding of the processes behind the impacts of a selected set of hypothesized cause-effect relationships highly relevant to the wind energy sector. This step is not only a pre-requisite for effective regulatory application, but also permits (1) current and future impact mitigation, (2) better prediction of future impacts, as well as (3) moving away from site-specific observations to more generic knowledge. More details on this topic can be found in Degraer & Brabant (2009) and Degraer *et al.* (2010).

In 2009, we reported on the lessons learnt and recommendations from the first two years of environmental monitoring (Degraer and Brabant, 2009). The integrated Degraer *et al.* (2010) report focused on the natural spatio-temporal variability and the evaluation of the early and localized environmental impacts at the C-Power and Belwind sites. This report targets a selection of major findings from the baseline and targeted monitoring.

2.4. References

Brabant, R. & Jacques, T.G., (2010). Offshore wind energy development in the Belgian part of the North Sea and anticipated impacts. pp. 9-18. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Spatio-temporal variability and early impact assessment. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine ecosystem management unit. 184 pp. + annexes.

Degraer, S. & Brabant, R., (Eds.) (2009). Offshore wind farms in the Belgian part of the North Sea: State of the art after two years of environmental monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine ecosystem management unit. 287 pp. + annexes.

Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Spatio-temporal variability and early impact assessment. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine ecosystem management unit. 184 pp. + annexes.

MUMM, (2004). Milieueffectenbeoordeling van het project ingediend door de n.v. C-Power. Rapport van het Koninklijk Belgisch Instituut voor Natuurwetenschappen, departement Beheerseenheid van het Mathematisch Model van de Noordzee (BMM). 155 pp.

MUMM, (2007). Milieueffectenbeoordeling van het BELWIND offshore windmolenpark op de Bligh Bank. Rapport van het Koninklijk Belgisch Instituut voor Natuurwetenschappen, departement Beheerseenheid van het Mathematisch Model van de Noordzee (BMM). 183 pp.

Peire, K., Nonneman, H. & Bosschem, E., (2009). Gravity Based Foundations for the Thornton Bank Offshore Wind farm. Terra et Aqua, 115, 19 – 29.

Van den Eynde, D., Brabant, R., Fettweis, M., Francken, F., Van Lancker, V., Sas, M. & Melotte, J., (2010). Monitoring of hydrodynamic and morphological changes at the C-Power and Belwind offshore wind farm sites – A synthesis pp. 19-36. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 3: 19-36.

Chapter 3. Characterisation of the operational noise, generated by offshore wind farms in the Belgian part of the North Sea.

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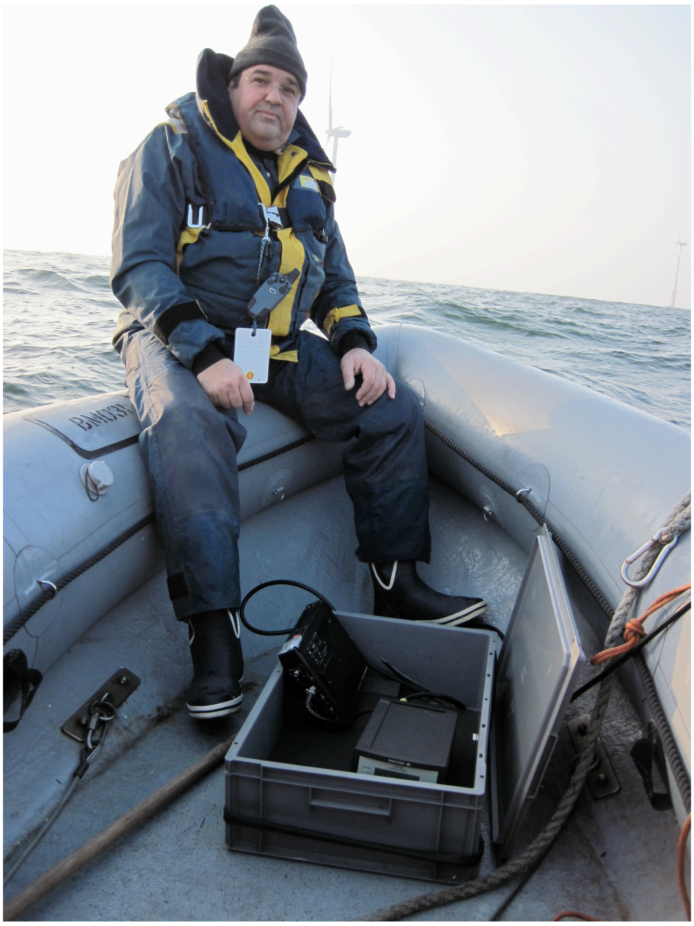

Underwater noise measurements on the Thorntonbank

Photo B. Rumes / RBINS / MUMM

Abstract

Offshore wind farms generate underwater noise during construction, operation and decommissioning. Underwater noise emitted by windmills in operational (production) mode needs to be quantified in order to better understand the full range of environmental impacts that wind energy production at sea may have on the surrounding marine life.

In this paper, operational underwater noise emitted by offshore wind farms in the Belgian part of the North Sea (BPNS) is quantified and compared to other locations in European Marine waters as well as the background situation prevailing before implementation. Measurements undertaken at two different offshore wind farms, one with 5 Megawatt (MW) turbines on concrete gravity based foundations (GBF) and one with 3 MW turbines on steel monopile foundations showed a different operational noise emission. The GBF offshore wind farm featured a slight increase of sound pressure level (SPL) of max 8 dB re 1µ Pa compared to ambient noise measured before construction. A more important SPL increase of 20 to 25 dB re 1µ Pa was observed for an offshore wind farm built using steel monopile foundations. Such noise emissions are much lower than those during piling in the construction phases. Nevertheless, this noise is being emitted during the operational phase of the wind farm, a period that is foreseen to last at least 20 years. As such, it is important to quantify the emissions in order to identify any possible impact.

Samenvatting

Een offshore windpark genereert onderwatergeluid tijdens de bouw-, operationele en ontmantelingsfase. Onderwatergeluid van windmolens in de operationele (productie)-modus moet worden gekwantificeerd om beter inzicht te verwerven in de gevolgen die de productie van windenergie op zee kan hebben op het omliggende mariene milieu.

In dit hoofdstuk is het operationeel onderwatergeluid afkomstig van offshore windparken gesitueerd in het Belgische deel van de Noordzee (BDNZ) gekwantificeerd en vergeleken met de resultaten uit andere parken in de Europese mariene wateren, alsook met de achtergrondsituatie voor de constructie van de windparken. Metingen uitgevoerd in twee verschillende offshore windparken, één waarbij men gebruik maakt van een gravitaire funderingen (gravity based foundation - GBF) en één met stalen monopile funderingen, wijzen op verschillende operationele geluidsemissies. In het offshore windpark met GBF werd een lichte stijging van het geluidsdrukniveau (Sound Pressure Level - SPL) waargenomen van max. 8 dB re 1µ Pa ten opzichte van omgevingsgeluid gemeten voor de bouw. Een belangrijkere verhoging in SPL van 20 tot 25 dB re 1µ Pa werd waargenomen in een offshore windpark waar stalen monopile funderingen worden gebruikt. Dergelijke geluidsemissies zijn veel lager dan tijdens de bouwfase, vooral indien de bouwfase het heien van palen vereist. Echter, operationele geluidsemissies vinden plaats tijdens de hele levensduur van het windpark (voorzien voor minstens 20 jaar) en daarom is het belangrijk om deze te kwantificeren om zo eventuele gevolgen te identificeren.

3.1. Introduction

According to the Marine Strategy Framework Directive (MSFD), EU Member States have to determine and control good environmental status (GES) for their marine waters (Tasker *et al*., 2010). One of the 13 descriptors of GES relates to anthropogenically induced underwater noise, as this may conflict with various ecosystem processes among which marine mammal communication (Richardson *et al.,* 1985; NRC, 2005; Nowacek *et al.,* 2007). Excessive underwater noise hence is considered a potential threat to the marine environment, receiving attention even at the European level. Human activities at sea indeed may generate underwater noise that could be harmful for marine life. Boyd *et al*. (2008) identified air guns, pile driving, intense low -or mid- frequency sonar, dredges, drills, bottom towed fishing gear, explosions, recreation vessels, acoustic deterrents, overflying aircraft (including sonic booms) and shipping as sources of anthropogenic noise that could affect marine mammals.

At present major attention is paid to the underwater noise and its ecological impacts generated by the construction, operation and in the future also dismantlement of offshore wind farms (Huddelston, 2010). When such underwater noise is considered, four different phases should be distinguished during the life cycle of an offshore wind farm: (1) before implantation - 'T reference' situation, (2) the construction phase, (3) the operational phase and (4) the dismantlement phase (Nedwell *et al.,* 2004). For the Belgian part of the North Sea (BPNS), several studies already documented the first two phases. The initial situation (T reference) at the Thorntonbank (C-Power site) was documented by Henriet *et al*. (2006), while Haelters *et al*. (2009) investigated the initial situation (T reference) at the Bligh Bank (Belwind site). Both T reference spectra are presented in Figure 2 and feature mean SPL just little above 100 dB re 1µ Pa for Thortonbank and just below 100 dB re 1µ Pa at the Bligh Bank. The construction phase was documented by Haelters *et al.* (2009) for six gravity-based founded (GBF) wind mills at the Thorntonbank and by Norro *et al*. (2010) for piling activities at the Bligh Bank. The spectrum measured 770 m away from the piling source is presented in Figure 2 and a peak SPL of 193 dB re 1 µPa was measured at that distance. The operational and – later on – dismantlement phases are yet to be quantified.

During the operational phase, underwater noise is produced by the rotation of the wind turbines and is transmitted to the water by the support structure. Operational underwater noise produces SPL much lower than that emitted during the construction phase, especially when pile-driving is applied (Huddleston, 2010). However, the construction noise generally lasts for a limited period of time (weeks to months), while operational noise is produced throughout the lifetime of the wind farm (more than 20 years) and may therefore have a chronic impact on the marine ecosystem.

Measurements of operational noise emitted by the Horns Rev and Nysted offshore wind farms for instance showed a higher than background noise intensity at a frequency below 1 kHz. Boesen & Kjaer (2005) provided that information without quantification. Betke (2006) further demonstrated the operational noise of a 2 MW turbine to have its highest sound pressure levels at about 150 Hz and 300 Hz, with a respective sound pressure level of 118 dB and 105 dB re 1 µPa. The operational noise also proved to depend on the type of foundation used (Uffe, 2002): concrete and steel pile foundations showed different spectral features such as a difference of 10 dB re 1µ Pa at 100 Hz and 15 dB re 1µ Pa at 200 Hz between the two types of foundations (steel foundation being noisier). That study further qualified the noise emitted by both types of foundation as stronger than the ambient noise for the frequencies below 1kHz (30dB re 1µ Pa at 100 Hz and 20 dB re 1µ Pa at 200 Hz). However, Nedwell *et al*. (2007) concluded that operational noise produced by windmills could fall well within the natural range of variability in background noise levels.

This paper presents the first data on operational underwater noise of both the C-Power and Belwind offshore wind farms and, as such, contributes to the characterisation of human induced underwater noise in the BPNS.

3.2. Material and Methods

3.2.1. Measurements methodology

The same measurement protocol as used for previous underwater noise measurements in Belgian wind farms was used for the present study. In summary: measurements of wind farm operational noise were performed from a drifting Rigid Hull Inflatable Boat (RHIB) inside the park in the vicinity of the windmills (Figure 1a & b). To avoid interaction with the hydrophone, the engine, radar and echosounder were turned off. The geographic position and time were recorded with a handheld GPS GARMIN GPSMap60 every 5 seconds. The clock of the recorder was synchronised beforehand with the GPS-time (UTC). At the start and the end of each measurement a reference signal was recorded. For more details: see Haelters *et al.* (2009).

Three recordings of 20 min each were made on the 8th of March 2010 at the Thorntonbank site, featuring concrete GBF foundations and on the 4th of March 2011 at the Bligh Bank site, featuring steel pile foundations. During the latter recording, a few small working boats were present in the area. Two recordings were well within the wind farm and as such truly measured operational noise (Figure 1), while one record was taken at great distance (+6 km) from the offshore wind farm and should hence be considered a background noise measurement. Weather conditions encountered on the 8th March 2010 and 4th March 2011 featured wind of 4-5 BF and a sea state of 2 to 3.

Table 1.
Geographic position and distance to the windmills of the selected recordings (coordinates in WGS84).

Selected recordings at the Thorntonbank (8th March 2010)					
Position start recording				Distance from windmill (m)	Type of noise
Northing		Easting			
51°	32.874’	2°	55.769’	12-520	Operational noise
51°	30.422’	2°	51.967’	6400-7200	Background
Selected recording at the Bligh Bank (4th March 2011)					
Position start recording				**Distance from windmill (m)**	
Northing		**Easting**			
51°	38.908’	2°	48.064’	186-1200	Operational noise

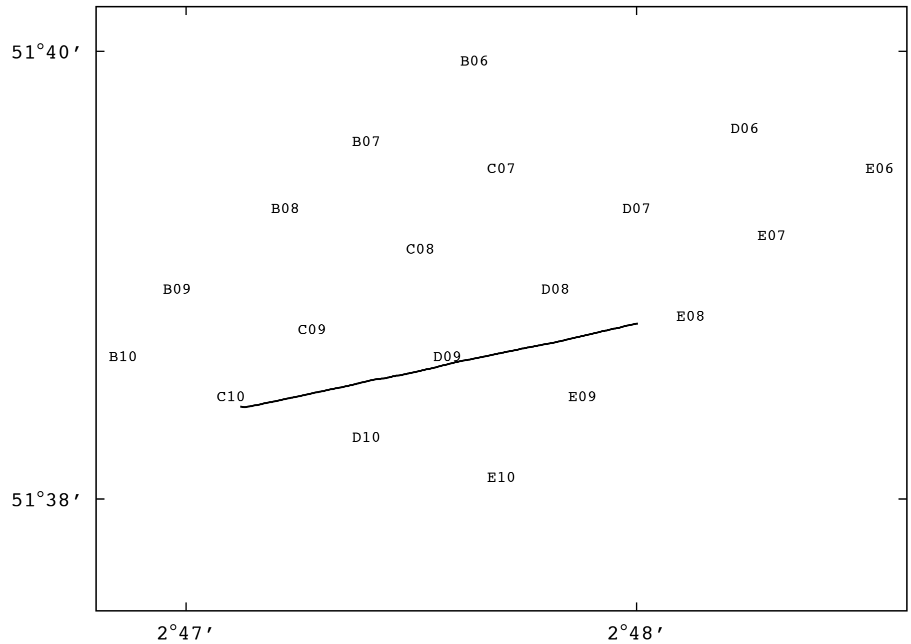

Figure 1a. Track path (black line), realised inside the Belwind (Bligh Bank) wind farm on the 4th April 2011. Steel monopile positions at the centre of the name label. Latitude North and Longitude East from Greenwich.

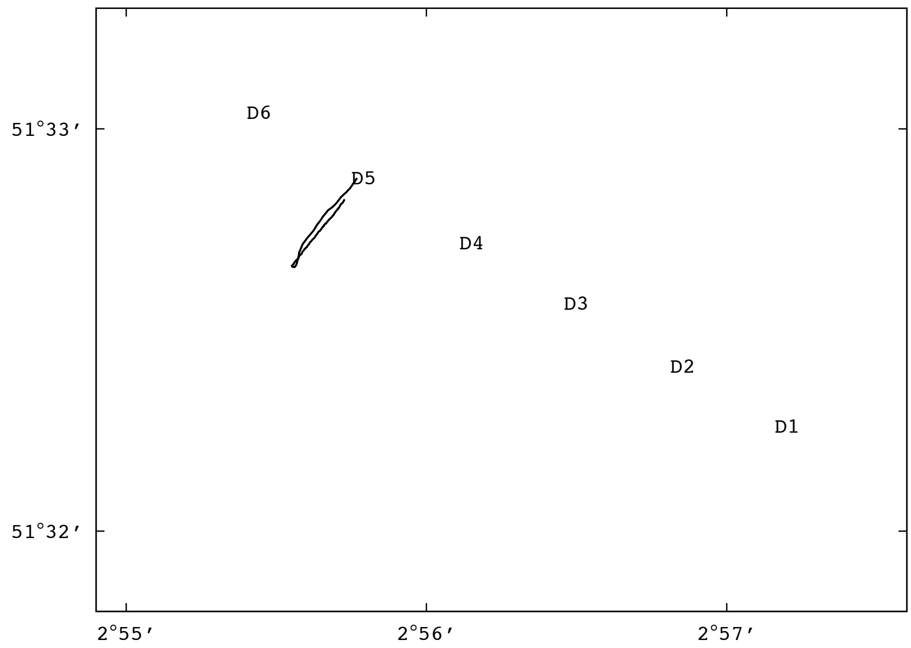

Figure 1b. Track path (black line), realised inside the C-Power (Thorntonbank) wind farm on the 8th March 2010. GBF positions at the centre of the name label. Latitude North and Longitude Est from Greenwich

3.2.2. Acoustic measurement equipment

At every measurement, one Brüel & Kjær hydrophone (type 8104) was deployed at a depth of 10 m. A Brüel & Kjær amplifier (Nexus type 2692-0S4) was connected between the hydrophone and the recorder in order to allow for an amplification of the signal. The reference signal was used together with the output sensitivity of the Nexus to calibrate the recorded signal. The signal was recorded using an audio MARANTZ Solid State Recorder (type PMD671). It was operated with the highest possible sampling rate of 44100 Hz. The signal was recorded in WAVE format (.wav) on Compact Flash cards of 2 GB (Sandisk Ultra II). Batteries powered all equipment.

3.2.3. Analysis of the recordings

Analysis here focused on the third octave band spectrum of the underwater SPL. The spectra were computed using MATLAB routines built according to the norm IEC1260. For reasons of comparison, the spectra of the three recordings (Belwind and C-Power in operation and the background noise at the C-Power site) were further complemented with former measurements of (1) the T reference noise at the Thorntonbank (Henriet *et al.*, 2006) and the Bligh Bank (Haelters *et al.*, 2009) and (2) the piling noise at the Bligh Bank (Norro *et al.,* 2010).

3.3. Results

The three spectra representing T reference, background and operational situation at the Thorntonbank all showed a similar amplitude all along the frequency domain (Figure 2). Some differences of 5 to 8 dB re 1 µPa were observed between the T reference noise (CP T_{ref}) and the two newly recorded spectra (CP Background and CP Operational) at the Thorntonbank. These differences were maximal at 110 and 200 Hz and at 4 kHz. At the Bligh Bank, an overall difference in SPL of about 20 dB re 1 µPa was observed between the reference measurement (BW T_{ref}) and operational noise (BW Operational). This difference in amplitude increased to 25 dB re 1 µPa at a frequency of 8 kHz. Except for the Belwind operational noise, all spectra decayed at frequencies higher than 1 kHz.

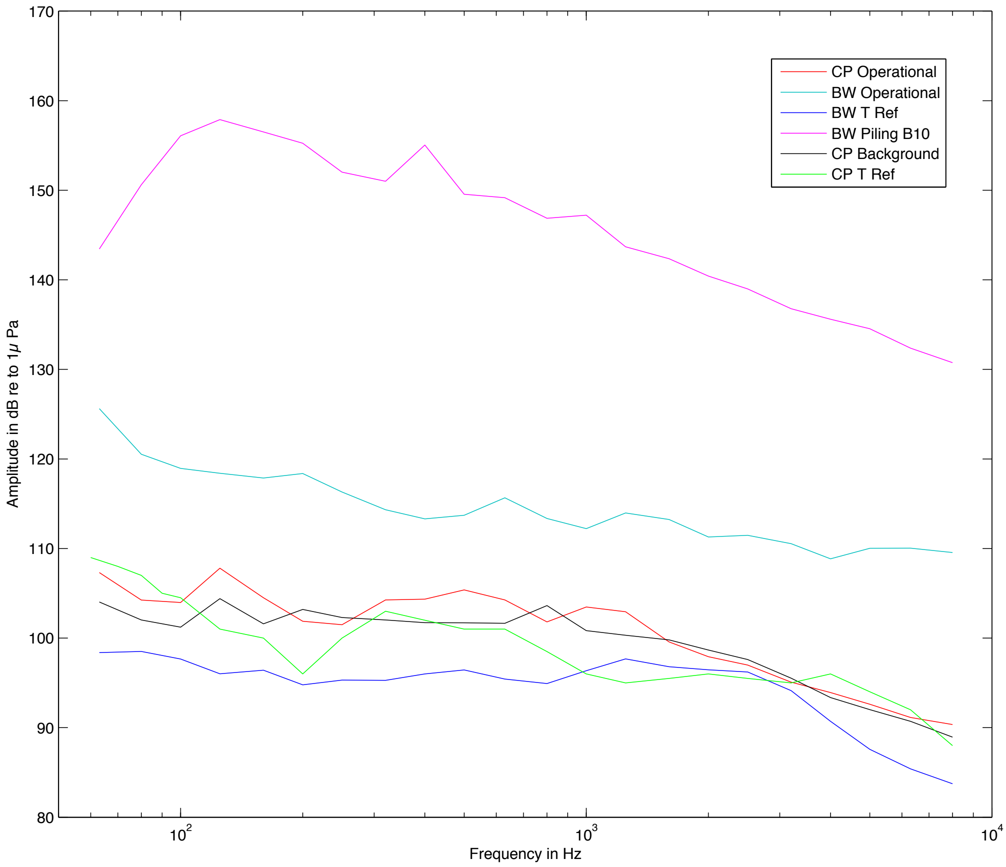

Figure 2. Spectra of underwater noise, measured inside the C-Power (CP) and Belwind (BW) wind farms, located respectively at the Thorntonbank and Bligh Bank. Operational noise generated during wind farm operation; T Reference (T ref), measurement before the construction activities started; background: measurement at > 6 km from the C-Power wind farm in operation; piling B10, spectra measured at 770 m from the piling activities at location B10.

All T reference and background spectra were at minimum 34 dB re 1 μPa below the piling spectrum (Figure 2). The operational noise, generated by the C-Power GBF windmills in operation was 52 dB re 1 μPa lower at 110 Hz, while this difference decreased to 39 dB re 1 μPa at 110 Hz for the operating Belwind steel monopile windmills.

The operational spectra of both wind farms showed clear SPL peaks at frequencies ranging from 100 Hz to 1 kHz (Figure 2). A first peak at about 130Hz was visible at the C-Power site, while the first peak visible within the operating Belwind wind farm was shifted to about 200 Hz. At higher frequencies, several peaks were observed at similar frequencies (i.e. 600 Hz and 1,3 kHz) for both wind farms. The absolute lowest SPL was recorded during the reference noise measurement at the Bligh Bank.

Finally, some differences in reference and background noise levels were observed within both offshore wind farms, with the Bligh Bank situation representing the most quiet condition.

3.4. Discussion

3.4.1. Operational noise versus T reference noise and importance of the foundation type

A difference of about 20 dB re 1 µPa was found between the Belwind T reference and operational noise. As different weather conditions could not explain such difference (see next §) the difference should be interpreted as true operational noise, produced by steel monopiles, as supported by the fact that the RHIB was inside the concession area throughout its complete drift (Figure 1a) and was passing close to the E08, D09 and C10 windmills. Furthermore, only a few small working boats were present in the direct vicinity of the hydrophone during measurement.

Compared to the T reference noise levels, the operational noise measurements at the C-Power wind farm (Figure 2) showed a slight increase from 5 to 8 dB re 1 µPa at e.g. 110 Hz, 200 Hz and at frequencies a little higher than 1 kHz, while the difference was neglectable at 60 Hz, 100 Hz, 320 Hz and 3,2 kHz. As such, the operational noise of the C-Power GBF windmills can be considered low. It should however be noted that the number of windmills, contributing to the recorded noise, was potentially (much) higher in the Belwind wind farm compared to the C-Power wind farm (Figures 1a, b), which might explain the increased SPL at the Belwind site. This effect might however have been counteracted by the fact that the recordings at the C-Power site started closest to the windmill. Although the differential effect of both issues cannot be evaluated for the time being, there is no basis to assume that these might have largely influenced our measurements.

We consequently demonstrated that concrete GBF windmills are likely to be less noisy (- 20dB re 1 µPa) than steel foundation windmills. We furthermore showed that, contrary to what was forecasted by Uffe (2002), the operation of steel pile foundation windmills is noisier than the natural ecosystem conditions over the frequency of 1 kHz (cf. reference noise levels). Steel pile foundation windmills finally lacked the decay of the spectrum at frequencies higher than 1 kHz, typical for the reference, background and operational GBF windmill noise as observed at the C-Power and Belwind wind farms.

Nedwell *et al.* (2007), Boesen C. & Kjaer J. (2005) and Betke (2006) all demonstrated that operational noise represent a light SPL increase of few dB re 1 µPa over the background levels. We observe a similar situation even if the turbines in the BPNS are more powerful with six 5 MW turbines at the C-Power site and 55 3 MW turbines at the Belwind site. The differences are situated on the higher SPL measured (20 to 25 dB re 1 µPa) for steel foundation as well as the decay of the spectrum over the frequency of 1kHz measured for steel foundation that is not present here but that Betke (2006) and Uffe (2002) proposed.

We have to remark however that the lack of standardization in underwater sound measurements and treatment complicates detailed comparison with other studies. Betke (2006) for example measured the operational noise at 100 m from the source or standardized the SPL to 100 m using a linear propagation model. Nedwell *et al.* (2007) on the other hand measured while drifting inside or outside the wind farm and presented noise spectra at various distances from a given windmill. Attempts to develop a necessary standardization are ongoing (de Jong *et al.*, 2010; Muller & Zerbs, 2011).

3.4.2. T reference and background noise levels are influenced by weather conditions and geographic position

The differences in reference and background noise levels could be partially attributed to the differences in weather conditions encountered during field work, and partially to the geographic position of both wind farms. The Belwind background noise was measured in very calm weather conditions (Haelters *et al.*, 2009). The C-Power background noise measurement was measured with moderately windy conditions (BF 4-5), whereas the C-Power reference condition was measured in very calm weather conditions (Henriet *et al.*, 2006). At least we can conclude that within the range of calm to moderate wind conditions and sea state, weather is not significantly impacting the measurement. The distance to a shipping traffic lane or the presence of pipelines in the area, as is the case for the C-Power site (Henriet *et al*., 2006), further explain the difference in T reference and background SPLs between C-Power and Belwind sites with Belwind being the less noisy site. One should however keep in mind that in the BPNS there is no place free of any anthropogenic activity. As such, disentangling the influence of the various sources of noise on the noise spectra remains impossible at this time.

3.4.3. Compliance with the EU MSFD descriptors

As the MSFD is yet to be fully implemented and applied in the EU Member States, a final operational definition of GES for Descriptor 11 "Underwater noise" is yet to set. Nevertheless, efforts to provide an overview of indicators and possible thresholds for GES are already undertaken. Tasker *et al*. (2010), for example, proposed for the continuous low frequency underwater noise an average sound pressure level of maximum 100 dB re 1 μPa for the octave band centred on 63 and 125 Hz. More recently, however, the identification of trends in SPL within the same two 1/3-octave bands rather than maximum values are proposed. A clear cut evaluation of whether or not the operational noise of Belgian offshore wind farms meet the MSFD criteria is hence not possible at present.

In the BPNS all operational noise measured so far is over the limit of 100 dB re 1 μPa. Moreover steel pile foundations equipped with a 3 MW generator (Bligh Bank) are some 20 dB re 1 μPa noisier in operation than GBF windmills equipped with a 5 MW generator. At this stage, the limited data available makes it impossible to detect a statistically significant trend. More noise recordings are advised in order to draw firm conclusions. A trend analysis based on the method developed in Norro *et al.* (2006) could be used in the future.

It is however expected that because of (1) the relatively low increase of underwater noise, generated by the GBF and steel pile wind mills, and (2) the relatively high natural variability in underwater noise, caused by e.g. varying position and possibly weather conditions, such operational noise of will not be qualified as intolerable.

3.4.4. Possible impact on the marine life

Betke (2006) concluded that the operational noise emitted by the Horns Rev wind farm cannot be noticed by a harbour porpoise (*Phocoena phocoena*) at a 100 m distance from the turbine, but that caution is needed because of the actual limited knowledge on this topic. Nedwell *et al.* (2007) stated that the slight increase in noise in the immediate vicinity of operating windmills is very unlikely to cause any behavioural response in seabass (*Dicentrarchus labrax*), cod (*Gadus morhua*), dab (*Limanda limanda*) herring (*Clupea harengus*), salmon (*Salmo salar*), bottlenose dolphin (*Tursiops truncatus*), harbour porpoise and common seal (*Phoca vitulina*). Ward *et al.* (2006) however indicated that bottlenose dolphins and harbour porpoises would be aware of the operational noise at a distance of 200 m from the North Hoyle Offshore wind farm, but concluded that the SPL (105 to 135 dB re 1 μPa at 100 Hz) could not cause any hearing damage.

Our data suggests that hearing damage to marine mammals should not be expected from the operational noise of offshore wind farms. Whether or not a 20 dB re 1 μPa increase of underwater SPL as observed for steel pile foundations may cause a behavioural response in marine mammals or other organisms remains an open question.

3.5. Conclusions and perspectives

The operational noise emitted by offshore wind farms in the BPNS showed an increase compared to T reference SPL. An increase of about 20 dB re 1 μPa for frequencies below 3 kHz and about 25 dB re 1 μPa at 8 kHz were observed for the Belwind offshore wind farm located at the Bligh Bank (consisting of 55 5 m diameter steel piles equipped with 3 MW turbines). The increase in SPL observed at the Thorntonbank was lower with a maximum of 8 dB re 1 μ Pa measured at the C-Power offshore wind farm (consisting of 6 concrete GBF equipped with 5 MW turbines). No data are available yet to confirm or infirm any effect such increase may have on the marine life on this zone of the BPNS.

3.6. Acknowledgements

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3.7. References

Betke, K., (2006). Measurement of underwater noise emitted by an offshore wind turbine at Horns Rev. ITAP report 13/02/2006. 19pp.

Boesen, C. & Kjaer, J., (2005). Review report 2004. The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind Farms, Environmental impact assessment and monitoring. Elsam Engineering and ENERGI E2, 135 pp.

Boyd, I., Brownell, B., Cato, D., Clarke, C., Costa, D., Evans, P., Gedanke, J., Gentry, R., Gisner, B., Gordon, J., Jepson, P., Miller, P., Rendell, L., Tasker, M., Tyack, P., Vos, E., Whitehead, H., Wartzok, D. & Zimmer, W., (2008). The effects of anthropogenic sound on marine mammals. A draft research strategy. European Science Foundation Marine Board Position paper 13. 92 pp.

De Jong, C.A.F, Ainslie, M.A & Blacquière, G., (2010). Measuring Underwater Sound: Towards measurement standards and noise descriptors. TNO 2010. 45 pp and 5 annexes.

Haelters, J., Norro, A. & Jacques, T., (2009). Underwater noise emission during the phase I construction of the C-Power wind farm and baseline for the Belwind wind farm. *In:* Degraer, S. & Brabant, R. (Eds.) Offshore wind farms in the Belgian part of the North Sea. State of the art after two years of environmental monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 3: 17-37.

Henriet, J.-P., Versteeg, W., Staelens, P., Vercruysse, J. & Van Rooij, D., (2006). Monitoring van het onderwatergeluid op de Thorntonbank: referentietoestand van het jaar nul, eindrapport. Studie in opdracht van het KBIN/BMM, rapport JPH/2005/sec15 , Renard Centre of Marine Geology Ghent University, Belgium July, 2006.

Huddelston, J., (ed) (2010). Understanding the environmental impacts of offshore windfarms COWRIE 138 pp.

Muller, A. & Zerbs, C., (2011). Offshore wind farms. Measurement instruction for waterborne sound measurements. Report N° M88 607/5. Muller-BBM GmbH. 21 pp.

Nedwell, J.R. & Howell, D., (2004). A review of offshore wind farm related underwater noise sources. Report N° 544 R 0308 COWRIE oct 2004. 57 pp.

Nedwell, J.R., Parvin, S.J., Edwards, B., Workman, R., Brooker, A.G. & Kynoch, J.E., (2007). Measurements and interpretation of underwater noise during construction and operation of offshore wind farms in UK waters. COWRIES- Subacoustech. NOISE 03-2003. 80pp.

Nowacek, D.P., Thorne, L.H., Johnston,D.W. & Tyack, P.L., (2007). Responses of cetaceans to anthropogenic noise. Mammal Rev, 37: 81-115.

Norro, A., Pichot, G., Pison, V. & J., Ozer, (2006). A bi-dimentional approach to assessing the volumetric evolution of an exploited sandbank. Ices Journal of Marine Science, 63:176-186.

Norro, A., Haelters, J., Rumes, B. & Degraer, S., (2010). Underwater noise produced by the piling activities during the construction of the Belwind offshore wind farm (Bligh Bank, Belgian marine waters). *In:* Degraer, S., Brabant, R., Rumes, B., (eds) (2010). Offshore wind farms in the Belgian part of the North Sea. Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 4: 37-51.

NRC, (2005). National Research Concil. Marine Mammal Populations and Ocean Noise. Determining when noise causes biologically significant effects. The national academies press. Washington DC. 126 pp.

Richardson, W.J., Fraker, M.A., Wuersig, B. & Wells, R.S., (1985). Behaviour of bowhead whales, *Balaena mysiticetus* summering in the Baeufort sea/ reactions to industrial activities. Bilogical Cpnservation, 32:195 – 230.

Tasker, M.L., Amundin, M., Andre, M., Hawkins, A., Lang, B., Merck, T., Sholik-Scholmer, A., Teilmann, J., Thomsen, F., Werner, S. & Zakharia, M., (2010). Indicator for the good environmental status for underwater noise and other form of energy. The main report of task group 11 for Marine Strategy Framework Directive's descriptor 11 Draft 11:01/2010. 39pp ICES/JRC report.

Uffe, D., (2002). Measurements of noise induced from offshore wind turbines and ambient noise in the sea water. Giga Wind Hannover, Germany. 23 pp.

Ward, P.D., Harland, E. & Dovey, P., (2006). Measuring ambient noise in relation to offshore wind farm characterisation. QinetiQ 2006. 5 pp.

Chapter 4. Offshore intertidal hard substrata: a new habitat promoting non-indigenous species in the Southern North Sea: an exploratory study.

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Visual inspection of the intertidal hard substrata in the Belwind wind farm

Photo B. Rumes / RBINS / MUMM

Abstract

There is a world-wide concern of the expansion of non-indigenous species because they alter local biodiversity and sometimes compete with native species, some of which of commercial interest. This is especially the case in shallow coastal waters, subject to a multitude of human activities, including the construction of artificial hard substrata. We took the opportunity of the construction of numerous windmills off the Belgian coast to study the colonisation of non-indigenous species on these new artificial structures. Therefore we monitored the fouling communities of the wind farms on a regular basis from the beginning of their installation. We demonstrated that the new artificial hard substrata of the windmills offer new opportunities for non-indigenous species (introduced and southern Northeast Atlantic range-expanding species) to enter the Southern North Sea. Or, if already present, to expand their population size and hence strengthen their strategic position in the Southern North Sea. This is particularly important for the obligate intertidal hard substrata species, for which other offshore habitat is rare to non-existing.

Samenvatting

De toename van het aantal niet-inheemse soorten zorgt wereldwijd voor bezorgdheid omdat ze de locale biodiversiteit wijzigen en in bepaalde gevallen in competitie treden met inheemse soorten waaronder sommige van commercieel belang. De opmars van niet-inheemse soorten is vooral onmiskenbaar in de ondiepe kustwateren die onderhevig zijn aan talloze menselijke ingrepen, niet het minst de constructie van allerlei artificiële harde substraten. Wij hebben de bouw van talrijke windmolens voor de Belgische kust aangegrepen om de kolonisatie van deze nieuwe structuren door niet-inheemse organismen te onderzoeken. We onderzochten daartoe, vanaf hun installatie, op regelmatige basis de aangroeigemeenschap op de peilers. We konden aantonen dat de nieuwe kunstmatige structuren inderdaad aan niet-inheemse soorten de kans bieden om de Zuidelijk Noordzee binnen te dringen, er zich te vestigen en, indien al aanwezig, om zich verder in de Noordzee te verspreiden en er hun positie te verstevigen. Dit bleek vooral belangrijk voor obligaat intertidale soorten omdat een intertidale habitat van offshore hard substraat nog niet in de Zuidelijk Noordzee voorhanden was.

4.1. Introduction

In a geological perspective, the North Sea is a very young basin: only after the last glaciation biota could start to move in (colonise) the new water body, either from the north or from the English Channel via the Dover Strait (Wolff, 2005). However, not all species that are capable of living in the new environment did effectively do so. The lack of suitable habitat hampered the spread of several species. As it comes to hard substratum species, especially the lack of hard substrata in the soft sediment dominated Southern North Sea (Cameron & Askew, 2011) should be considered a major obstacle.

Human activities inevitably resulted in changes of the marine biodiversity in historical times (Carlton, 1989). One of the major changes was the introduction of artificial hard substrata all along the coasts of the former predominantly sandy shores of the shallow Southern North Sea. More recently quite some artificial hard substrata was even introduced in the offshore environment. Artificial structures offer opportunities for newcomers that were formerly unable to live in the Southern North Sea. Consequently, the expansion of many rocky shore species living west of the Dover Strait into the North Sea was facilitated by these human-mediated environmental changes (Wolff, 2005).

From the onset of the hardening of the coast, which started in the 16th century (Wolff, 1999), many hard substrata species successfully colonised the new habitat. Through history, shipwrecks further augmented the extent of suitable habitat for many of these hard substrata species (Zintzen & Massin, 2010). With the construction of offshore wind farms finally, a new habitat of artificial hard substratum was introduced in a region mostly characterized by sandy sediments, enhancing the habitat heterogeneity and biodiversity of the region (Kerckhof *et al.*, 2009, 2010; Reubens *et al.*, 2010), but also interacting with the surrounding natural sandy sediments (Coates *et al.*, 2011). The effect of the introduction of these hard substrata – the so-called reef effect – is regarded as one of the most important changes of the original marine environment caused by the construction of wind farms (Petersen & Malm, 2006).

While the major part of these new artificial hard substrata consists of subtidal habitat, it is the offshore intertidal hard substratum that forms a truly new habitat in the Southern North Sea. Indeed, offshore subtidal hard substratum was already known from the (natural) gravel beds, as well as from (artificial) shipwrecks or oil and gas platforms. Because many subtidal hard substratum species, such as the barnacle *Elminius modestus*, the amphipod *Jassa marmorata*, the Japanese oyster *Crassostrea gigas*, the bryozoan *Bugula stolonifera*, can live on both natural and artificial hard substrata, subtidal non-indigenous species already had plenty of habitat and time to colonise the Southern North Sea, although they were not always recorded (Zintzen and Massin, 2010). This has, however, not been the case for offshore intertidal hard substrata fauna. While coastal (i.e. turbid waters) intertidal habitat was already available in the Southern North Sea, mainly in the English Channel both as (natural) rocky shores and (artificial) hard coastal defence structures, such habitat was largely absent from the clear offshore waters. Abundantly available buoys for example, only represent a splash zone, while a true intertidal zone is missing. The full array of offshore intertidal habitat was yet only to be found on the much scarcer piles of e.g. offshore oil and gas installations.

As such, offshore wind farms facilitate (1) the establishment of intertidal species previously not present in the Southern North Sea, an environment dominated by soft sediment habitats, (2) a strengthening of the strongholds of non-indigenous intertidal rocky shore species, as well as (3) a further spread of the latter from the English Channel into the Southern North Sea.

In this study, we therefore aim at quantifying the importance of offshore intertidal hard substrata, created by the wind farms, to non-indigenous i.e. range expanding and introduced species.

4.2. Material and Methods

4.2.1. Study area

Samples were collected in the C-Power and Belwind wind farms, located in a special dedicated zone (see Brabant *et al.*, 2011) of the BPNS. The C-Power wind farm (at present six concrete GBF with 5 MW turbines) is located on the Thornton Bank some 30 km offshore (Figure 1). The Belwind wind farm (at present 56 steel monopiles with 3 MW turbines) is constructed on the Bligh Bank at about 50 km off the coast. Both banks belong to the Zeeland Banks system (Cattrijsse & Vincx, 2001). Local water depth within the wind farms ranges from 7 - 30 m and the surrounding soft sediment seabed is composed of medium sand (mean median grain size: between 350 and 500 µm) (Reubens *et al*., 2009).

We monitored the fouling community of the intertidal part of the foundations of both wind farms as well as the subtidal erosion protection layer from (almost) the beginning of their installation. The concrete C-Power GBF foundations were sampled from autumn 2008, about 3 ½ months after installation (Kerckhof *et al.,* 2009). Later, samples were taken seasonally (starting in spring 2009). At Belwind, sampling of the steel monopile foundations started in February 2010, two months after construction (Kerckhof *et al.,* 2010). In total (from autumn 2008 - spring 2011) *intertidal* samples were collected on 10 and 5 occasions for the C-Power and the Belwind wind farms, respectively.

The samples were collected from a selected set of windmills: windmills D5 and D4 at the C-Power site and windmill BB08 at the Belwind site. The colonisation patterns observed on the sampled foundations were confirmed for the other foundations of both wind parks based on visual inspections and video footage.

Figure 1. Concrete C-Power GBF foundation (D5) with epifouling in the eulitoral and splash zone (situation early 2011).

4.2.2. Sample collection and processing

Samples were collected by scraping the fouling organisms with a putty knife from the foundation surface. In the subtidal a sampling surface area of 0.25 x 0.25 m was used, whereas the intertidal scrape samples were collected in a non-quantitative manner; this because of practical constraints linked to operating from a detached RIB. In addition, we visually inspected the intertidal of neighbouring piles of the respective wind farms. Video footage collected by the divers and during intertidal sampling was used to determine to what extent the scrape samples represent the actual fauna and to identify a number of rare, large and/or mobile invertebrate species that are otherwise not (adequately) represented in the scrape samples.

All scraped material was collected in plastic bags that were immediately sealed and transported to the laboratory for further processing: fixation using a 5% formaldehyde-seawater solution, sieving through a 1 mm mesh-sized sieve, sample sorting, preservation in 75% ethanol and finally species identification and relative abundance estimation.

The biota (further called species) were identified to species level whenever possible. Identifications were based on the most recent systematic literature and we followed the World Register of Marine Species (WoRMS) for the nomenclature and taxonomy (http://www.marinespecies.org/). We used the SACFOR scale for the estimation of the relative abundance, as developed by the Joint Nature Conservancy Council (JNCC) (Connor & Hiscock 1996). Depending on the growth form and size of the organisms - encrusting, solitary… abundance estimates are made for either percentage cover or numerical abundance. This is then linked to the scale and converted to SACFOR (Table 1).

Table 1.
The SACFOR scale and its relation to coverage and density. S, superabundant; A, abundant; C, common; F, frequent; O, occasional; R, rare.

Growth form			**Size of individuals/colonies**					
% cover	Crust/meadow	Massive/Turf	<1cm	1-3 cm	3-15 cm	>15 cm	Density	
>80%	S		S				>1/,.001 m² (1x1 cm)	>10.000 / m²
40-79%	A	S	A	S			1-9/0.001 m²	1000-9999 / m²
20-39%	C	A	C	A	S		1-9 / 0,01 m² (10 x 10 cm)	100-999 / m²
10-19%	F	C	F	C	A	S	1-9 / 0,1 m²	10-99 / m²
5-9%	O	F	O	F	C	A	1-9 / m²	
1-5% or density	R	O	R	O	F	C	1-9 / 10m² (3,16 x 3,16 m)	
<1% or density		R		R	O	F	1-9 / 100 m² (10 x 10 m)	
					R	O	1-9 / 1000 m² (31,6 x 31,6 m)	
						R	>1/10.000 m² (100 x 100 m)	<1/1000 m²

4.2.3. Intertidal non-indigenous species

This study only focused on the fauna of the eulitoral and splash zone, further referred to as intertidal species. Species were considered as intertidal *sensu stricto* if they inhabit solely or predominantly the eulitoral zone, while species having mainly a sublitoral distribution and only occurring occasionally in the infralitoral fringe (i.e. lower mussel zone) were considered subtidal species (e.g. Hayward & Ryland, 1990; Hiscock *et al.*, 2005; http://www.marlin.ac.uk/).

In this study a non-indigenous species is defined as any species that occurs outside its natural range (past or present) and that has become established in a certain region in the wild with self-sustaining populations. As such, non-indigenous can be synonymised with non-native and allochthonous. This means that the occurrence of such species derives from an intervention by man either through deliberate/ intentional (e.g. import for aquaculture) or non-deliberate/ non-intentional (e.g. climate change, habitat creation, accidental propagule introduction) human action. We further make a distinction between introduced species and range expanding species. Range expanding species are a subset of non-indigenous species that are spreading from adjacent regions by natural means. For the Southern North Sea, this encompasses Atlantic species with a Northeast Atlantic origin. Introduced species are another subset of non-indigenous species that are introduced in a certain region – in this case the North Sea – by historical human intentional or unintentional activities (e.g. Carlton, 1996) across natural dispersal barriers. This means that they came from remote areas elsewhere around the globe including the Mediterranean, the Black and Caspian Sea (Wolff, 2005).

For a number of species, now with a cosmopolitan occurrence in harbour and coastal habitats and therefore possibly non-indigenous, it is often difficult to unravel whether or not they are native in the North Sea especially in the absence of fossil evidence. Such species of which the status – native or not – in a certain geographical area cannot sufficiently be proved are termed cryptogenic (Carlton, 1996).

4.3. Results

During the considered period – late 2008-mid 2011 – we identified 26 species in the intertidal samples at the windmills. Of these species we considered 17 species as intertidal (Table 1). The non-indigenous species form an important part of the intertidal fouling community. We found eight non-indigenous species. These include six introduced species: the oyster *Crassostrea gigas*, the barnacles *Elminius modestus* and *Megabalanus coccopoma*, the amphipod *Jassa marmorata*, the crab

Hemigrapsus sanguineus and the midge *Telmatogeton japonicus*, and two range expanding species: the barnacle *Balanus perforatus* and the limpet *Patella vulgata*. The ratio for non-indigenous to introduced species is high 1/3. Their relative abundance, as estimated from the SACFOR scale, is in most cases high almost from the beginning (Table 2).

Table 2.
Overview of recorded intertidal species at the C-Power and Belwind site with indication of their abundance as indicated by the SACFOR scale. S, superabundant; A, abundant; C, common; F, frequent; O, occasional; R, rare. Non-indigenous species are indicated in bold.

	C-POWER				BELWIND	
	Year One	**Year Two**	**Year Three**	**Year Four**	**Year One**	**Year Two**
***Megabalanus coccopoma* (Darwin, 1854)**	**C**				**F**	
***Balanus perforatus* Bruguiére, 1789**	**S**	**A**	**A**	**C**		**C**
***Telmatogeton japonicus* Tokunaga, 1933**	**S**	**S**	**S**	**S**		**S**
***Elminius modestus* Darwin, 1854**	**A**	**A**	**A**	**A**	**C**	**C**
***Jassa marmorata* (Holmes, 1903)**	**C**	**C**	**C**	**C**	**C**	**S**
Mytilus edulis (Linneaus, 1758)	**F**	**S**	**S**	**S**	**C**	**C**
Semibalanus balanoides (Linnaeus, 1758)		**S**	**S**	**S**	**C**	**C**
Balanus crenatus Bruguiére, 1789		**F**			**C**	**R**
***Patella vulgata* Linnaeus, 1758**			**F**	**F**		
***Hemigrapsus sanguineus* (De Haan, 1835)**			**F**	**F**		
***Crassostrea gigas* (Thunberg, 1793)**			**O**	**O**		
Littorina littorea (Linnaeus, 1758)			**F**	**F**		
Balanus improvisus Darwin, 1854			**O**		**O**	**R**
Emplectonema gracile (Johnston, 1873)			**O**			
Emplectonema neesii (Örsted, 1843)			**O**			
Pleioplana atomata (OF Müller, 1776)			**O**			
Eulalia viridis (Johnston, 1829)				**O**		

During the first two years the number of non-indigenous species was the same for both windmill farms and encompassed the same species: *M. coccopoma*, *B. perforatus*, *E. modestus*, *T. japonicus* and *J. marmorata*. An additional three species, the limpet *P. vulgata* (Figure 2), the crab *H. sanguineus* and the Japanese oyster *C. gigas* (Figure 2) were found during the third and fourth year on the C-Power wind farm.

Except for *M. coccopoma*, the presence of all other non indigenous species seems permanent. Juveniles of all species considered have been found during subsequent years. From the Japanese oyster *C. gigas*, only juveniles have been found so far.

Figure 2. (*left*) A group of limpets *Patella vulgata*, accompanied by periwinkles *Littorina littorea* on the concrete foundation D5 of the C-Power wind farm (May 2011). The surrounding barnacles are nearly all *Elminius modestus*, except for some larger white ones, being *Semibalanus balanoides*. Figure 2. *(right)* A young specimen of the Japanese oyster *Crassostrea gigas* (indicated by the red arrow) settled upon the barnacles in the barnacle zone on foundation D5 of the C-Power wind farm (July 2010). The barnacles are *Semibalanus balanoides* except the larger one on the bottom of the picture being a *Balanus perforatus*.

4.4. Discussion

4.4.1. Non-indigenous species

From the very beginning the newly available substrata were colonised by non-indigenous species. Both introduced species and range expanding took advantage of the increased availability of hard substrata of the windmills to settle and further spread into the North Sea and, if already present in the region, to expand their overall population size.

We found the greatest number of non-indigenous species in the intertidal, whereas subtidally we so far only found one: the introduced slipper limpet *Crepidula fornicata,* present on both wind farms (Kerckhof *et al.,* 2010; Kerckhof unpublished)

Approximately 1/3rd of the intertidal species were introduced, which is somewhat higher than the numbers reported for coastal habitats such as estuaries or lagoons (1/4th in Reise *et al*., 2006). All introduced species were known opportunists and early colonisers, taking advantage of man-made structures and disturbed conditions for settlement (Kerckhof *et al.*, 2007).

Most introduced species are known from coastal habitats, but our findings illustrate that they are very well capable to live in offshore conditions, provided that suitable habitat is available. Since juveniles of all species considered have been found during subsequent years, they must reproduce either on site or have a regular influx of larvae. All non-indigenous species found in our study were already known to occur in the Southern North Sea and that several of them such as *E. modestus, C. gigas, M. coccopoma, T. japonicus, J. marmorata* and *B. perforatus* were already detected in the vicinity of the wind parks e.g. on buoys (Kerckhof *et al.,* 2007; Kerckhof unpublished). These buoys do form a somewhat comparable habitat, but lack a real intertidal zone as they move up and down with the tides. As such, only the uppermost and lowermost intertidal zones, i.e. splash zone and infralittoral fringe, are present on buoys. Other species such as *Littorina littorea* and *Patella vulgata* were never (or only rarely) found on buoys.

Illustrative for the fast expansion of some non-indigenous species is the presence of the crab *Hemigrapsus sanguineus*, one of the latest reported introductions in the region. This species originates from the northwest Pacific and was first recorded in Europe in the late 1990s (d'Udekem d'Acoz and Faasse, 2002) and in Belgian waters in 2006 (d'Udekem d'Acoz, 2006). This species is now very common in intertidal coastal areas and our findings prove that *H. sanguineus* is not limited to coastal areas, but can thrive in offshore areas too, provided that a suitable habitat available, more specifically the intertidal zone, is available.

For some species a suitable habitat had previously been available, but other factors had prevented them from establishing themselves. This is the case for the Lusitanian barnacle *B. perforatus*, which used to have its northern boundary in the eastern English Channel, but started a range expansion into the western English Channel from the 1990s onward (Herbert *et al.*, 2003). Here we recorded its presence in large numbers on the windmill pilings. This is thus a further range expansion and subsequent establishment in the Southern North Sea of this species. This expansion is likely favoured by the current warming of the coastal waters of the Southern North Sea (MacKenzie & Schiedek, 2007).

Finally, some introduced species can become invasive and may become a threat to the native biodiversity and even affect commercially important species. One example is the non native Japanese oyster *C. gigas,* which is thriving and spreading along the coasts of the Southern North Sea (Troost, 2010). The species is competing with native biota, especially the blue mussel *Mytilus edulis*. In certain regions, such as the Wadden Sea, mussel banks have even been replaced by *Crassostrea* reefs (Markert *et al.,* 2009; Kochmann *et al.*, 2008; Diederich, 2006). Although both species may co-exist (Diederich, 2005) it is clear that commercial exploitation becomes difficult if mussel beds are infested with wild *Crassostrea*, itself without any commercial value. If *Crassostrea* were able to establish (semi-) permanent offshore populations in the Southern North Sea, it would be able to further strengthen its competitive position in the Southern North Sea; possibly to the detriment of the commercially valuable coastal mussel banks, which are already under severe pressure (OSPAR, 2010).

The intertidal habitat on the windmill pilings could be attributed to the LR.HLR.MusB biotope of the JNCC Marine Habitat Classification (Connor *et al*., 2004) a biotope that also has been identified on the pilings of other wind farms in the North Sea (e.g. EMU, 2008; Bouma & Lengkeek, 2009; Leonhard & Pedersen, 2006). This is typicaly a biotope for very exposed to moderately exposed eulitoral bedrock. For the characteristic high intertidal splash zone, often with a conspicuous *Telmatogeto*n zone, and also present elsewhere on wind farms in the Southern North Sea e.g. on the Danish Horns Rev wind farm (Leonhard & Pedersen, 2006) no such biotope code is available. A similar habitat and zonation pattern in the intertidal (Kerckhof *et al*. 2010) have been reported on artificial hard substrata in the intertidal zone and on other wind farms in the North Sea (e.g. EMU, 2008; Whomersley & Picken, 2003; Joschko *et al*., 2008; Bouma & Lengkeek, 2009; Leonhard & Pedersen, 2006).

Although some of the above listed studies on wind farms in the North Sea do mention the presence of non-indigenous species, the number is always lower than in our study and the presence of *H. sanguineus*, *C. gigas*, *B. perforatus*, *M. coccopoma* and *P. vulgata* has not been mentioned elsewhere. Part of this difference can be attributed to a less intensive monitoring, decreasing the chance of encountering species (initially) occurring in low numbers (e.g. *C. gigas, M. coccopoma*), but also to problematic taxonomic issues hampering a proper distinction between morphologically similar species resulting in a lower taxonomic resolution. This was the case for difficult taxa such as *Jassa* or *Balanus* (e.g. Bouwma & Lengkeek, 2009). The following three non-indigenous species are mostly mentioned: *E. modestus, T. japonicus* and *Jassa* spec. For example, in a report on the Kentish Flats wind farm in the Thames estuary off the UK east coast only the presence of the barnacle *E. modestus* (EMU, 2008) was observed. *Jassa* is present in all cases but only *J. marmorata* was identified in the Danish Horns Rev wind farm (Leonhard & Pedersen, 2006) then as a new and introduced species. A conspicuous *Telmatogeton* zone, as we have found, was also present on the Horns Rev wind farm (Leonhard & Pedersen, 2006), but initially not on the windmills off the Dutch coast (Bouwma & Lengkeek, 2009). However, in a later survey, the species was detected (Lengkeek, pers. communication).

4.4.2. Colonisation and succession of offshore intertidal hard substrata

The colonisation of the intertidal zone of the foundation structures in both wind farms was rapid and non-indigenous species constituted a major part of the colonists. However, some clear differences in colonisation rate and subsequent succession could be found between both wind farms, of which part could be attributed to the construction time of the windmills. The foundations of the C-Power wind farm for example were available for colonisation in late summer, favouring species that are reproducing late in the season such as *B. perforatus* and *M. coccopoma* (Bassindale, 1964; Kerckhof unpublished data). After these species hence abundantly colonised the windmills shortly after installation, their numbers gradually declined as a result of an increased competition with other species.

Within both wind farms, we further witnessed a gradual increase of the species richness. This has been most clearly demonstrated at the C-Power site, where colonisation could have taken place during three consequent recruitment periods, and was less obvious at the Belwind site, where colonisation only took place during one recruitment period. We hence expect that the number of species will continue to increase on the pilings of the Belwind wind farm too, including the arrival and subsequent establishment of new non-indigenous species. We also expect that other non-indigenous species might pop up within the wind farms, since more non-indigenous species have been observed in the area of the wind farms and also on ships operating in the area (Kerckhof *et al*., 2007; Kerckhof unpublished data). For example, the barnacle *Balanus (Amphibalanus) amphitrite* was present in the fouling community on the research vessel Belgica and on a buoy marking the Thornton Bank and an empty specimen of the large barnacle *Megabalanus rosa* has been found on a buoy marking the Belwind wind farm, together with specimens of another Megabalanus, *M. tintinnabulum*. At least *B. amphitrite* and *M. tintinnabulum*, have the capacity to colonise the Belgian wind farms. The former is a spreading species, already common in Belgian marinas and occasionally recorded on offshore buoys (Kerckhof *et al.*, 2007; Kerckhof & Cattrijsse, 2001), whereas the latter is common in the fouling community of ships and has been noted before, e.g. on buoys (Kerckhof *et al.*, 2007; Kerckhof & Cattrijsse, 2001). *Megabalanus rosa*, on the other hand, is also an introduction through shipping but has never been found before in the North Sea. In conclusion, we expect the intertidal (non-indigenous) fauna of the Belwind and the C-Power sites to become richer in species number over the course of the next few years and more similar. However, some differences in the composition of the intertidal fauna may remain since different foundation types were used large concrete GBF versus smaller steel monopiles (see also Brabant *et al.*, 2011).

4.5. Conclusion

This study demonstrated that the newly introduced hard substrata within offshore wind farms play an important role in the establishment and the expansion of the population size of non-indigenous species, thus strengthening their strategic position in the Southern North Sea. This is particularly important for the obligate intertidal hard substrata species, for which offshore habitat is rare to non-existing.

4.6. References

Bassindale, R., (1964). British barnacles with keys and notes for the identification of the species. - Synop. Brit. Fauna, 4:1 68.

Bouwma, S. & Lengkeek, W., (2009). Development of underwater flora- and fauna communities on hard substrates of the offshore wind farm Egmond aan Zee (OWEZ). Report Bureau Waardenburg nr 08-220.

Brabant, R., Degraer, S. & Rumes, B., (2011). Offshore wind energy development in the Belgian part of the North Sea & anticipated impacts: an update. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2011). Offshore wind farms in the Belgian part of the North Sea: Selected findings from the baseline and targeted monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 2: 9-16.

Cameron, A. & Askew, N., (eds.). (2011). EUSeaMap - Preparatory Action for development and assessment of a European broad-scale seabed habitat map final report. Available at http://jncc.gov.uk/euseamap.

Carlton, J.T., (1989). Man's Role in Changing the Face of the Ocean: Biological Invasions and Implications for Conservation of Near-Shore Environments. Conservation Biology, 3 (3): 265–273.

Carlton, J. T., (1996). Biological invasions and cryptogenic species. Ecology, 77(6): 1653-1655.

Coates, D., Vanaverbeke, J., Rabaut, M. & Vincx, M., (2011). Soft-sediment macrobenthos around offshore wind turbines in the Belgian Part of the North Sea reveals a clear shift in species composition. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2011). Offshore wind farms in the Belgian part of the North Sea: Selected findings from the baseline and targeted monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 6: 47-63.

Connor, D.W. & Hiscock, K., (1996). Data collection methods (with Appendices 5 - 10). In: Marine Nature Conservation Review: rationale and methods, ed. by K. Hiscock, 51-65, 126- 158. Peterborough, Joint Nature Conservation Committee. (Coasts and seas of the United Kingdom. MNCR series.).

Connor, D.W., Allen J. H., Golding, N., Howell, K. L., Lieberknecht, L. M., Northen, K. & Reker, J. B., (2004). The Marine Habitat Classification for Britain and Ireland Version 04.05. Joint Nature Conservation Committee, Peterborough.

Diederich, S., (2005). Differential recruitment of introduced Pacific oysters and native mussels at the North Sea coast: coexistence possible? Journal of Sea Research 53, 269–281.

Diederich, S., (2006). High survival and growth rates of introduced Pacific oysters may cause restrictions on habitat use by native mussels in the Wadden Sea. Journal of Experimental Marine Biology and Ecology 328, 211–227.

d'Udekem d'Acoz C., (2006). First record of the Asian shore crab Hemigrapsus sanguineus (De Haan, 1835) in Belgium (Crustacea, Brachyura Grapsoidea). De Strandvlo 26(3): 74-82

d'Udekem d'Acoz, C., Faasse, M., (2002). De huidige status van Hemigrapsus sanguineus (De Haan, 1835) en H. penicillatus (De Haan, 1835) in de noordelijke Atlantische Oceaan, in het bijzonder in Nederland, met opmerkingen over hun biologie (Crustacea, Decapoda, Brachyura). Het Zeepaard 62(4): 101-115.

EMU, (2008). Kentish Flats Offshore Wind Farm turbine foundation faunal colonisation Diving Survey. Report nr. 08/J/1/03/1034/0839/AMB/Nov 2008.

Hayward, P.J. & Ryland, J.S., (Ed.) (1990). The marine fauna of the British Isles and North-West Europe: vol 1 and 2. Clarendon Press: Oxford.

Herbert, R.J.H., Hawkins, S.J., Sheader, M. & Southward, A.J., (2003). Range extension and reproduction of the barnacle Balanus perforatus in the eastern English Channel J. Mar. Biol. Ass. U.K. 83(1): 73-82.

Hiscock, K., Smith, A, Jenkins, S., Sewell, J. & Hawkins, S. (2005). Development of a hard substratum Benthic invertebrate Water Framework Directive compliant classification tool. Report to the Environment Agency and the Joint Nature Conservation Committee from the Marine Biological Association. Plymouth: Marine Biological Association. JNCC Contract F90-01-790. 54 pp + Annexes.

Kerckhof, F. & Cattrijsse, A. (2001). Exotic Cirripedia (Balanomorpha) from buoys off the Belgian coast. Senckenbergiana maritima 31: 245-254.

Kerckhof, F., Haelters, J. & Gollasch, S. (2007). Alien species in the marine and brackish ecosystem: the situation in Belgian waters Aquatic Invasions 2(3): 243-257.

Kerckhof, F., Norro, A., Jacques, T. & Degraer, S. (2009). Early colonisation of a concrete offshore windmill foundation by marine biofouling on the Thornton Bank (southern North Sea). *In:* Degraer, S. & Brabant, R. (Eds.) (2009). Offshore wind farms in the Belgian part of the North Sea: State of the art after two years of environmental monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 4: 39-51.

Kerckhof, F., Rumes, B., Norro, A., Jacques, T.G. & Degraer, S., (2010). Seasonal variation and vertical zonation of the marine biofouling on a concrete offshore windmill foundation on the

Thornton Bank (southern North Sea). *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 5: 53-68.

Kochmann, J., Buschbaum, C., Volkenborn, N. & Reise, K., (2008). Shift from native mussels to alien oysters: differential effects of ecosystem engineers. Journal of Experimental Marine Biology and Ecology 364, 1–10.

Leonhard, S.B. & Pedersen, J., (2006). Benthic communities at Horns Rev before, during and after construction of Horns Rev Offshore Wind Farm. Final report 2005. Udarbejdet af Bio/consult as for ELSAM Engineering 96 pp.

MacKenzie, B.R. & Schiedek, D., (2007). Daily ocean monitoring since the 1860s shows record arming of northern European seas. Global Change Biology, 13, 1335–1347.

Markert, A., Wehrmann, A. & Kröncke, I., (2009). Recently established Crassostrea-reefs versus native *Mytilus*-beds: differences in ecosystem engineering affects the macrofaunal communities (Wadden Sea of Lower Saxony, southern German Bight). Biological Invasions.

OSPAR, (2010). Quality Status Report 2010. Case Reports for the OSPAR List of threatened and/or declining species and habitats – Update. Intertidal Mytilus edulis beds on mixed and sandy sediments.

Orejas, C., Joschko, T., Schröder, A., Dierschke, J., Exo, M., Friedrich, E., Hill, R., Hüppop, O., Pollehne, F., Zettler, M. L. & Bochert, R., (2005). Ökologische Begleitforschung zur Windenergienutzung im Offshore-Bereich auf Forschungsplattformen in der Nord- und Ostsee (BeoFINO), AP2 Prozesse im Nahbereich der Piles Nordsee. 161 – 234.

Petersen, JK. & Malm, T., (2006). Offshore windmill farms: threats to or possibilities for the marine environment. AMBIO: A Journal of the Human Environment, 35: 75-80.

Reise, K., Olenin, S. & Thieltges, D.W., (2006). Are aliens threatening European aquatic coastal ecosystems? Helgol. Mar. Res. 60(2): 77-83.

Reubens, J.T., Degraer, S., Vincx, M., (2010). The importance of marine wind farms, as artificial hard substrata, for the ecology of the ichthyofauna. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. 184 pp. + annexes.

Schröder, A., Orejas, C. & Joschko, T., (2006). Benthos in the vicinity of the piles: FINO 1 (North Sea) In Offshore Wind Energy. Research on Environmental Impacts pp. 185-200. Ed. by J. Köller, J. Köppel & W. Peters. Springer Verlag Heidelberg, Berlin. 371 pp.

Troost, K., (2010). Causes and effects of a highly successful marine invasion: Case-study of the introduced Pacific oyster Crassostrea gigas in continental NW European estuaries Journal of Sea Research 64: 145–165.

Whomersley, P. & Picken, G.B., (2003). Long-term dynamics of fouling communities found on offshore installations in the North Sea. J. Mar. Biol. Ass. U.K. 83(5): 897-901.

Wolff, W.J. (1999). The conservation value of artificial habitats in the marine environment: a case study of the artificial rocky shores of The Netherlands. Aq. Conservation: Mar. Freshw. Ecosystems 9: 541-544.

Wolff, W.J., (2005). Non-indigenous marine and estuarine species in The Netherlands. Zoologische Mededelingen 79: 1-116.

Zintzen, V., Norro, A., Massin, C. & Mallefet, J., (2007). Spatial variability of epifaunal communities from artificial habitat: shipwrecks in the Southern Bight of the North Sea. *In:* Zintzen, V. (2007). Biodiversity of shipwrecks from the Southern Bight of the North Sea. pp. 185-228.

Zintzen, V. & Massin, C. (2010) Artificial hard substrata from the Belgian part of the North Sea and their influence on the distributional range of species Belg. J. Zool. 140(1): 20-29.

Chapter 5. Spatial and temporal movements of cod (*Gadus morhua*) in a wind farm in the Belgian part of the North Sea using acoustic telemetry, a VPS study

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Line fishing at the C-Power wind farm on the Thorntonbank

Abstract

Monitoring of fish communities near windmills in the Belgian Part of the North Sea (BPNS), which should be considered artificial reefs, revealed that pouting (*Trisopterus luscus*) and cod (*Gadus morhua*) were present in high densities in the vicinity of the windmills during part of the year (Reubens *et al.*, 2010). This study documents the first results of acoustic telemetry to investigate spatial and temporal migration patterns of cod in a wind farm in the BPNS. The main objective is to gain a better understanding in the daily and seasonal migration patterns.

These first results on fish behaviour and habitat utilization nearby Belgian offshore windmills already suggest that, although major differences in individual cod behaviour were detected:

- Individual cod may be attracted to offshore windmills and their surrounding erosion protection layers as shown by the high residency of some tagged specimen.
- The spatial fine scale distribution (i.e. habitat choice) of individual cod nearby the windmills tends to be influenced by the diurnal cycle for some individual cod.

It should be noted that this is work in progress. The results are limited and refer to a period of 88 days (06/08/2010 - 01/11/2010).

Samenvatting

Monitoring van de visgemeenschappen rond windmolens in het Belgisch deel van de Noordzee (BDNZ), die moeten gezien worden als artificiële riffen, toonde aan dat steenbolk (*Trisopterus luscus*) en kabeljauw (*Gadus morhua*) tijdens bepaalde periodes van het jaar in grote densiteiten aanwezig waren in de nabijheid van die windmolenfunderingen (Reubens *et al.*, 2010). Voorliggende studie stelt de eerste resultaten voor van een acoustisch telemetrie onderzoek op kabeljauw in een windmolenpark in het BDNZ. Het doel van deze studie is om de seizoenale en dagelijkse migratie van kabeljauw te onderzoeken.

De eerste resultaten betreffende het gedrag van de vissen en habitatgebruik in de buurt van de windmolens sugereren dat:

- Afgaand op de tijd die bepaalde getagde individuen doorbrengen in de buurt van offshore windmolens en hun erosiebescherming, doet vermoeden dat ze er tot aangetrokken worden
- De kleinschalige ruimtelijke verspreiding (i.e. habitat keuze) van individuele kabeljauw wordt beïnvloed door de diurnale cyclus

Er dient te worden opgemerkt dat er grote verschillen waren in de resultaten van verschillende individuen en dit resultaten zijn van een studie in voortgang. De resultaten zijn beperkt en refereren naar een periode van 88 dagen (06/08/2010 – 01/11/2010).

5.1. Introduction

An enhanced demand for green energy resources has stimulated the implementation of wind farms at sea. In the Belgian part of the North Sea (BPNS), an area has been reserved for seven wind farm concessions. Currently two wind farms are (partially) built, a third will be developed from 2012 onwards. Three more projects need to obtain their environmental permits for the construction and exploitation of a wind farm. This substantial expansion of offshore wind farms induces a growing interest in the possible effects of these constructions on the marine environment.

Monitoring of fish communities near windmills in the BPNS, which should be considered artificial reefs, revealed that pouting (*Trisopterus luscus*) and cod (*Gadus morhua*) were present in high densities in the vicinity of the windmills during part of the year. Few individuals were present during spring, densities peaked in summer and declined from autumn onwards (Reubens *et al.*, 2011; Reubens *et al.*, 2010). Stomach content analyses indicated the importance of hard substrate associated prey in the diet of pouting (Reubens *et al.*, 2011) and cod (Reubens J., unpublished data). The dominant epifaunal communities (Kerckhof *et al.*, 2010) present on the windmills were reflected in the diet of these fish species. These results revealed the importance of windmills within the ecology of certain demersal fish species for at least part of their life cycle.

However, to date little research focused on migration and site fidelity of cod and pouting at offshore wind farms. No information is available on the residency of these species in the Belgian wind farms, nor about the diurnal and seasonal variation in migration patterns between piles within a wind farm. With the recent advances in acoustic telemetry, valuable information on spatial and temporal migration patterns of fish species can however now be acquired (Winter, 1996).

This study documents the first and preliminary results of acoustic telemetry to investigate spatial and temporal migration patterns of cod in a wind farm in the BPNS. The main objective is to gain a better understanding in the daily and seasonal migration. Specific aims are to identify individual (1) fish residency, (2) movements between wind turbines, (3) migration between habitat types (artificial hard substrate and sandy bottom) and (4) seasonality in occurrence of the fish within the wind farm.

For this study it was decided to focus on cod, a commercially important species with high economical value for the Belgian fisheries industry. Pouting was not used in this telemetry study as survival rates after surgical interventions were low and unpredictable. Although, attempts are made to improve survival and to use this species in future research, as offshore wind farms may play an important role for this species as well.

5.2. Material and Methods

5.2.1. Study site description

The wind farm under consideration is located at the Thorntonbank, a natural sandbank 27 km offshore in the BPNS. At present six wind turbines have been built on gravity-based foundations. The company C-Power has recently started with the construction of the remaining 48 turbines. Those will however not be build on gravity based foundations, but on steel, jacket foundations. So, a total of 54 wind turbines will be constructed on this sandbank, covering an area of approximately 14 km². Each gravity-based foundation has a diameter of 6 m at the sea surface widening to 14 m at the seabed, about 25 m deep at high tide. The foundation is surrounded by a scour protection layer that consists of two coats: a filter layer, made up by pebble (2.5 mm up to 75 mm) which is overtopped by the armour layer that consists of a protective stone mattress with rocks (250 mm up to 750 mm). The armour layer has a width of 44-58 m (1400-2500m²). The surrounding soft sediment is composed of medium sand (median grain size 374 µm, SE 27 µm) (Reubens *et al.*, 2009).

5.2.2. Acoustic telemetry: surgical procedures and setup

The cod specimens tracked at the wind farm, were collected in the study area using hook and line gear. After capture the individual fishes were kept in an aerated water tank for 2 hours before surgical implantation of the transmitter (i.e. tagging). Surgical procedures were similar to those of Baras and Jeandrain (1998), Arendt *et al.* (2001) and Jadot *et al.* (2006). Prior to tagging the fish were anaesthetized in a 0.3ml l^{-1} 2-phenoxyethanol solution. Following anaesthesia, showing no reaction to external stimuli, slow opercular rate and loss of equilibrium (McFarland & Klontz, 1969), the fish were placed ventral side up in a V-shaped support. Most of the body, except the ventral side, stayed in the water and a continuous flow of aerated water was pumped over the gills to avoid dehydration and provide continuous oxygenation. A small incision (15-22 mm) was made on the mid-ventral line and an acoustic transmitter (Vemco, coded, V9-1L) was inserted in the visceral cavity. The incision was closed with two sutures (polyamide monofilament, DS19 3/0). All instruments and transmitters used were disinfected with iso-betadine. In total, 19 cod specimens were tagged. The fish were further externally tagged with a T-bar anchor tag. After full recovery and two hour observation for survival, the fish were released at their capture site.

A laboratory experiment, conducted to test the surgical procedure and survival rate, revealed that internal tagging of cod had no or minimal influence on activity and swimming behaviour (Reubens J., unpublished data).

The acoustically tagged cod specimens were tracked with eleven automated underwater acoustic receivers (Figure 1) (Vemco, VR2W), which were positioned around two wind turbines. Each receiver was equipped with a synchronisation transmitter. The receiver mooring units consisted of a cast iron heating element with an anchor attached. A surface buoy was connected to the mooring using a polypropylene cable. The receiver was attached to the cable approximately 1 m above the seabed and held straight using a subsurface float. A reference transmitter was attached to the cable 1 m above the receiver, to control receiver detection capability. The receivers were retrieved every three to four months to download the receiver data, after which the receivers were put back in place.

Fish positioning was obtained using the VR2W Positioning System (VPS) of Vemco, a non-real-time underwater acoustic fine-scale positioning system. The receivers were laid out as a patchwork of triangles or squares, making position calculation possible.

On August 6th 2010 a one-year study was set up to investigate diurnal and seasonal migration of cod at a wind farm in the BPNS.

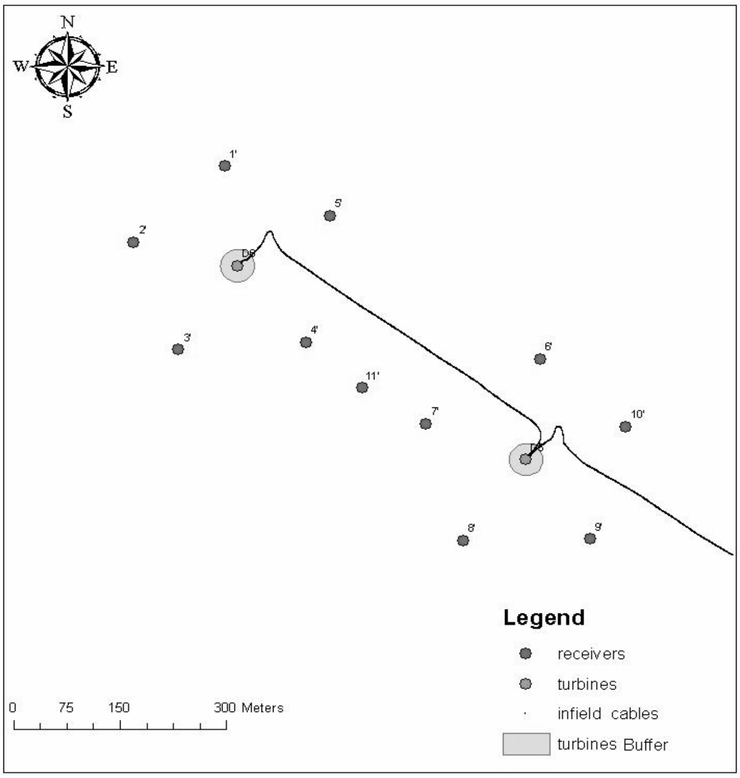

Figure 1. Spatial distribution of the eleven receivers around two wind turbines, allowing for a geographic position calculation for each signal, coming from a tagged fish. The turbines in combination with the buffer (i.e. erosion protection layer) form the artificial hard substrate. The infield cable is imbedded in the soft sediment.

5.2.3. Analyses

To quantify site fidelity of the tagged cod in the study area a residency index was determined for each specimen. This index was calculated dividing the number of days a specimen was detected by the days at liberty (Abecasis & Erzini, 2008). Days at liberty is defined as the number of days between the date of release and the date of the last detection. A fish was defined as being present in the study area on a given day if it was detected at least two times on that day. Single transmitter detections were defined as spurious and removed from the analyses (Meyer *et al.*, 2007). The residency index was determined for the whole array of receivers.

To investigate the diurnal activity pattern of cod, detection frequencies during day-(from dawn till dusk) or night-time(from dusk till dawn) were determined for each individual. Detections were summed per day and compared using χ^2 tests. Sunrise and –set data were obtained for Ukkel, Belgium from the Royal Observatory of Belgium (http://www.astro.oma.be).

Mean daytime and night-time distance to the windmill were calculated for every individual fish. T-tests were used to determine whether time of the day had an effect on distance of the fish to the windmill.

Detection data were further used to identify whether individuals exhibited diurnal changes in habitat preferences. A two-way contingency table was constructed for habitat (hard-soft)/time (day-night) comparison using χ^2-tests. T-tests were performed in Statistica (version 7.0, Statsoft, Tulsa, Oklahoma) and the χ^2-tests were carried out in R (version 2.5.1, www.r-project.org). A significance level of $p < 0.05$ was used in all tests.

5.3. Results

5.3.1. Activity patterns

The activity of 19 cod specimens ranging between 280 mm and 388 mm, was monitored between August and November 2010 (i.e. first four months of the anticipated one year monitoring programme) (Table 1). The 13 Fish that were detected for less than five days were restrained from the residency analysis. All specimens analysed showed high degrees of site fidelity (0.62-1) of the days at liberty over the course of the study.

Five fish were known to be caught by fishermen. However, only one fish could be identified (T14). T14 was only detected in the studied area the day of release. It has been caught in December near the Belgian coast, on the border with the Netherlands (approximately 30 km southeast of the release site). Two fishes were caught in the Westerscheldt estuary the 11th and 29th of December 2010 respectively, approximately 50 km southeast of the release site. One fish was caught the 19th of May 2011 at a shipwreck in the Netherlands, approximately 55 km of the release site. From the fifth fish (caught in May 2011) no capture position data was available.

Only fish tracked for some consecutive days (T01, T02, T04, T05, T11, T17) were accounted for in the day/night analysis.

Table1.
General information of cod *Gadus morhua* tagged and released at the wind farm located at the Thorntonbank in the Belgian part of the North Sea

Fish Code	Total length (mm)	Release site	Date of release (+UTC)	Time tracked (days)	Residency
T01	388	D5	06/08/2010	44	0.62
T02	352	D5	06/08/2010	33	0.66
T03	370	D5	06/08/2010	1	/
T04	292	D5	06/08/2010	10	1.00
T05	350	D5	06/08/2010	10	1.00
T06	370	D6	09/08/2010	1	/
T07	315	D5	06/08/2010	1	/
T08	385	D6	09/08/2010	1	/
T09	344	D6	09/08/2010	1	/
T10	328	D6	09/08/2010	1	/
T11	346	D6	09/08/2010	85	1.00
T12	328	D6	09/08/2010	1	/
T13	314	D6	11/08/2010	1	/
T14	375	D5	01/10/2010	1	/
T15	380	D6	11/08/2010	1	/
T16	315	D6	11/08/2010	3	1.00
T17	280	D5	01/10/2010	28	1.00
T18	380	D5	01/10/2010	1	/
T19	320	D5	01/10/2010	1	/

No differences in activity pattern between day and night were found, except for fish T11 (χ^2-test, χ^2= 126, p = 0.002), which showed a significantly higher number of detections during daytime (table 2).

Table 2.
Results of the χ^2 test by time of the day for cod *Gadus morhua* tagged and released in the wind farm.

Fish Code	χ^2	df	p-value
T01	33.36	43	0.85
T02	14.28	32	1.00
T04	2.95	9	0.97
T05	7.30	9	0.61
T11	125.89	84	0.002
T17	24.04	27	0.63

5.3.2. Fish positioning

Fishes T01, T05 and T11 were frequently detected by several receivers for consecutive days, therefore these fishes could be used to determine the average distance (T01: 21m, SD 20m; T05: 40m, SD 10m; T11: 49m, SD 30m) the fish stayed from a wind turbine. All three specimens stayed in the vicinity of the hard substrate as the scour protections extend approximately 30 m from the centre of a turbine. A significant difference in distance from a turbine between day and night was present for T05 (T-test, df = 441, p = 0.007) and T11 (T-test, df = 1838, p = 0.006) (Figure 2). For both fish, mean distance was smaller during the night. Distance did not differ significantly over time for T01 (T-test, df = 86, p = 0.15).

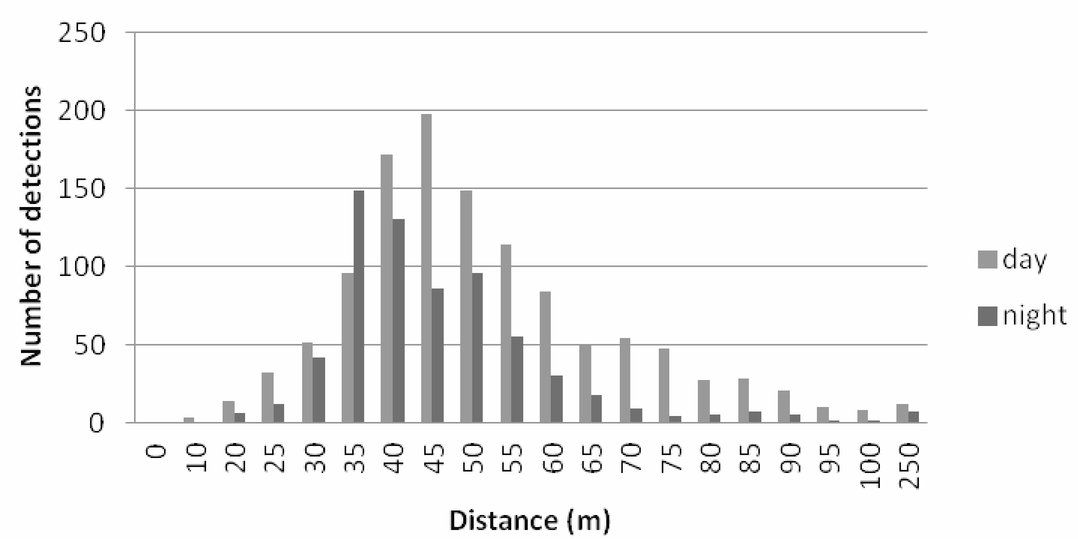

Figure 2. Number of detections as a function of distance to centre of wind turbine of cod, specimen T11

The diurnal habitat selectivity, based upon substrate type, was investigated in detail for fish T01, T04, T05 and T11. T11 showed a clear diurnal pattern in habitat selection from the 5th of September onward (Figure 3). During daytime the fish was mainly detected at the soft substrate. At night there were detections both at the hard and the soft substrate. Before the 5th of September no pattern could be seen. It should however be noted that distance from the windmill was not brought into account in this analysis. Although the fish was located at the soft substrate, it could still be in close vicinity to the windmill, as suggested in figure 2. A significant difference in habitat utilisation was present between day and night for this fish (χ^2= 144.4, p < 0.01). The odds ratio indicated that the chance of being present at the soft substrate during daytime was higher than being present at the hard substrate during daytime (Table 3). For fish T04 and T05 no significant (χ^2-tests) differences were found between the habitat types and the time of the day. Habitat utilisation of fish T01 differed significantly, with preference for the hard substrate (Table 3).

Table 3.
χ^2-tests for individual fish comparing habitat (hard and soft substrate) and time of the day (day and night) using contingency tables.

	χ^2-value	**p-value**	**Odds ratio**
T01	4.38	0.04	0.20
T04	0.55	0.46	2.30
T05	0.17	0.68	1.13
T11	144.41	< 0.01	4.24

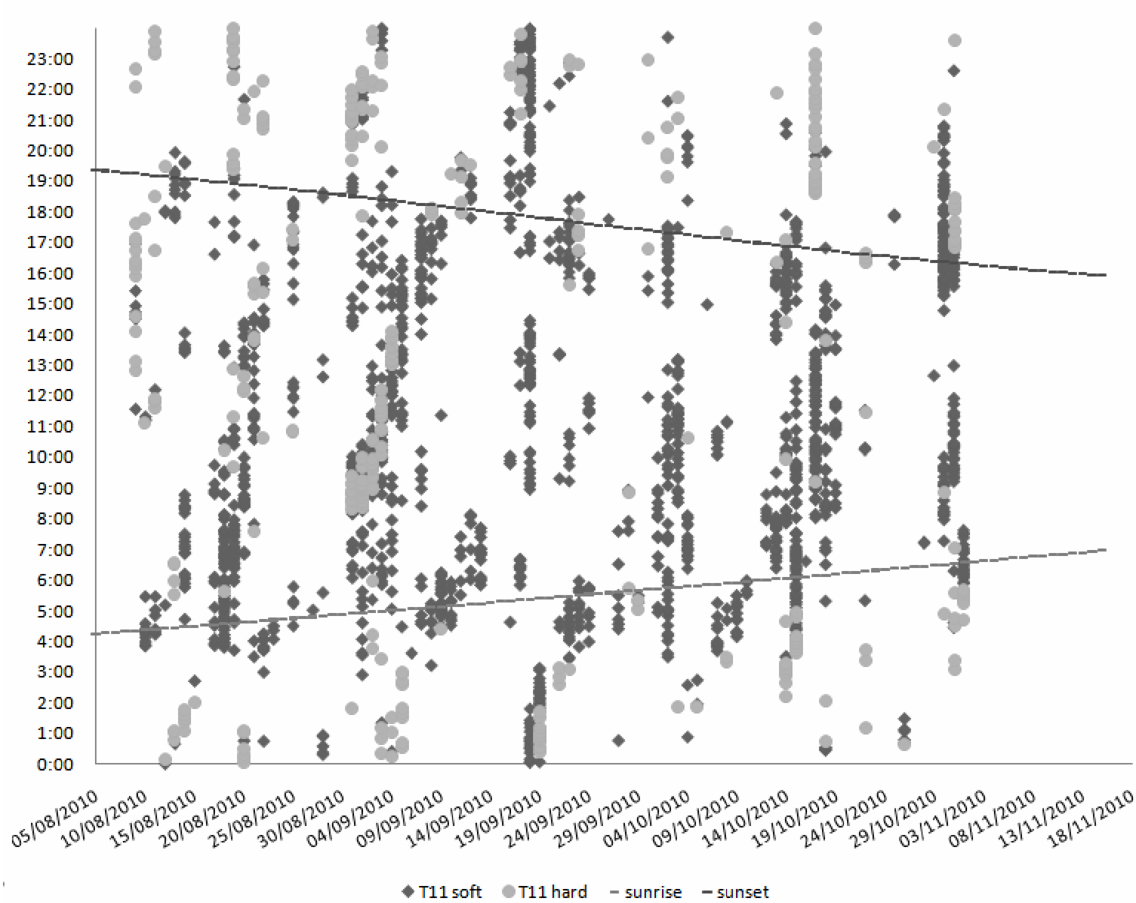

Figure 3. Diurnal habitat selectivity (based upon substrate type) for fish T11. The lines indicate length of the day, black squares represent detections at the soft sediment, grey dots detections at the hard substrate.

5.4. Discussion

Although the presented data should be considered preliminary and should hence be interpreted with caution, these first results on fish behaviour and habitat utilization nearby Belgian offshore windmills already suggest that, although major differences in individual cod behaviour were detected:

- Individual cod may be attracted to offshore windmills and their surrounding erosion protection layers as shown by the high residency of some tagged specimen.
- The spatial fine scale distribution (i.e. habitat choice) of individual cod nearby the windmills tends to be influenced by the diurnal cycle for some individual cod.

It should be noted that this is work in progress. The results are limited to the first receiver data retrieval which took place on November 1st 2010. All results refer to this first period of 88 days (06/08/2010 - 01/11/2010). Point 2 and 4 of the aims, migration between wind turbines and seasonality, were not analysed hitherto as more data are needed.

5.5. Acknowledgement

The first author acknowledges a FWO predoctoral grant. This paper contributes to the Belgian wind farm monitoring programme, with the financial support of C-Power nv and Belwind nv. We are thankful to the crew of the RV "Zeeleeuw", the fishing vessel N95 and the diving team. We thank the Management Unit of the North Sea Mathematical Models (MUMM) and the Flanders Marine Institute (VLIZ) for their technical and logistic support.

5.6. References

Abecasis, D. & Erzini, K., (2008). Site fidelity and movements of gilthead sea bream (*Sparus aurata*) in a coastal lagoon (Ria Formosa, Portugal). Estuar. Coast. Shelf Sci. 79, 758-763.

Arendt, M.D., Lucy, J.A. & Evans, D.A., (2001). Diel and seasonal activity patterns of adult tautog, *Tautoga onitis*, in lower Chesapeake Bay, inferred from ultrasonic telemetry. Environ. Biol. Fishes 62, 379-391.

Baras, E. & Jeandrain, D., (1998). Evaluation of surgery procedures for tagging eel Anguilla anguilla with biotelemetry transmitters. Hydrobiologia 371, 107-111.

Jadot, C., Donnay, A., Acolas, M.L., Cornet, Y. & Bégout Anras, M.L., (2006). Activity patterns, home-range size, and habitat utilization of Sarpa salpa (Teleostei: Sparidae) in the Mediterranean Sea. ICES J. Mar. Sci. 63, 128.

Kerckhof, F., Rumes, B., Norro, A., Jacques, T.G. & Degraer, S., (2010). Seasonal variation and vertical zonation of the marine biofouling on a concrete offshore windmill foundation on the Thornton Bank (southern North Sea). *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine ecosystem management unit. Chapter 5: 53-68.

McFarland, W.N. & Klontz, G.W., (1969). Anesthesia in fishes. p. 1535.

Meyer, C.G., Holland, K.N. & Papastamatiou, Y.P., (2007). Seasonal and dial movements of giant trevally *Caranx ignobilis* at remote Hawaiian atolls: implications for the design of marine protected areas. Marine ecology progress series 333, 13-25.

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

Reubens, J., Eede, V. & Vincx, M., (2009). Monitoring of the effects of offshore wind farms on the endobenthos of soft substrates: Year-0 Bligh Bank and Year-1 Thorntonbank. *In:* Degraer, S. & Brabant, R., (Eds.) (2009). Offshore wind farms in the Belgian part of the North Sea: State of the art after two years of environmental monitoring, Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine ecosystem management unit. Chapter 6: 61-91.

Reubens, J.T., Degraer, S. & Vincx, M., (2010). The importance of marine wind farms, as artificial hard substrata, for the ecology of the ichthyofauna. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: early environmental impact assessment and spatio-temporal variability, Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine ecosystem management unit. Chapter 6:69-82.

Winter, J.D., (1996). Advances in underwater telemetry. Fisheries Techniques 2, 572-575.

Chapter 6. Soft-sediment macrobenthos around offshore wind turbines in the Belgian Part of the North Sea reveals a clear shift in species composition

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Sampling campaign on the Thorntonbank Photo UGent

Abstract

Two offshore wind farms became operational in the Belgian part of the North Sea during 2009 and 2010 on respectively the Thorntonbank (C-Power) and the Bligh Bank (Belwind). During the past five years, a monitoring programme has been carried out to determine the baseline situation on the soft-sediment macrobenthos in these areas, together with any primary impacts that could have arisen during and after construction. During the first and second years after implementation of the turbines no large-scale impacts were detected on the macrobenthos (Reubens *et al.*, 2009; Coates *et al.*, 2010). A targeted sampling strategy was carried out during 2010 to detect any smaller scale impacts around the fifth gravity based foundation on the Thorntonbank. Macrobenthic communities can be highly dependent of sedimentological characteristics such as median grain size and organic matter content (Pearson and Rosenberg, 1978; Wilhelmsson and Malm 2008). The increased epifaunal communities colonizing the hard substrates (turbines) produce organic enriched sediments, possibly modifying the soft-sediment macrobenthic communities (Kerckhof *et al.*, 2010). The construction of offshore wind turbines could also produce shifts in the macrobenthic communities due to changing hydrography (Hiscock *et al.*, 2002; Wilhelmsson & Malm, 2008; Zucco *et al.*, 2006). Sediment samples were taken along four gradients alongside turbine D5, two parallel (Southwest and Northeast) and two perpendicular (Southeast and Northwest) to the main tidal currents. Samples at one and seven metres from the scour protection system (boulders) were taken by divers, while samples further away from the boulders (15, 25, 50, 100 and 200m) were collected using a Van Veen grab. Unfortunately, due to logistic problems (bad weather, availability of sampling vessels...) important samples were missing to reveal an accurate comparison of the biotic and abiotic data. Nevertheless, the following important trends were observed: firstly, a lower median grain size and higher macrobenthic densities were detected in closer vicinity to the turbine. Secondly, a difference in gradients was observed with high chlorophyll a concentrations and a lower median grain size together with high densities for *Lanice conchilega* and *Spiophanes bombyx* along the Southwest and Northeast gradients. The Southeast and Northwest gradients were mainly dominated by the tube building amphipod *Monocorophium acherusicum*. These species are known for stabilising soft substrates and therefore provide a clear indication of a shifting macrobenthic community. At this moment, the macrobenthic community around the turbines on the Thorntonbank is very dynamic and could change rapidly as the system has probably not reached its balance. This study illustrates the importance of a small-scale monitoring strategy together with an in depth research on the morphology of the seabed, to determine the effects of wind turbines on the soft-sediment macrobenthos.

Samenvatting

Twee offshore windmolenparken werden operationeel in het Belgisch deel van de Noordzee tijdens 2009 en 2010 op respectievelijk de Thorntonbank (C-Power) en de Bligh Bank (Belwind). Tijdens de laatste vijf jaar werd een monitoringsprogramma uitgevoerd in deze gebieden om de baseline (jaar-0) situatie op het zachte substraat macrobenthos te bepalen samen met primaire impacten die tijdens en na constructie zouden kunnen opduiken. Tijdens de eerste en tweede jaar na installatie werden geen grootschalige effecten waargenomen op het macrobenthos (Reubens *et al.*, 2009; Coates *et al.*, 2010). Een gerichte staalname strategie werd uitgevoerd tijdens 2010 om kleinschalige impacten rondom de vijfde gravitaire fundering op de Thorntonbank te detecteren. Macrobentische gemeenschappen zijn zeer afhankelijk van de sedimentologische karakteristieken zoals mediane korrelgrootte en organisch materiaal (Pearson and Rosenberg, 1978; Wilhelmsson and Malm, 2008). De ontwikkelde epifauna gemeenschappen op het harde substraat (turbine) zal organisch aangerijkte sedimenten produceren wat op zijn beurt het zachte substraat macrobenthos kan beïnvloeden (Kerckhof *et al.*, 2010). De geïnstalleerde turbines kunnen ook shifts in het macrobenthos creëren door veranderende hydrografische eigenschappen (Hiscock *et al.*, 2002; Wilhelmsson & Malm, 2008; Zucco *et al.*, 2006). Sediment stalen werden langs vier gradiënten langs turbine D5 genomen, twee parallel (Zuidwest en Noordoost) en twee evenwijdig (Zuidoost en Noordwest) met de stroming. Stalen op één en zeven meter van de erosiebeschermingslaag (stortstenen) werden met behulp van duikers genomen. Stalen op verdere afstand (15, 25, 50, 100 en 200m) werden met een

Van Veen grijper genomen. Belangrijke stalen zijn door logistieke problemen (slechte weersomstandigheden, beschikbaarheid van onderzoeksschepen,...) niet genomen waardoor een nauwkeurige vergelijking van de biotische en abiotische data ontbreekt. Desondanks werden de volgende belangrijke trends geobserveerd: Ten eerste werd een lagere mediane korrelgrootte gemeten dichtbij de turbine, samen met hogere macrobenthische densiteiten. Vervolgens werd een verschil in gradiënten geobserveerd met hoge cholophyll a concentraties en een lagere mediane korrelgrootte op de Zuidwestelijke en Noordoostelijke gradiënten samen met hogere densiteiten van *Lanice conchilega* en *Spiophanes bombyx*. De Zuidoostelijke en Noordwestelijke gradiënten werden voornamelijk gedomineerd door de koker vormende soort *Monocorophium acherusicum*. Deze soorten zijn gekend voor hun stabiliserende werking op het zachte substaat en zijn daardoor een duidelijke aanwijzing van een shift in de macrobenthische gemeenschap. Op dit moment zijn de macrobenthische gemeenschappen rondom de turbines zeer dynamisch en kunnen zeer snel veranderen aangezien het systeem waarschijnlijk nog geen balans heeft bereikt. Dit onderzoek toont het belang aan van een kleinschalige monitoring samen met een grondig onderzoek van de morfologie van de zeebodem, om de effecten van wind turbines op het zachte substraat macrobenthos te bepalen.

6.1. Introduction

During 2009 and 2010 the first offshore wind farms became operational in the Belgian part of the North Sea on respectively the Thorntonbank (C-Power) and the Bligh Bank (Belwind). To determine the baseline (Year-0) situations on the soft-sediment macrobenthos in these areas, a large-scale monitoring programme was set up in 2005 and 2008 (De Maersschalck *et al.*, 2006; Reubens *et al.*, 2009). Large-scale impacts on the macrobenthos were absent during the first and second years after construction of the first six turbines on the Thorntonbank (Coates & Vincx, 2010; Reubens *et al.*, 2009). During 2010, a small scale sampling strategy was carried out, next to the large scale monitoring, to detect possible impacts on the soft-sediment macrobenthos in the immediate vicinity of one single turbine, two years after construction.

Macrobenthic communities are highly dependent of the granulometric characteristics (e.g. median grain size), organic matter content and the hydrographic regimes above the seabed (Pearson & Rosenberg, 1978; Wilhelmsson & Malm, 2008). Since major offshore wind farms have been established across the world and will alter these properties, it is very important to understand the possible changes they will cause to the marine environment. Introducing anthropogenic structures such as wind turbines and artificial reefs increases for example the amount of epifaunal organisms associated with the hard substrates (Kerckhof *et al.*, 2010; Köller *et al.*, 2006; Petersen & Malm, 2006). A rapid colonisation with a high species turnover was detected on the gravity based foundations on the Thorntonbank (Kerckhof *et al.*, 2010). The presence of hard substrate epifauna produces a depositional flow of faeces and other organic material which could create organic enriched sediments and therefore alter the soft-sediment macrobenthic communities (Köller *et al.*, 2006; Maar *et al.*, 2009; Ysebaert *et al.*, 2009). In addition, the abundance of fish around the turbines can increase due to the occurrence of epifauna and the exclusion of fisheries activities (Reubens *et al.*, 2010). Therefore, depositional material produced by these organisms and other organic material will cause additional organic enrichment on the seafloor (Falcao *et al.*, 2007). Furthermore, the construction of wind turbines could also produce shifts in the macrobenthic communities due to changing hydrography (Hiscock *et al.*, 2002; Wilhelmsson & Malm, 2008; Zucco *et al.*, 2006). According to Hiscock *et al.* (2002), currents and waves can increase in speed around turbines causing resuspension and transportation of soft sediments and the production of scouring pits, which can extend several meters away from the turbines. Therefore, scour protection systems, such as boulders and rocks, are often placed around wind turbines to reduce or prevent scouring and erosion around the foundation (Hiscock *et al.*, 2002; Petersen & Malm, 2006). A scour protection system, consisting of a filter and an armour layer, was installed around the six gravity based wind turbines on the Thorntonbank to protect the turbine against erosion (Brabant & Jacques, 2010). However, this scour protection does not eliminate the possibility of secondary erosion occurring around the scour protection systems, causing subsequent changes in the sediment composition (Köller *et al.*, 2006; Whitehouse *et al.*, 2008). The granulometric characteristics of the seabed were also altered before installation of the gravity based wind turbines on the Thorntonbank. The seabed was flattened by removing loose sand and placing a foundation bed consisting of a filter and gravel layer (Brabant & Jacques, 2010).

Objectives of the small scale study: (1) to investigate if the sediments are altered due to organic enrichment and/or changing hydrodynamics around the turbine and subsequently modify the soft-sediment macrobenthic communities, and (2) to investigate if any impacts detected at small-scale can be extrapolated to a large-scale impact that would otherwise only be detected after longer exposure periods.

6.2. Material and Methods

The following study focused on the soft-sediment macrobenthos in close vicinity of the fifth gravity based turbine on the Thorntonbank (D5). D5 is also used as a target turbine for the investigation of the hard substrate epifauna and for the fish populations attracted to the epifauna (Kerckhof *et al.*, 2010; Reubens *et al.*, 2010; Reubens *et al.*, 2011). Samples were taken at the end of spring when both densities of the hard-substrate epifauna and the deposition of the organic material (phytoplankton) start to increase. Samples were also taken in autumn when the macrobenthic densities reach their maximum abundances.

6.2.1. Sampling

Sediment samples were obtained around the turbine and along four gradients (Figure 1). Two gradients were directed parallel to the main tidal current pattern (Northeast and Southwest) at both sides of the turbine, two other gradients were perpendicular to the main currents (Northwest and Southeast). Each gradient started next to the scour protection layer (boulders), in the depression formed during construction. Samples close to the turbines in and next to the depression (1 and 7m) were collected by divers (operating from the RV Zeeleeuw) in July 2010 and September 2010, while a Van Veen grab operated from a small research vessel (Geosurveyor III, GEO.XYZ bvba) was used to sample the stations further away from the turbine (15, 25, 50, 100, 200m) in September 2010 (Table 1).

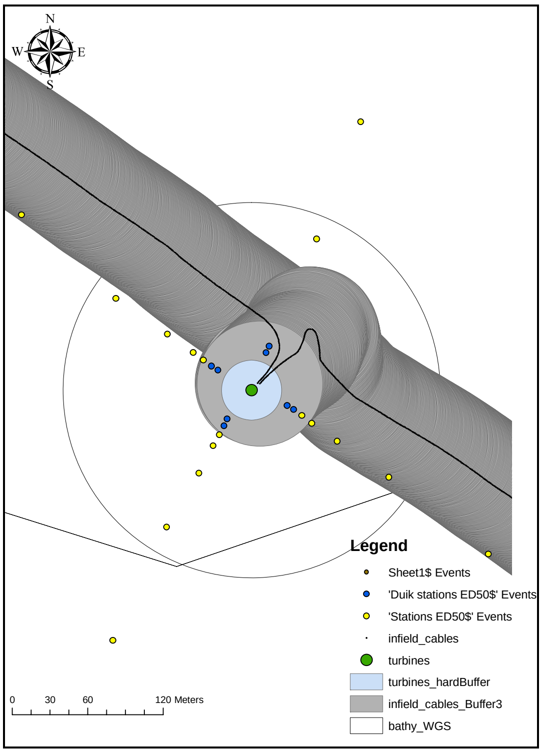


Figure 1. Sampling locations of the monitoring campaign during 2010 around the D5 turbine (Green). Stations close to the turbine (blue) were taken by divers while the stations further away from the turbine (yellow) were taken with a small research vessel.

Divers employed an airlift suction device (surface area 0.1026m²) to sample the soft-sediment macrobenthos. The collected sediment was sieved over a 1mm sieve table and the remaining residual was subsequently fixed in an 8% formaldehyde-seawater solution. Macrobenthic samples at one and seven meters from the scour protection layer (boulders) were taken for all four gradients in July 2010, the position of samples taken at the end of September could not be determined accurately due to bad visibility and currents (Table 1). The samples were not replicated due to a shortage of volunteer divers.

Cores (diameter 27mm) were taken by divers along the Northeast and Southwest gradients in June and/or July 2010 to measure median grain size, total organic matter and chlorophyll *a* concentrations in the sediment. The first five centimetres of the sediment were analysed for median grain size and total organic matter, while the first two centimetres were analysed for chlorophyll *a* concentrations.

Samples further away from the boulders (15, 25, 50, 100 and 200m) were taken in September 2010 by means of a Van Veen grab (surface area 0.1026m²) deployed from the Geosurveyor III (GEO.XYZ bvba) (Figure 1, Table 1). Before opening the Van Veen grab, one core sample (diameter 27mm) was obtained for the physical-chemical analyses. The collected sediment was treated as described above. The Northeast gradient was not sampled due to the presence of cables on the seabed (Figure 1). Due to severe weather conditions during sampling no replicates were taken with the Van Veen grab and the Reineck box corer could not be employed (to measure chlorophyll *a)* for safety reasons.

Table 1.
Sampling locations and dates for the Dive (1 & 7m) and Van Veen samples (15, 25, 50, 100 and 200m) around the turbine in 2010. (*)The position of Dive samples taken in September (1m & 7m) could not be determined accurately due to bad visibility and currents.

Dive samples (1&7m)			**Van Veen samples**	
	Abiotic factors	Macrobenthos		Abiotic & macrobenthos
Northeast	03/06/10 + 05/07/10	05/07/2010	Northeast	/
Southeast	02/07/10	02/07/2010	Southeast	11/09/2010
Southwest	04/06/10 + 06/07/10	06/07/2010	Southwest	11/09/2010
Northwest	02/07/10	01/07/2010	Northwest	11/09/2010
1 & 7m (*)	29/09/10 + 30/09/10	29/09/10 + 30/09/10		
Total		12 samples		15 samples

6.2.2. Analyses

6.2.2.1. Abiotic analysis

The grain size partition was determined with a Malvern Mastersizer 2000G, hydro version 5.40. The Mastersizer utilizes a laser diffraction method with a measuring range of 0.02 – 2000µm. The median grain size and proportions of the Wentworth fractions can therefore easily be determined. Fractions are given as volume percentages with a range from fine clay (< 4µm) to coarse gravel/shell material (>1600µm). The total amount of organic material (TOM %) was determined per sample by applying the following, simplified equation:

$$TOM\% = \frac{DW - AW}{DW - CrW} \, x \, 100$$

The dry weight (DW) was determined after 48 hours at 60°C and the ash weight (AW) after 2h20min at 550°C. For every sample, the used crucible was weighed (CrW) in order to determine the TOM % (Heiri et al., 2001).

The Chlorophyll a samples (µg/g) from the top 2cm of the sediment were sampled and stored at -80°C. The samples were freeze dried, weighed and subsequently sonicized for 30 seconds after the addition of 90% acetone. After 2 hours the supernatants were filtered over a Teflon 0.2µm filter and injected into the HPLC-system (Franco *et al.*, 2007).

6.2.2.2. Biotic analysis

Samples were stained with *1% Rose Bengal* and rinsed over a 1mm sieve. The macrobenthic organisms were removed from all debris, identified to species level and counted. If the species level could not be defined, a higher taxonomic level was permitted. Nematoda, Pisces and rare species (all species found in maximum three samples, with a maximum of two individuals per sample) were excluded from all analyses as they are not efficiently sampled with a Van Veen grab or they do not belong to the standard remains on a 1 mm sieve. After analysis, organisms were stored per species and per sample in a 4% neutralized formaldehyde solution at the Marine Biology Research Group (Biology Department, Ghent University). The species list is given in Annex 1 – Systematic species list of the soft-substrate macrobenthos. The most recent systematic-taxonomic literature as well as species lists for the Belgian part of the North Sea were consulted (Adema, 1991; Bick *et al.*, 2010; De Bruyne, 1994; Degraer *et al.*, 2006; Fiege *et al.*, 2000; Fish & Fish, 1996; Hartmann-Schröder, 1996; Hayward & Ryland, 1995; Jones, 1976; Lincoln, 1979; Naylor, 1972; Tebble, 1966). A reference collection of all species is stored in 4% formaldehyde.

Hill's diversity index N_0 or the species richness (the number of species per sample) was calculated and attributes the same weight to all species, independent of their abundance.

The total biomass per species was obtained in three ways. Firstly, the biomass of Amphipoda, Mysida, Decapoda and *Nephtys cirrosa* was calculated by means of length/weight regressions. Secondly, the conversion factors of Brey (Brey, 2001) were applied to all other species. These factors allow a determination of the ash free dry weight (AFDW) through a conversion of the wet weight (WW). When neither regressions nor conversion factors existed for a certain species, a third method was used: weight loss by cremation. Per sample and per (higher) taxon, every organism was placed in either an aluminium crucible (smaller organisms) or a small clean porcelain cup (larger organisms). They were dried for 48 hours at 60°C. After cooling, the crucibles and cups were weighed (dry weight, DW) and put in a muffle furnace (2 hours at 550°C). They were cooled again before final weighing (ash weight, AW). The ash free dry weight (AFDW) is the difference between the dry (DW) and ash weight (AW).

6.2.3. Data analysis

The following data were collected per sampling station: date, location, sediment composition, macrobenthic species list, number of individuals per species and total biomass per species. The number of individuals per sample and per species were standardised to the number of individuals per m² (abundance). The data of the small and large scale monitoring are stored in the Belgian Marine Data Centre (BMDC).

Statistical analyses were carried out with the programmes Statistica 7 and Primer v6 (Clarke & Gorley, 2006), distribution figures were created with the programme ArcView GIS. Differences between stations were tested using one-way ANOVA with Log transformed data (Logx+1), after compliance with the assumptions. When significant differences were observed, the Tukey HSD test was applied to identify significant differences ($p<0.05$) between pairs of groups. However, if the assumptions for parametric analyses were not fulfilled, the data were analysed using the non-parametric Kruskal-Wallis test.

Multivariate analyses were carried out with the Primer v6 programme. Before analysis, the data was square-root transformed. Bray-Curtis similarity matrices were used to build up non-metric multidimensional scaling (MDS) plots. MDS plots give information on relationships between data points. The stress values indicate how well the relationships are represented. Only results with a stress value lower than 0.2 are reliable (Clark 1993). SIMPER analysis allows the detection of which species contribute to the distinctness of certain communities as it gives similarity and dissimilarity percentages. Furthermore, a one way analysis of similarity (ANOSIM) allows the detection of differences between groups.

The C-Power wind farm is located on the Thornton Bank, a 20 km long natural sandbank located in the BPNS, near the border between the exclusive economic zones of Belgium and the Netherlands. The bank lies some 30 km offshore and belongs to the Zeeland banks system (Cattrijsse and Vincx, 2001). Local water depth is about 30 m and the surrounding soft sediment seabed is composed of medium sand (mean median grain size 374 µm, standard error 27 µm) (Reubens *et al.*, 2009).

6.3. Results

6.3.1. Abiotic analysis

6.3.1.1. Median grain size and Total organic matter

The Dive samples from September 2010 were removed from the dataset to obtain two full datasets of Dive samples from July 2010 and Van Veen samples from September 2010.

Closer to the turbine, the median grain size showed a lower value compared to samples taken at a larger distance (Figure 2, Left). However, all samples fell under the medium grain size class (250-500µm) and were not significantly different from each other (One-way ANOVA).

From the samples taken at one and seven meters in July, the mean median grain size was calculated for every gradient (Figure 2, right). The lowest mean median grain size was detected on the Northeast and Southwest gradients (parallel to the prevailing currents) with significantly lower values (ANOVA Tukey HSD test, p=0.036 and p=0.015) compared to the Southeast gradient.

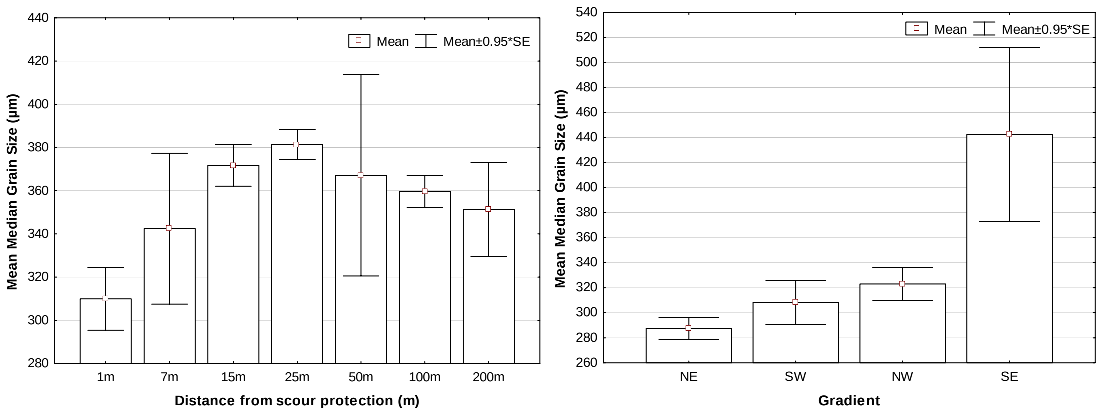


Figure 2. Left: Mean median grain size (µm) from one to 200 meters from the scour protection system (data from 1m and 7m from July 2010; data from 15m-200m from September 2010). Right: Mean median grain size (µm) of Dive samples taken at every gradient around the D5 turbine (data from 1m and 7m from July 2010).

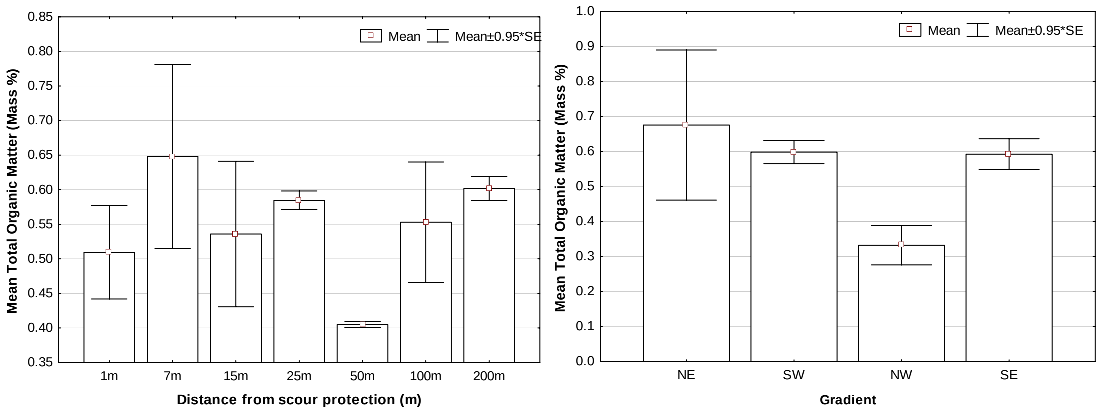


Figure 3. Left: Mean total organic matter (Mass %) from one to 200 meters from the scour protection system (1m and 7m from July 2010; 15m-200m from September 2010). Right: Mean total organic matter (Mass %) of the Dive samples taken at every gradient around the D5 turbine (data from 1m and 7m from July 2010).

The mean total organic matter (Mass %) was highest at seven meters and lowest at fifty meters from the scour protection system (Figure 3, Left). When comparing the four gradients, the lowest mean total organic matter content was measured on the Northwest gradient (Figure 3, Right), however no significant differences were detected (One-way ANOVA).

6.3.1.2. Chlorophyll *a* concentrations in the sediment

A steep decrease in Chlorophyll *a* concentrations was detected between June and July on the Northeast and Southwest gradients (Figure 4, Left). Only 3% of the chlorophyll *a* concentrations measured at one meter on the Northeast gradient in June was still present in July. At seven meters on the Southwest gradient 11% of the chlorophyll *a* concentrations measured in June was present in July. In July, chlorophyll *a* measurements on all four gradients were very low in general (< 2µg/g) and show the highest concentrations on the gradients parallel to the currents (Northeast and Southwest) (Figure 4, Right).

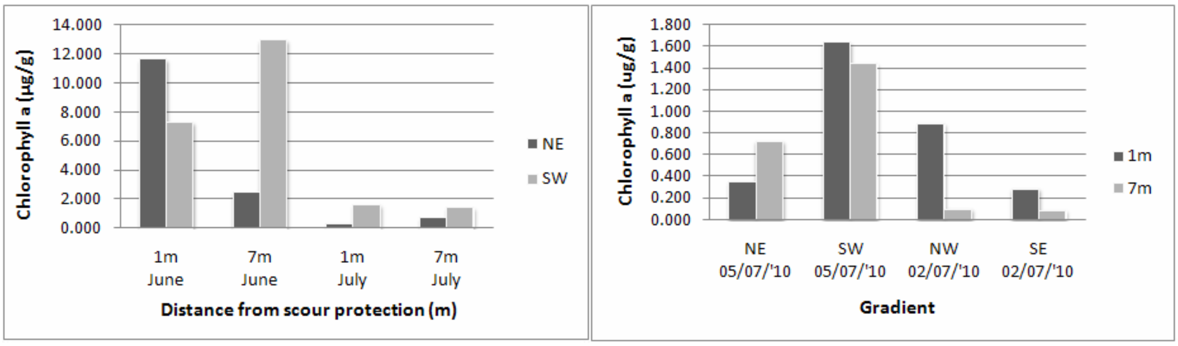


Figure 4. Left: Chlorophyll *a* concentrations at one and seven meters from the scour protection system on the Northeast and Southwest gradients in June and July. Right: Chlorophyll *a* concentrations at one and seven meters on the four gradients in July.

6.3.2. Biotic variables

6.3.2.1. Samples from one to 200 meters from the turbine

Dive samples taken at one and seven meters from the scour protection system in July 2010 were characterized by extremely high macrobenthic densities, ranging from a minimum of 955 ind./m² at seven meters along the Southeast gradient to a maximum of 12407 ind./m² at seven meters along the Southwest gradient. Van Veen grab samples taken further away from the boulders in September 2010 were characterized by lower densities ranging from a minimum of 234 ind./m² at 50 meters to a maximum of 2115 ind./m² at 100 meters both along the Southeast gradient.

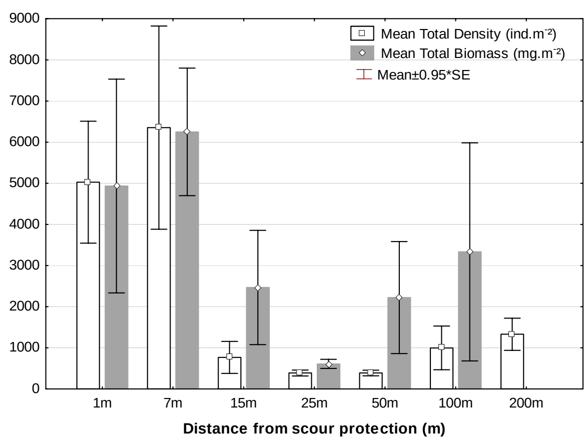
A one way analysis of similarity (ANOSIM) based on the distance (1m–200m) from the scour protection system revealed the highest R-statistic values (significance level 1.2%) for samples taken at one metre in comparison to samples taken at 15m, 25m, 50m, 100m and 200m (0.926; 0.988; 1; 0.975; 0.864). With an R-statistic value of one (two completely different groups), a SIMPER analysis was carried out for one and 50 meters from the scour protection system (Table 2). The results provided more insight in the difference in macrobenthic community structure by illustrating the average abundance of species for both sites. Four hard substrates species (*Monocorophium acherusicum*, *Jassa herdmani*, *Asteriidae* juv. and *Phtisica marina*) and two soft-substrate species (*Spiophanes bombyx* and *Lanice conchilega*) were the main contributors to the differences in densities.

Table 2.
The contribution of macrobenthic species to the average similarity of the group (SIMPER), for one and 50 meters from the scour protection system. Diss/SD=coefficient of dissimilarity, Contrib%=contribution of the species to the total percentage. Cumm.%=Accumulation of the percentages (Contrib%) until the cut-off of >60% is reached.

Groups 1m & 50m Average dissimilarity = 78.33						
Species	Group 1m Average Abundance	Group 50m Average Abundance	Average Dissimilarity	Diss/SD	Contrib%	Cum.%
Monocorophium acherusicum	25.59	0	8.66	1.94	11.06	11.06
Jassa herdmani	20.01	0	7.01	3.45	8.95	20.01
Asteriidae juv.	21.06	0	6.37	1.03	8.13	28.14
Phtisica marina	11.33	0	3.87	1.75	4.94	33.08
Spiophanes bombyx	14.48	6.26	3.71	0.91	4.73	37.81
Lanice conchilega	10.65	0	3.34	0.94	4.26	42.08
Corophium sp.	7.58	0	2.68	1.65	3.42	45.5
Actiniaria sp.	8.37	0	2.65	1.2	3.38	48.88
Hydrozoa sp.	11	4.41	2.58	1.53	3.29	52.17
Urothoe brevicornis	7.17	4.35	2.19	1.2	2.8	54.97
Gastrosaccus spinifer	2.69	7.62	1.99	1.41	2.54	57.51
Spio goniocephala	3.5	6.07	1.47	1.45	1.87	59.38
Phyllodoce rosea	3.85	0	1.32	1.09	1.68	61.06

For the following analyses the Dive samples from the end of September were removed to obtain two full datasets of Dive samples from the beginning of July and Van Veen samples from the beginning of September.

Samples taken at one and seven metres from the scour protection system had a significantly higher (ANOVA Tukey HSD test) mean total density in comparison to the samples taken at 15m, 25m and 50m and a significantly higher (ANOVA Tukey HSD test) species richness in comparison to samples taken at 15m, 25m, 50m, 100m and 200m (Table 3, Figure 5). The mean total biomass showed a similar trend, with a wide distribution from a minimum of 607.97mg/m² at 25 meters from the scour protection system to a maximum of 38849.56mg/m² at 200 meters (not shown in Figure 5). The latter had an extremely high total biomass due to the occurrence of large *Ophiura ophiura* and *Echinocardium cordatum* individuals. Nevertheless, no significant differences (One-way ANOVA) in mean total biomass were observed between sites.



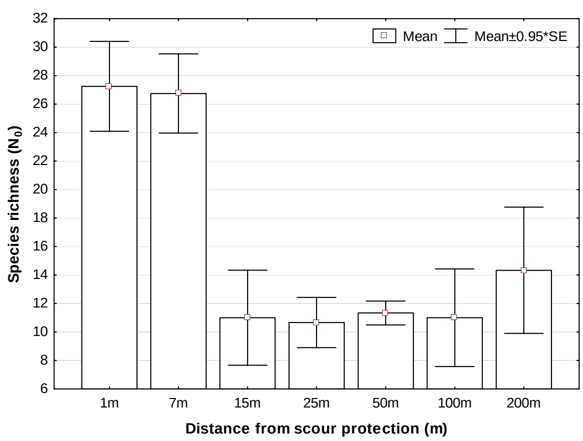


Figure 5. Left: Mean total density (ind.m^{-2}) and biomass (mg.m^{-2}) for samples taken close to the scour protection system (1m–200m). Right: Species richness (N_0) for samples from one to 200 meters.

Table 3.
Significance of differences between samples taken between 1m and 200m from the scour protection system, based on mean total density (above) and species richness (below) (ANOVA Tukey HSD test).

	1m	**7m**	**15m**	**25m**	**50m**	**100m**
1m						
7m	1.00					
15m	0.049	0.051				
25m	0.011	0.012	0.989			
50m	0.011	0.012	0.991	1.000		
100m	0.010	0.105	0.100	0.922	0.929	
200m	0.332	0.346	0.930	0.575	0.587	0.991
	1m	**7m**	**15m**	**25m**	**50m**	**100m**
1m						
7m	1.000					
15m	0.008	0.007				
25m	0.009	0.008	1.000			
50m	0.009	0.008	1.000	1.000		
100m	0.013	0.012	1.000	1.000	1.000	
200m	0.031	0.027	0.993	0.997	0.997	0.100

Lanice conchilega, *Spiophanes bombyx*, *Monocorophium acherusicum* and *Jassa herdmani*, together with three other soft-sediment macrobenthic species (*Nephtys cirrosa*, *Spio goniocephala* and *Urothoe brevicornis*) which are known to be dominant in the macrobenthic communities on the Thorntonbank (Coates & Vincx, 2010; De Maersschalck *et al.*, 2006) were selected from the SIMPER analysis (Table 2). The mean total density of each species was calculated for every distance (1, 7, 15, 25, 50, 100 and 200m) from the scour protection, without making a difference in gradients (Figure 6).

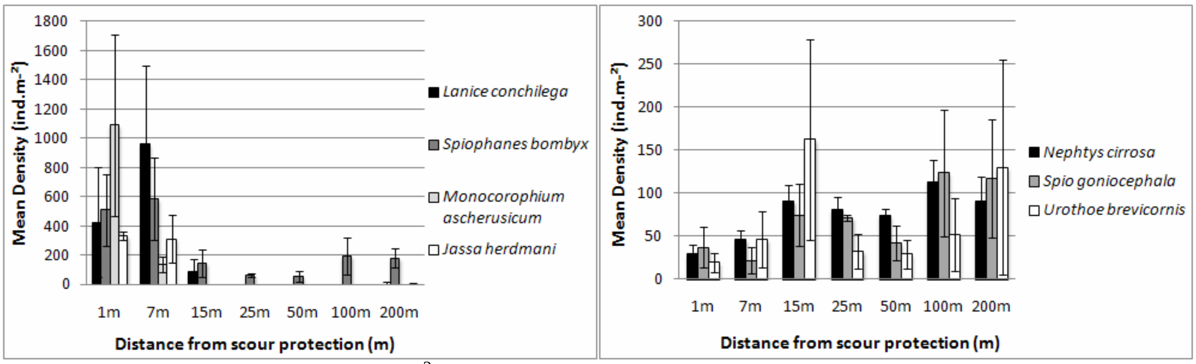


Figure 6. Left: Mean density (ind.m^{-2}) of species occurring in high densities close to the turbine, based on SIMPER analysis. Right: Mean density (ind.m^{-2}) of typical macrobenthic species occurring on the Thorntonbank.

The hard substrate species (*M. acherusicum* and *J. herdmani*) had high mean densities close to the turbine at one and seven metres with a peak of 1089 ind./m² for *M. acherusicum* at one meter from the scour protection system (Figure 6, Left). The two soft-sediment macrobenthic species (*L. conchilega* and *S. bombyx*) also had high mean densities at one and seven meters from the boulders with a peak of 960 ind./m² for *L. conchilega* and 584 ind./m² for *S. bombyx*, both at seven meters. The relative abundance of *M. acherusicum*, *J. herdmani* and *L. conchilega* decreased with increasing distance from the scour protection system. However, *S. bombyx* illustrated the opposite with an increasing dominance (in relation to the other species) further away from the turbine. The typical soft-sediment macrobenthic species for the Thorntonbank also showed this trend with higher mean densities at stations further from the turbine (Figure 6, Right).

6.3.2.2. Gradients around the turbine

From the samples taken in July and September 2010 (1m-200m), the mean macrobenthic density for every gradient was calculated. The two gradients parallel to the main currents (Northeast and Southwest) showed higher mean total densities (p=0.442, One-way ANOVA) in comparison to the two gradients perpendicular to the currents (Northwest and Southeast) (Figure 7).

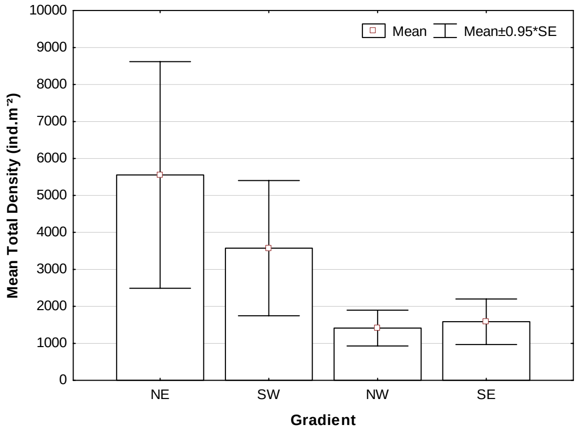


Figure 7. Mean total density (ind.m^{-2}) for the four gradients around the turbine (1m-200m).

Focusing on the samples taken at one and seven meters in July 2010, the same species as above (*L. conchilega, S. bombyx, M. acherusicum, J. herdmani, N. cirrosa, S. goniocephala* and *U. brevicornis)* were selected to calculate the mean total densities (ind./m²) of each species at every gradient (Northeast, Southwest, Southeast and Northwest), without making a difference between one and seven meters from the scour protection system (Figure 8).

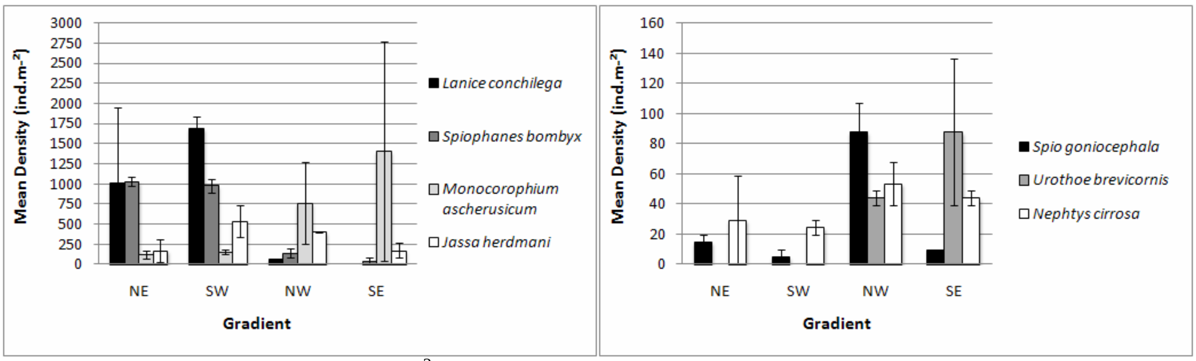


Figure 8. Left: Mean density (ind.m^{-2}) of species occurring in high densities close to the turbine, based on SIMPER analysis. Right: Mean density (ind.m^{-2}) of typical macrobenthic species occurring on the Thorntonbank.

Lanice conchilega and *Spiophanes bombyx* both had higher mean densities along the Northeast and Southwest gradients (Figure 8, Left). *Lanice conchilega* reached a maximum mean density of 1691 ind./m² on the Southwest gradient, the mean density of *S. bombyx* was relatively equal on both gradients with a maximum of 1082 ind./m² in the Northeast. The mean density of the hard substrate related species *Monocorophium acherusicum* was highest along the Northwest and Southeast gradients, with a maximum of 1408 ind./m² on the Southeast. *Jassa herdmani* however, had a relatively stable distribution over the four gradients with the lowest maximum mean density of 536 ind./m² in the Southwest. The typical soft-sediment macrobenthic species for the Thorntonbank (*N. cirrosa*, *S. goniocephala* and *U. brevicornis*) showed the lowest mean densities along the Northeast and Southwest gradients and an increase along the Southeast and Northwest gradients (Figure 8, Right).

6.4. Discussion

This pilot study was performed in order to investigate possible small scale impacts of the gravity based turbines on the soft-sediment macrobenthos. Due to bad weather conditions at the moment of the small-scale sampling campaigns, the Van Veen samples could not be replicated and the Dive and Van Veen samples were taken in a time interval of two to three months. Nevertheless, this study clearly suggests changes occurring to the system in close vicinity to the wind turbine.

The macrobenthic densities around the turbine ranged from a minimum of 234 ind./m² to a maximum of 12407 ind./m². These densities are considerably higher in comparison to the results from the large-scale monitoring programme where macrobenthic densities on the Thorntonbank ranged between 770 and 1930 ind./m² in the autumn of 2009 (Coates & Vincx, 2010; Reubens *et al.*, 2009). Many species detected in the soft sediment at one and seven meters from the scour protection system around the turbine were in close correlation to the hard substrate epifauna: numerous juvenile starfish (*Asteriidae* juv.), brittle stars (*Ophiurae* juv.) and hydrozoans were found together with the abundant tube building amphipods *Monocorophium acherusicum* and *Jassa herdmani* (Kerckhof *et al.,* 2010). Furthermore, the small-scale results showed a clear difference between the Northwest-Southeast and the Northeast-Southwest gradients around the turbine. Along the Northwest and Southeast gradients, *M. acherusicum* showed a dominance with high densities of 2778 ind./m² on the Southeast and 1277 ind./m² on the Northwest gradient, both at one meter from the scour protection system. Not only could we see an increase in generally rare soft-sediment macrofauna, the ecosystem engineer *Lanice conchilega* showed high densities along the Northeast (1949 ind./m² at seven meters) and Southwest gradients (1832 ind./m² at seven meters) or parallel to the currents. *Spiophanes bombyx*, a common species on the Thorntonbank (Coates & Vincx, 2010; De Maersschalck *et al.*, 2006), also showed higher densities at the Northeast (1082 ind./m² at seven meters) and Southwest (1062 ind./m² at seven meters) gradients. Other typical soft-sediment macrofauna species for the Thorntonbank (*Nephtys cirrosa*, *Spio goniocephala* and *Urothoe brevicornis*) still occurred closer to the turbine. Their densities were lower compared to previous studies (Coates & Vincx, 2010; Reubens *et al.*, 2009), possibly because of seasonal differences with lower macrobenthic densities in spring compared to autumn (De Maersschalck *et al.*, 2006). Similarly, the mean total biomass of species occurring in close vicinity to the turbine was higher than previously recorded results on the Thorntonbank (Coates & Vincx, 2010). Certain individuals of *Ophiura ophiura* and *Echinocardium cordatum* caused extremely high biomass values at 200 meters from the scour protection system.

Why is there an increase in soft-sediment macrobenthic densities in closer vicinity to the turbine and along the Northeast and Southwest gradients? The macrobenthic changes in density and diversity could be due to several causes such as changing hydrodynamics around the base of the turbine, modification of granulometric characteristics, higher organic matter deposition from the epifauna occurring on the turbines and sand pits created during preparation dredging activities.

Changes in the hydrodynamic characteristics around the turbine could produce sheltered areas which stimulate the settlement of larvae. The main tidal currents on the Thorntonbank are parallel to the Northeast and Southwest gradients (Van den Eynde, 2005) and could decrease in speed close to the turbine due to the shadow effect of the construction. However, increasing currents around the turbine in the Northwest and Southeast gradients, could cause resuspension, transportation and scouring effects of the seabed (Hiscock *et al.*, 2002).

At smaller distances from the scour protection layer (one and seven meters) and along the gradients parallel to the currents (Northeast and Southwest), smaller median grain sizes were observed. Although these observations were not statistically different, this suggests the creation of a microhabitat along the four directions, possibly affecting the macrobenthic community. These changes could be due to changing hydrodynamics around the turbine or the activities carried out before installation e.g. removal of sand and the placement of a foundation bed consisting of a filter and gravel layer (Brabant & Jacques, 2010).

An increase in food availability also has an effect on the abundance of macrobenthic species (Köller *et al.*, 2006) and is reflected in the chlorophyll *a* concentrations measured in June (Figure 4). *Chl a* concentrations were higher (maximum 12.8µg/g) than previous studies carried out in similar sandy sediments where a maximum of 0.3µg/g was measured at a corresponding sandy location

(Franco *et al.*, 2007; Vanaverbeke *et al.*, 2004). These results suggest a high depositional flow of organic material produced by the hard substrate epifauna. Even though the turnover rate of organic matter in these coarse sandy, permeable sediments is rapid (Figure 4) (Ehrenhauss *et al.*, 2004), the organic enrichment around the turbine (after the spring bloom) in combination with a slightly lower median grain size is most likely sufficient enough to enhance the larval settlement and survival rate of certain macrobenthic species such as the filter feeder *Lanice conchilega.* With a reproduction peak in spring followed by two smaller peaks during summer and autumn (Van Hoey, 2006), the aulophora larvae of *L. conchilega* is able to feed in the water column, where it stays for a prolonged period of time (up to 60 days) (Bhaud & Cazaux, 1990). Important factors which trigger benthic settling are the availability of habitat structures and the effects of these on the local hydrodynamic regime, enhancing the settlement of larvae in areas already populated by adults (Callaway, 2003a). Other species such as the opportunistic *Spiophanes bombyx* could also make use of this situation as a selective deposit feeder which is positively associated with *L. conchilega* (Rabaut *et al.*, 2007). In a next phase, *L. conchilega* itself could increase the total density of the soft-sediment macrobenthic community by enhancing the settlement of larvae on the tubes (Qian *et al.*, 1999).

A fourth cause for the increased macrobenthic densities and the differences between gradients could be the creation of sand pits to the Southwest of the turbines (4-4.5m depth) during dredging activities before installation (Van den Eynde *et al.*, 2010). Sand pits create areas of decreased current flow enhancing the settlement of organic matter and larvae. As Van den Eynde *et al.* (2010) observed no natural filling and a stable evolution of the sand pits; an ideal environment is created for larval development. The collection of morphological data and monitoring of the seabed around the turbines should be continued to attain a thorough interpretation of the biological data.

A succession is hence observed from a species poor, homogenous sand bank to a heterogeneous, highly diverse area within the Thorntonbank. Will this succession continue and create areas with a high abundance of bivalves after the colonization of *Lanice conchilega*? Previous studies have observed these successions where juveniles of *Mya arenaria* were found in higher numbers in plots where they used tube structures for attachment (Zühlke *et al.*, 1998). In the longer run, Callaway (2003b) described how the juveniles of the blue mussel *Mytilus edulis* used artificial tubes to attach to and turn the plots into fully developed intertidal mussel banks. The author suggests that under favourable conditions mussel banks may also develop on natural intertidal *L. conchilega* aggregations. Moreover, mussel banks have been reported centrally in *L. conchilega* aggregations (Hertweck, 1995), suggesting that mussel bank development may indeed be favoured by the presence of high density *L. conchilega* patches. Whether this succession might also be possible in the sediment nearby offshore wind turbines is yet to be investigated.

6.5. Conclusions

The first results of the small-scale monitoring around the turbine suggest noticeable differences in the soft-sediment macrobenthic communities with respect to distance from the turbine. In close vicinity to the turbine, certain hard substrate species were found in high densities in the soft sediment. In addition, a decrease in median grain size coincided with an increase in polychaete densities (such as *Lanice conchilega* and *Spiophanes bombyx*) at short distance from the turbine. Furthermore, a distinction in the two main gradients around the turbine could be made. Along the Northeast and Southwest gradient, high chlorophyll *a* concentrations and a low median grain size were observed together with high *Lanice conchilega* and *Spiophanes bombyx* densities. This gradient is possibly situated in an area with decreased current speeds due to changing hydrodynamics or due to the created and ‘stable’ sand pits during pre dredging activities. This probably caused the accumulation of organic matter and enhanced larval settlement. Along the Northwest and Southeast gradient, lower chlorophyll *a* concentrations, a slightly higher median grain size and a dominance of the tube building amphipod *Monocorophium acherusicum* was observed.

This small-scale pilot study suggests that the introduction of the hard substrate turbine induced a local shift in the soft-sediment macrobenthic community. The homogenous sandy environment of the Thorntonbank has therefore received a higher heterogeneity at a small scale, mostly along the Northeast and Southwest gradients. The question can be asked which driving force around the turbine initiated and maintains this shift: Changing hydrodynamics? Organic enrichment? Changing granulometric characteristics? Previous created pits due to dredging activities? Unravelling these questions is crucial as changes can be rapid and at present it is unknown into what type of community this shift will evolve into. Three different turbine structures are currently being installed (gravity based, monopiles and the Jacket structure) in the Belgian part of the North Sea, possibly impacting the seabed and the soft-sediment macrobenthic communities in three different and to us unknown ways.

Research on the small-scale spatial patterns of macrobenthic communities and the morphology of the seabed around the turbines must be continued as this study has arisen from a once-only observation around one gravity based turbine. Soon, hundreds of turbines will occupy the Belgian part of the North Sea creating an opportunity for changes to evolve at a large scale. Will the turbines provide colonization of the tube worm *Lanice conchilega* at a large scale? And will the next step be a colonization of bivalves on the seabed such as mussels or oysters?

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6.7. References

EN ISO 19493, (2007). Water quality - Guidance on marine biological surveys of hard-substrate communities. 32 pp.

Bassindale, R., (1964). British barnacles with keys and notes for the identification of the species. - Synop. Brit. Fauna, 4:1 68.

Adema, J.P.H.M., (ed.) (1991). De krabben van Nederland en België (Crustacea, Decapoda, Brachyura). Nationaal Natuurhistorisch Museum Leiden.

Bhaud, M.R. & Cazaux, C.P., (1990). Buoyancy characteristics of *Lanice conchilega* (Pallas) larvae (Terebellidae). Implications for settlement. J Exp Mar Biol Ecol 141(1): 31-45.

Bick, A., Otte, K. & Meissner, K., (2010). A contribution to the taxonomy of Spio (Spionidae, Polychaeta, Annelida) occurring in the North and Baltic Seas, with a key to species recorded in this area. Marine Biodiversity 40(3): 161-180.

Brabant, R. & Jacques T.G., (2010). Introduction: offshore wind energy development in the Belgian part of the North Sea & Anticipated impacts. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 2: 9-18.

Brey, T., (2001). Population dynamics in benthic invertebrates. A virtual handbook. Version 01.2. http://www.thomas-brey.de/science/virtualhandbook.

Callaway, R., (2003a). Juveniles stick to adults: Recruitment of the tube-dwelling polychaete *Lanice conchilega* (Pallas, 1766). Hydrobiologia 503(1-3): 121-130.

Callaway, R. (2003b). Long-term effects of imitation polychaete tubes on benthic fauna: they anchor *Mytilus edulis* (L.) banks. J Exp Mar Biol Ecol 283(1-2): 115-132.

Clarke, K. & Gorley, R., (2006). PRIMER v6: User Manual/Tutorial. PRIMER-E, Plymouth.: 190.

Coates, D. & Vincx, M., (2010). Monitoring the effects of offshore wind farms on the soft substratum macrobenthos: Year-1 Bligh Bank and Year-2 Thorntonbank. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of

Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 7: 83-103.

De Bruyne, R.H., (ed) (1994). Schelpen van de Nederlandse kust: Stichting Jeugdbondsuitgeverij, Stichting Uitgeverij KNNV, Utrecht. Tweede druk.

De Maersschalck, V., Hostens, K., Wittoeck, J., Cooreman, K., Vincx, M. & Degraer, S., (2006). Monitoring van de effecten van het Thornton windmolenpark op de benthische macro-invertebraten en de visfauna van het zachte substraat. p. 136.

Degraer, S., Wittoeck, J., Appeltans, W., Cooreman, K., Deprez, T., Hillewaert, H., Hostens, K., Mees, J., Vanden Berghe, W. & Vincx, M., (eds.) (2006). De macrobenthosatlas van het Belgische deel van de Noordzee. Federaal Wetenschapsbeleid. D/20051191/5.

Ehrenhauss, S., Witte, U., Buhring, S.I. & Huettel, M., (2004). Effect of advective pore water transport on distribution and degradation of diatoms in permeable North Sea sediments. Marine Ecology-Progress Series 271: 99-111.

Falcao, M., Santos, M.N., Vicente, M. & Monteiro, C.C., (2007). Biogeochemical processes and nutrient cycling within an artificial reef off Southern Portugal. Marine Environmental Research 63(5): 429-444.

Fiege, D., Licher, F. & Mackie, A.S.Y., (2000). A partial review of the European Magelonidae (Annelida : Polychaeta): Magelona mirabilis redefined and M-johnstoni sp nov distinguished. Journal of the Marine Biological Association of the United Kingdom 80(2): 215-234.

Fish, J.D. & Fish, S., (eds.) (1996). A student's guide to the seashore. Second Edition.: Cambridge University Press, Cambridge.

Franco, M.A., De Mesel, I., Diallo, M.D., Van der Gucht, K., Van Gansbeke, D., Van Rijswijk, P., Costa, M.J., Vincx, M. & Vanaverbeke, J., (2007). Effect of phytoplankton bloom deposition on benthic bacterial communities in two contrasting sediments in the southern North Sea. Aquatic Microbial Ecology 48(3): 241-254.

Hartmann-Schröder, G., (ed) (1996). Die Tierwelt Deutschlands und der angrenzenden Meersteile nach ihren Merkmalen und ihrer Lebensweise. 58. Teil: Annelida - Borstenwürmer - Polychaeta. 2., neubearbeitete Auflage.: VEB Gustav Fischer Verlag Jena.

Hayward, P.J. & Ryland, J.S., (eds.) (1995). Handbook of the marine fauna of North-West Europe.: Oxford University Press, 800pp.

Heiri, O., Lotter, A.F. & Lemcke, G., (2001). Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. Journal of Paleolimnology 25(1): 101-110.

Hertweck, G., (1995). Distribution patterns of characteristic sediment bodies and benthos populations in the Spiekeroog backbarrier tidal flat area, southern North Sea. 1. Results of a survey of tidal flat structure 1988-1992. Senckenbergiana maritima Frankfurt/Main 26(1): 81-94.

Hiscock, K., Tyler-Walters, H. & Jones, H., (2002). High level environment screening study for offshore wind farm developments - marine habitats and species project. Report from the Marine Biological Association to The Department of Trade and Industry New & Renewable Energy Programme. (AEA Technology, Environment Contract: W/35/00632/00/00). p. 156.

Jones, N.S., (ed) (1976). Synopses of the British Fauna (N.S.) 7: British cumaceans (Arthropoda: Crustacea). Keys and notes for the identification of the species.: The Linnean Society of London, Academic Press London and New York.

Kerckhof, F., Rumes, B., Norro, A., Jacques, T.G. & Degraer, S., (2010). Seasonal variation and vertical zonation of the marine biofouling on a concrete offshore windmill foundation on the Thornton Bank (southern North Sea). *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 5: 53-68.

Köller, J., Köppel, J. & Peters., W., (2006). Offshore Wind Energy. Research on Environmental Impacts., Chapter 12: Benthos in the vicinity of piles: FINO 1 (North Sea), pp 185 - 200.

Lincoln, R.J., (ed) (1979). British marine amphipoda: Gammaridae: British museum (Natural History), London., 658pp.

Maar., M., Bolding, K., Petersen, J.K., Hansen, J.L.S. & Timmermann, K., (2009). Local effects of blue mussels around turbine foundations in an ecosystem model of Nysted off-shore wind farm, Denmark. journal of Sea Research 62(2-3): 159-174.

Naylor, E., (ed) (1972). Synopsis of the British Fauna (N.S.) 3: British Marine Isopods. Keys and notes for the identification of the species.: The Linnean Society of London, Academic Press London and New York.

Pearson, T.H. & Rosenberg, R., (1978). Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. Oceanog Mar Biol Ann Rev 16: 229-311.

Petersen, J.K. & Malm, T., (2006). Offshore windmill farms: Threats to or possibilities for the marine environment. Ambio 35(2): 75-80.

Qian, P.Y., Rittschof, D., Sreedhar, B. & Chia, F.S., (1999). Macrofouling in unidirectional flow: miniature pipes as experimental models for studying the effects of hydrodynamics on invertebrate larval settlement. Marine Ecology-Progress Series 191: 141-151.

Rabaut, M., Guilini, K., Van Hoey, G., Vincx, M. & Degraer, S., (2007). A bio-engineered soft-bottom environment: The impact of Lanice conchilega on the benthic species-specific densities and community structure. Estuarine Coastal and Shelf Science 75(4): 525-536.

Reubens, J., Degraer, S. & Vincx, M., (2010). The importance of marine wind farms, as artificial hard substrata, for the ecology of the ichthyofauna. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 6: 69-82.

Reubens, J., Vanden Eede, S. & Vincx, M., (2009). Monitoring of the effects of offshore wind farms on the endobenthos of soft substrates: Year-0 Bligh Bank and Year-1 Thorntonbank. In: Degraer, S. & Brabant, R., (eds) (2009). Offshore wind farms in the Belgian part of the North Sea: State of the art after two years of environmental monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical models, Marine ecosystem unit. Chapter 6: 61-91.

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

Tebble, N., (ed) (1966). British bivalve seashells. A handbook for identification: Trustees of the British Museum (Natural History), London. Alden Press Osney Mead, Oxford.

Van den Eynde, D., (2005) Numerieke modellering van het sedimenttransport ter hoogte van de Thorntonbank. p. 23.

Van den Eynde, D., Brabant, R., Fettweis, M., Francken, F., Melotte, J., Sas, M. & Van Lancker, V., (2010). Monitoring of hydrodynamic and morphological changes at the C-Power and the Belwind offshore wind farm sites - A synthesis. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 3: 19-36.

Van Hoey, G., (2006). Spatio-temporal variability within the macrobenthic Abra alba community, with the emphasis on the structuring role of *Lanice conchilega*. PhD Thesis, Biology Department - Marine Biology, Ghent University (UGent), Ghent.

Vanaverbeke, J., Steyaert, M., Soetaert, K., Rousseau, V., Van Gansbeke, D., Parent, J.Y. & Vincx, M., (2004). Changes in structural and functional diversity of nematode communities during a spring phytoplankton bloom in the southern North Sea. journal of Sea Research 52(4): 281-292.

Whitehouse, R., Harris, J. & Rees, J., (2008). Dynamics of scour pits and scour protection - Synthesis report and recommendations (Milestones 2 and 3). Department of energy and climate change.

Wilhelmsson, D. & Malm, T., (2008). Fouling assemblages on offshore wind power plants and adjacent substrata. Estuarine Coastal and Shelf Science 79(3): 459-466.

Ysebaert, T., Hart, M. & Herman, P.M.J., (2009). Impacts of bottom and suspended cultures of mussels Mytilus spp. on the surrounding sedimentary environment and macrobenthic biodiversity. Helgoland Mar Res 63(1): 59-74.

Zucco, C., Wende, W., Merck, T., Köchling, I. & Köppel, J., (2006). Ecological Research on offshore wind farms: International exchange of experiences (Part B Literature Review of Ecological impacts). p. 284.

Zühlke, R., Blome, D., Heinz van Bernem, K. & Dittmann, S., (1998). Effects of the tube-building polychaete Lanice conchilega (Pallas) on benthic macrofauna and nematodes in an intertidal sandflat. Senckenb Marit 29(1/6): 131-138.

Chapter 7. Monitoring the effects of offshore windmill parks on the epifauna and demersal fish fauna of soft-bottom sediments: baseline monitoring

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Beam trawl catches

Photo ILVO- fisheries

Abstract

This chapter reports on the condition of demersal fish, benthopelagic fish and epibenthos in the concession zones and reference zones of the Thorntonbank windmill park in the third year after the installation of the first six turbines, and on the effects of increased fishing effort just outside the Thorntonbank concessions. Due to practical issues following access restrictions in the Belwind concession area, no samples could be taken in 2010 of the Bligh Bank impact area. Hence, the data of 2010 on the Bligh Bank and Oosthinder reference zones were stored for future analyses concerning natural temporal variation in the vicinity of the Belwind windmill park.

In 2009, some alterations within the epibenthos and fish assemblages were observed in the impact area on the Thorntonbank. These included (1) higher densities of horse mackerel (*Trachurus trachurus*) in autumn 2009 and (2) lower densities of sole (*Solea solea*) in spring 2009, compared to the reference areas around the Thorntonbank. These observations, however, were not confirmed by the 2010 data. Newly observed differences between the impact area and the reference areas in 2010 included (1) generally larger individuals of the swimming crab *Liocarcinus holsatus* and the brown shrimp *Crangon crangon* at the impact station, which may reflect either increased growth due to a high food availability or increased predation pressure eliminating smaller individuals; (2) higher autumn densities of small whiting *Merlangius merlangus* at the impact station.

The observed increase in fisheries intensity of the Belgian fleet and recreational fisheries in the area north of the concession had little effect on the level of density, biomass and diversity. However, the length-frequency distributions of sole showed an absence of the smallest size classes in both seasons of 2010, which could be the result of increased indirect fishing mortality (such as discards) or of changes in the local benthic community. Similarly, there was a striking reduction in the individuals in the size classes ranging between 21 and 26 cm for whiting *M. merlangus* in spring 2010 at the fringe stations. There were some differences between fringe stations and reference stations for small demersal fish and for epibenthos. Generally, these differences were highest in 2009 and more or less normalized by 2010.

These differences between the impact station, fringe stations and reference stations may indicate changes in predation pressure, food supply and recruitment. Further monitoring and targeted research actions are needed to confirm causal relationships between these observations and the investigated pressures.

Samenvatting

Dit hoofdstuk geeft de resultaten weer van de analyses betreffende de toestand van het epibenthos, de demersale vissen en de benthopelagische vissen in de concessiezones van de Thorntonbank tijdens jaar 3, en betreffende de effecten van verhoogde visserijdruk aan de rand van deze concessies. Als gevolg van toegangsbeperkingen in het Belwind windmolenpark konden in de loop van 2010 geen stations worden bemonsterd in de Bligh Bank impact zone. De verzamelde gegevens over de referentiezones werden opgeslagen voor toekomstige analyses betreffende de natuurlijke temporele variatie in het gebied.

Tijdens de analyse van de gegevens van 2009 werden reeds verschillen aangetroffen tussen het impactgebied van de Thorntonbank en de referentiegebieden, nl. hogere densiteiten van de horsmakreel in het najaar en lagere densiteiten van tong in het voorjaar. Deze observaties herhaalden zich echter niet in 2010. ‘Nieuwe’ verschillen tussen de impact zone en de referentiezones omvatten (1) een verschuiving naar grotere individuen bij de zwemkrab en de grijze garnaal in het impactgebied, wat zou kunnen wijzen op een verhoogd voedselaanbod of een verhoogde predatiedruk bij kleinere individuen, en (2) een hogere najaarsdensiteit van jonge wijting ter hoogte van de turbines.

De geobserveerde veranderingen in visserijactiviteiten van de Belgische vloot en van de sportvisserij gingen niet gepaard met grote veranderingen in densiteit, biomassa en diversiteit van de verschillende ecosysteemcomponenten. Er werden echter wel belangrijke verschillen waargenomen betreffende de lengte-frequentiedistributies van tong (ontbreken van de kleinste lengteklasses tijdens voorjaar en najaar 2010) en wijting (lagere densiteiten van individuen in de lengteklasse 21-26cm in

het voorjaar). Deze verschillen zouden kunnen wijzen op een verhoging van indirecte sterfte (bijvoorbeeld door teruggooi) of veranderingen ter hoogte van de bodemgemeenschappen. Er waren tevens wat verschillen tussen het randgebied en de referentiegebieden bij epibenthos en kleine demersale vissoorten, vooral in 2009, maar deze waren grotendeels verdwenen in 2010.

De geobserveerde verschillen tussen het impactgebied, de randgebieden en de referentiegebieden zouden veranderingen kunnen weerspiegelen in predatiedruk, voedselaanbod en rekrutering. Om enige causale verbanden tussen deze observaties en de onderzochte menselijke activiteiten te bevestigen, zijn er echter verdere monitoring en gerichte onderzoeksacties nodig.

7.1. Introduction

The already constructed wind turbines at the Thorntonbank and the Bligh Bank constitute patches of hard substrate on a seafloor dominated by soft sediments. Next to reef effects on and in the near vicinity of the artificial hard substrates (e.g. Andersson *et al.*, 2009; Wilhelmsson *et al.*, 2009), effects are also expected on the fauna inhabiting the surrounding soft substrate. These effects include (adapted from Wilhelmsson *et al.*, 2009):

- Depletion of phytoplankton by high densities of filtrating organisms (i.e. mussels) on and around the turbine could adversely affect growth of filter feeders on the seabed
- Input of organic material from organisms associated with the turbines, as well as entrapment of material by the turbines, could enrich the seabed and enhance abundances of deposit-feeding organisms, and in turn benefit predators on these.
- Predation by fish and crabs associated with the turbines could negatively affect abundances of prey species.
- An artificial reef (here turbine and scour protection) can enhance abundances of pelagic fish species, and attract flatfishes to the reef.

Additionally, the exclusion of fisheries activities from windmill parks and their safety buffers may have positive effects within the closed areas (e.g. Jaworski *et al.*, 2006), but also negative effects outside the windmill park borders due to a local reallocation of fishing effort (Berkenhagen *et al.*, 2010). The effects of such reallocations on fauna inhabiting soft substrates were termed “fringe effects” in the current analysis. The changes in fisheries activities as observed by Vessel Monitoring System data (VMS) were described in Chapter 8.

This chapter specifically reports on the condition of demersal fish, benthopelagic fish and epibenthos in the concession zones and reference zones of the Thorntonbank windmill park in the third year after the construction of the first six turbines, and on the effects of increased fishing effort in the immediate vicinity of the closed areas concerning these ecosystem components. These results form the basis of the impact assessment concerning the construction and exploitation of the windmill parks under investigation.

7.2. Material and Methods

For the baseline monitoring in 2010, 17 stations were sampled in spring and 20 stations in autumn (Table 1). In 2010, the station WT1 was moved southward (WT1bis) due to increased sand extraction activities at the original position since 2007. Station 330 was included in the analyses since it proved to be a good reference for Thorntonbank gullies (Derweduwen *et al.*, 2010).

All fish tracks were ‘short’ tracks of 1/2 Nm instead of 1Nm as in the previous monitoring years (see Derweduwen *et al.*, 2010). On these track locations, demersal fish fauna and macro-epibenthos were sampled onboard the research vessel Belgica with an 8-meter shrimp trawl (stretched mesh width 22 mm in the cod end) and a bolder-chain but no tickler chains (to minimize the environmental damage). The net was dragged during 15 minutes at an average speed of 4 knots over the bottom. 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. After each fish track, a photograph was taken of the net content prior to the processing of the catch. All fish, except gobies, were identified, measured and/or counted or wet weighed on board. In the case of small catches , the epibenthos (including gobies) was processed on board as well; in the case of a large catch, a subsample of 6 litres was frozen for further laboratory analyses. Rare or peculiar species/individuals were stored for further reference or investigation. The net contents were divided into 'bentho-pelagic fish','demersal fish' and 'epifauna'. For these ecosystem components density, biomass (epibenthos only), diversity and length frequency distribution were analysed. The number of individuals per sample and per species was converted to number of individuals per 1000m² (abundance). Biomass was expressed as grams of wet weight (WW) per 1000m² and diversity was evaluated based on Hill's diversity indices N0 and N1 and on the variable Expected Number of Species (ES(n)).

The evolution of these parameters since 2005 was investigated on an ecosystem component level (benthopelagic fish, demersal fish, epibenthos). Density was analysed in further detail for a selection of species. This selection was based on the species' importance as discriminating components in the community composition analyses concerning the windmill park concession area and the adjoining reference areas, as conducted in Derweduwen *et al.* (2010).

For these analyses, stations were pooled based on their classification as windmill reference station, windmill impact station, impact fringe station or reference fringe station. The initial description of the BACI design (see table 3.1) was adapted according to the actual situation in 2010:

- Stations WT7-8 in zone B were considered as references for zone A, since there were still no turbines in this zone during the study year 2010.
- Stations WT6 and WT9 were considered as fringe stations, since VMS analyses indicated an increase in fisheries activities in the area north of the six existing turbines at the Thorntonbank (see chapter 8, this volume)

Table 1.
Overview of stations in the windmill park area sampled during the spring and autumn campaigns of 2005 and 2008-2010.

sandbank system	station	description	spring 2005	autumn 2005	spring 2008	autumn 2008	spring 2009	autumn 2009	spring 2010	autumn 2010
Goote Bank	WG1	reference C-Power gully	x	x	x	x				
	WG2	reference C-Power top	x	x	x	x			x	x
	WG3	reference C-Power gully	x	x	x	x				
Thorntonbank	WT1(bis)	reference C-Power gully	x	x	x	x			x	x
	WT2	reference C-Power top	x	x	x	x	x	x	x	x
	WT3	reference C-Power gully	x	x	x	x		x	x	x
	WT4(bis)	fringe C-Power top	x	x	x	x			x	x
	WT5(bis)	impact C-Power top	x	x	x	x	x	x	x	x
	WT6	fringe C-Power gully	x	x	x	x			x	x
	WT7	fringe C-Power gully	x	x	x	x	x	x	x	x
	WT8	impact C-Power top	x	x	x	x	x	x	x	x
	WT9	fringe C-Power gully	x	x	x	x	x	x	x	x
Bank Zonder Naam	BZN01	impact Eldepasco top					x	x	x	x
Bligh Bank	WBB01	reference Belwind gully			x	x		x	x	x
	WBB02	reference Belwind top			x	x		x	x	x
	WBB03	reference Belwind gully			x	x		x	x	x
	WBB04	fringe Belwind gully			x	x	x	x		x
	WBB05	impact Belwind top			x	x				
	WBB06	impact Belwind top			x	x	x	x		
	WBB07	impact Belwind gully			x	x		x		
	WBB08	fringe Belwind gully			x	x	x	x		x
Oosthinder	WOH01	reference Belwind gully			x	x				x
	WOH02	reference Belwind top			x	x		x	x	x
	WOH03	reference Belwind gully			x	x		x	x	x
other	330	reference C-Power gully	x	x	x	x	x	x	x	x
	340	reference C-Power gully	x	x	x	x	x	x		
	545	reference Belwind gully	x	x	x	x	x			
	840	reference Belwind gully	x	x	x	x	x	x		

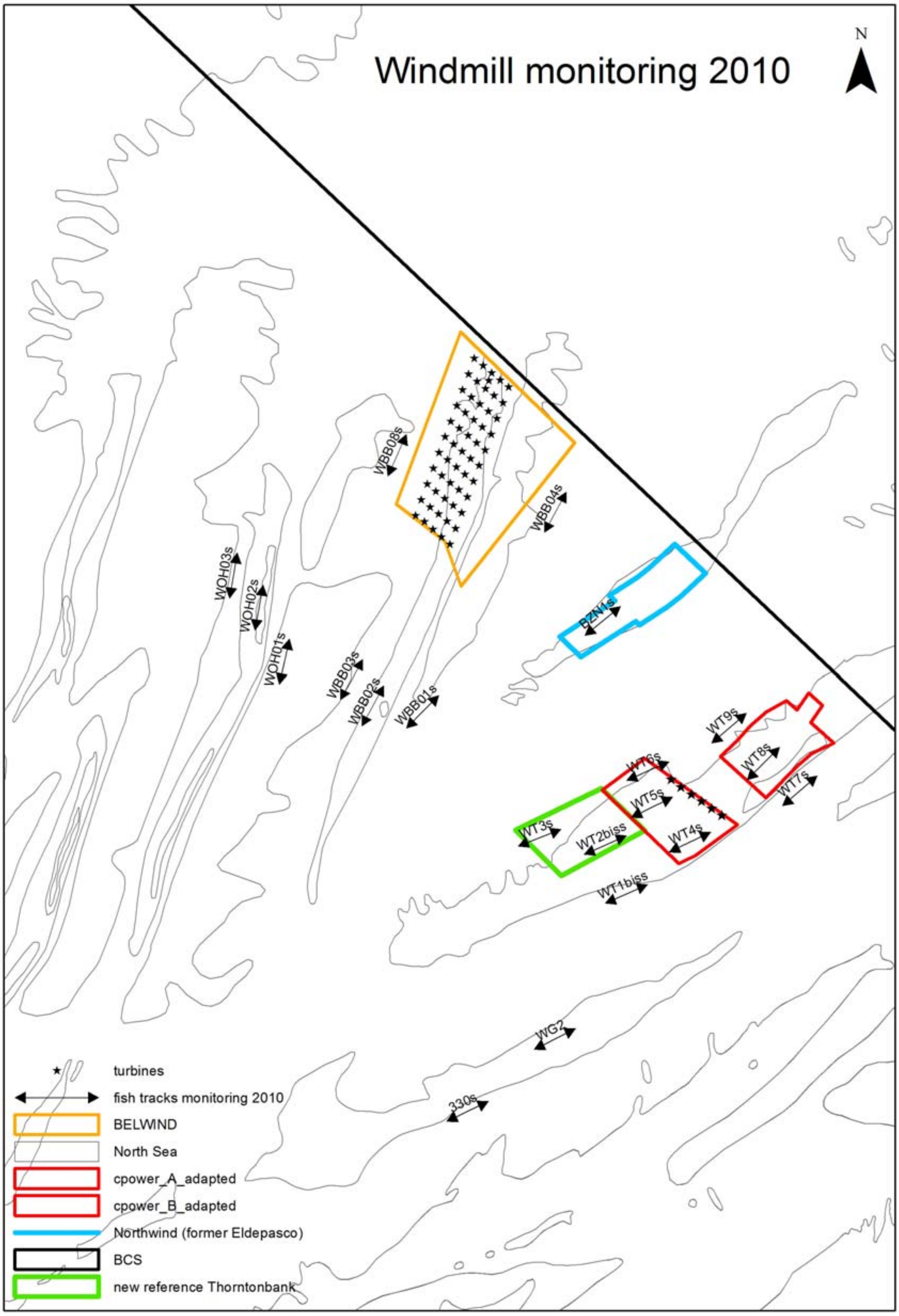


Figure 1. Sampling stations visited in 2010 in the framework of the windmill park monitoring activities.

Due to practical issues following access restrictions in the Belwind concession area, no samples could be taken of the Bligh Bank impact area in 2010. Consequently, the analyses were limited to the evolution of the soft sediment epibenthos and demersal fish at the Thorntonbank impact zone and in the adjoining reference areas. The data of 2010 on the Bligh Bank and Oosthinder reference zones were stored for future analyses concerning natural temporal variation in the vicinity of the Belwind windmill park.

7.3. Results

The analyses were split up according to the possible source of environmental change:

- Impact of the presence of turbines: the C-Power turbines are located on top of the Thorntonbank. One station (WT5biss) was considered as an impact station, other sandbank top stations were considered reference stations.
- Impact of changing fisheries activities in the vicinity of the windmill park concessions: these impacts were expected in the gullies outside the C-power concessions, and were confirmed by VMS analyses (see Chapter 8, this volume). Two stations were considered fringe stations, other gully stations were treated as references.

7.3.1. Impact of the presence of turbines

On an ecosystem component level (benthopelagic fish, demersal fish, epifauna), no impact on the total density could be observed in either of the seasons (Figure 2A). The fluctuations were considerable, but could all be attributed to natural interannual and seasonal variation. This was also the case for the epifaunal biomass (Figure 2B). The species richness fluctuated between 1 and 5 spp. for benthopelagic fish, between 4 and 8 spp. for demersal fish and between 6 and 20 spp. for epibenthos (Figure 2C). Persistent divergences between the impact station and the reference stations after 2008 were not observed. The same conclusion could be drawn from diversity estimates based on the Expected Number of Species method (figures not shown).

For the benthopelagic fish species horse mackerel (*Trachurus trachurus*) and sprat (*Sprattus sprattus*), the differences between the impact station and the reference stations were minimal. For whiting (*Merlangius merlangus*), a higher density was observed at the impact station (19 ind/1000m²) than at the references (av. 10 ind/1000m²) in autumn 2010 (Figure 2D). In spring, however, no individuals were found at the impact station, while low densities were observed at the references (av. 1 ind/1000m²). Insufficient data were available for herring (*Clupea harengus*) to evaluate the density evolution since 2005. Pouting (*Trisopterus minutus*) was not encountered in any sandbank top sample at the Thorntonbank since 2005.

For the flatfish species sole (*Solea solea*) and dab (*Limanda limanda*), the evolution of density over the seasons and years was almost identical for the impact station and the reference stations. For plaice (*Pleuronectes platessa*), the 2009 spring density at the impact station was a lot lower (0.2 ind/1000m²) than in the adjoining reference station (1 ind/1000m²). In 2010, the values were again very similar. In autumn, the values were similar in 2009, but the density at the impact station in 2010 was again a lot lower (0.1 ind/1000m²) than in the reference stations (av. 2 ind/1000m²).

For the dragonets *Callionymus lyra* and *C. reticulatus*, autumn densities were very similar for impact and reference stations. In spring 2009, the density of the common dragonet was higher (1.2 ind/1000m²) in the impact station than in the reference station (0.6 ind/1000m²), but the species was not seen in the impact station in 2010, while there were still low densities (av. 0.1 ind/1000m²) at the reference stations. The reticulated dragonet on the other hand was only seen at a very low density at the impact station in spring 2010, while the species was not seen at the reference stations.

The lesser weever (*Echiichthys vipera*) was abundantly present on top of the Thorntonbank, but in persistently lower densities at the impact station compared to the reference stations. That was already the case in 2005, so this feature is probably not the result of the presence of windmill turbines. The densities of solenette (*Buglossidium luteum*) were quite similar at the impact and the reference stations in spring. In autumn, however, densities were persistently higher at the impact station. Again, this was already the case prior to the construction activities. Hooknose (*Agonus cataphractus*) densities were very low at all sandbank top stations. In autumn, the species was no longer observed in any of the stations after 2007. In spring, low densities were only observed in 2005 and 2009 at the impact station. More individuals were retrieved from the reference samples.

For epibenthos, the differences between the impact station and the reference stations were generally smaller than for demersal and benthopelagic fish species. For the species *Ophiura albida*, *Ophiura ophiura*, *Allotheutis subulata*, *Pagurus bernhardus and Liocarcinus holsatus*, the observed density evolution was virtually identical for both station types. For the shrimp *Crangon crangon*, the density evolution was similar until 2009. In 2010, spring and autumn densities were both lower at the impact station (sp: 12ind/1000m²; aut: 9 ind/1000m²) than at the reference stations (sp: av. 21 ind/1000m²; aut: av. 35 ind/1000m²). The urchin *Psammechinus miliaris* and the shrimp *C. allmanni* were not found often enough to evaluate differences between impact and reference stations.

Concerning the length-frequency distributions determined for 8 species, there were some differences between the impact station and the reference stations, especially in autumn 2010:

- *Crangon crangon*: lower numbers and slightly larger individuals at the impact station (dominant size class: 50mm at impact station, 45mm at reference stations).
- *Liocarcinus holsatus*: lower numbers and slightly larger individuals at the impact station (dominant size class: 42mm at impact station, 30mm at reference stations).
- *Limanda limanda*: lower numbers of year class 0 at the impact station
- *Merlangius merlangus*: higher densities of individuals ranging between 10 and 17 cm in length, but lower densities of larger individuals compared to the reference stations.

A. Density: benthopelagic fish, demersal fish and epibenthos

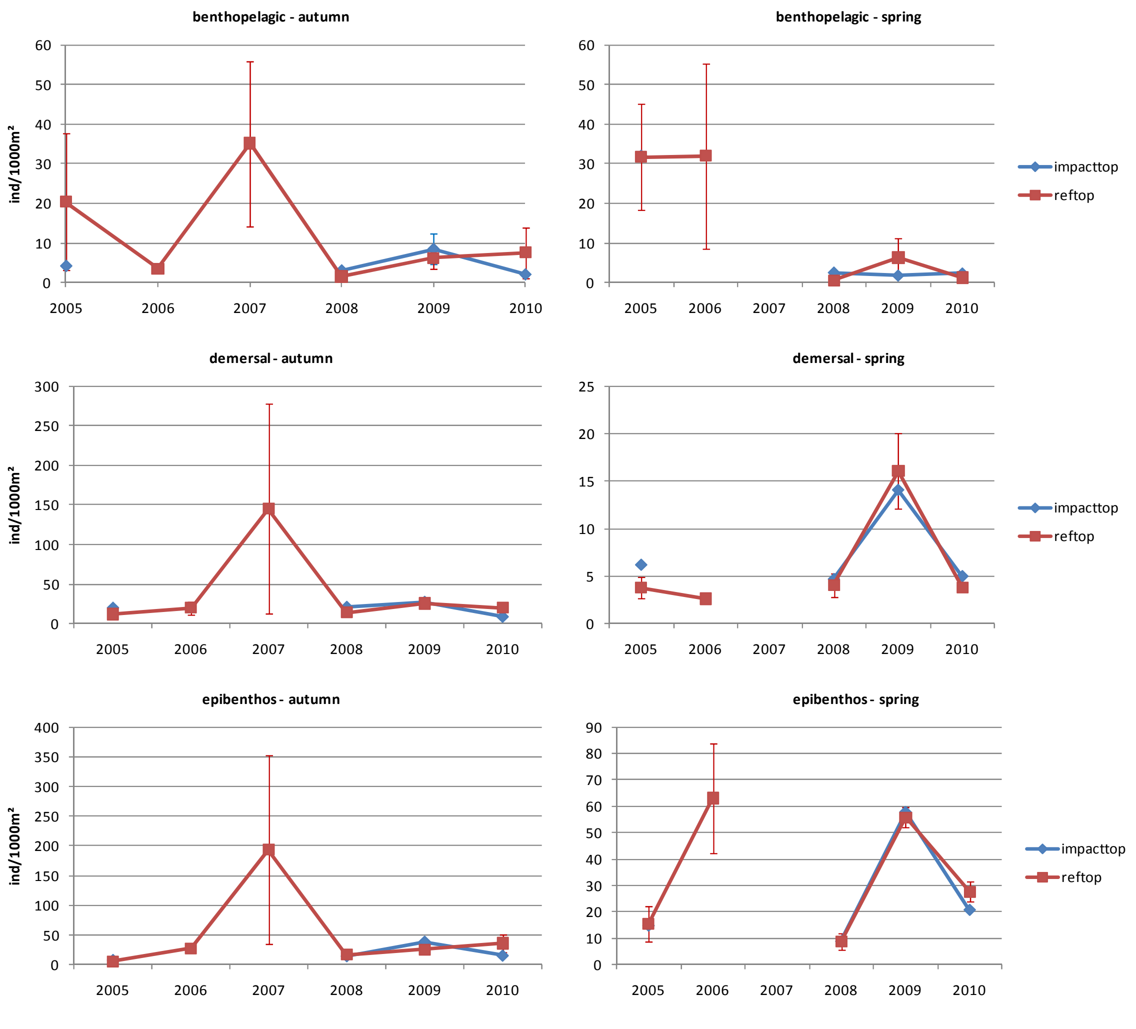


Figure 2. Charts representing differences between the impact station and reference stations concerning density, biomass and diversity for the species groups benthopelagic fish, demersal fish and epibenthos; differences in density for a selection of species; differences in length frequency distribution for a selection of species.

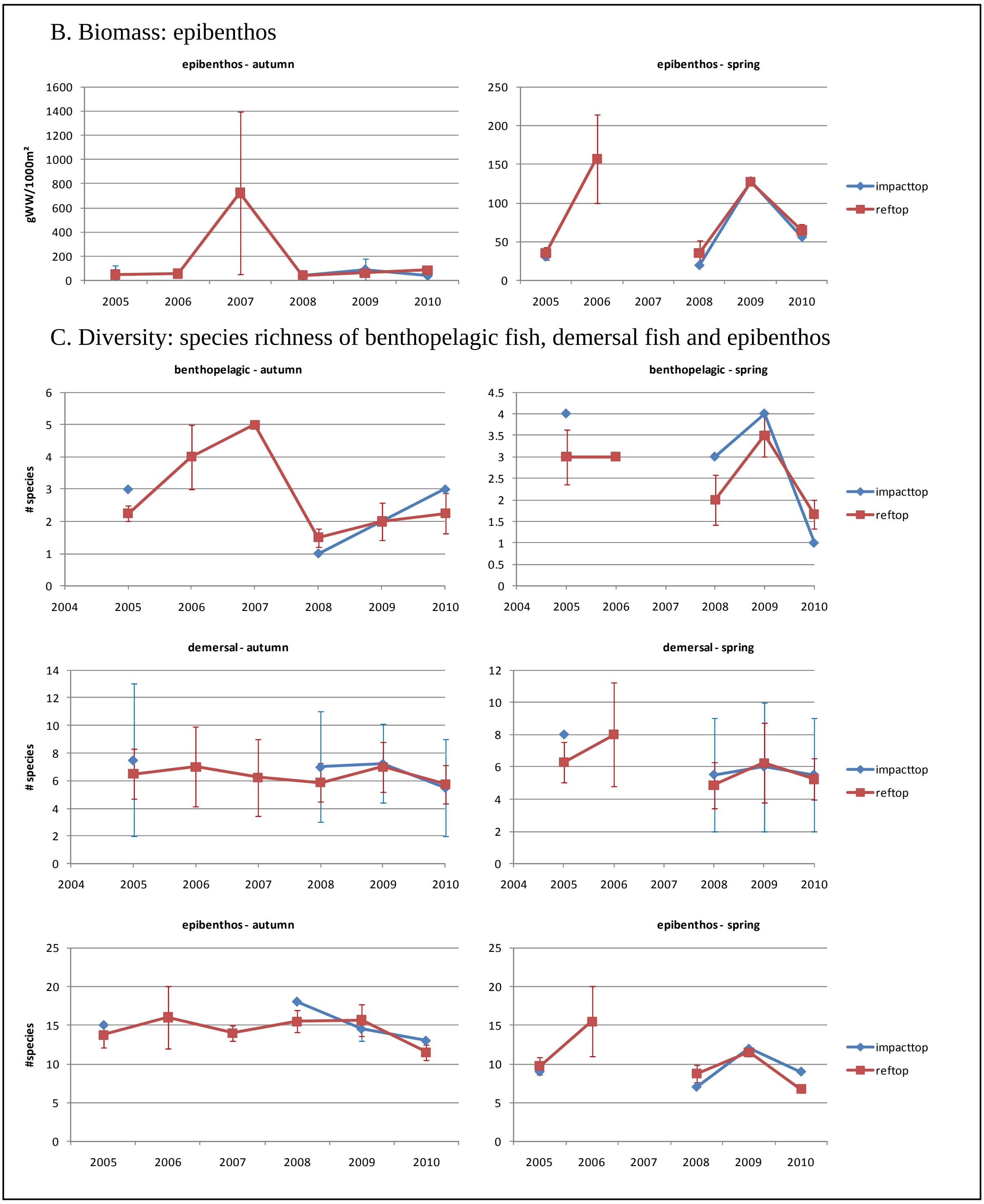


Figure 2. Continued.

D. Species selection: density evolution (only species featuring important differences between impact station and reference stations are shown)

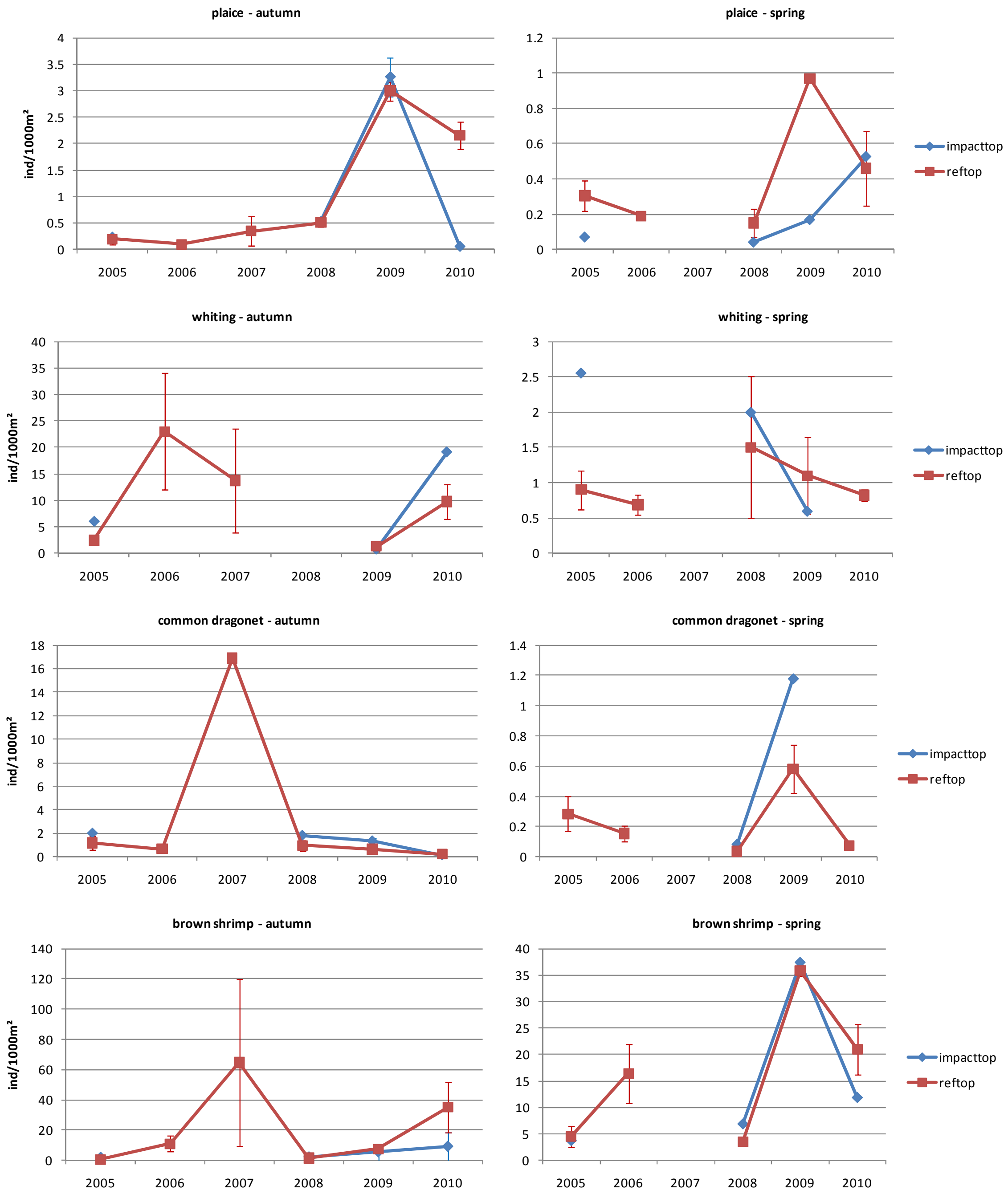


Figure 2. Continued.

E. Length-frequency distributions, data 2010 (only species featuring important differences between impact station and reference stations are shown)

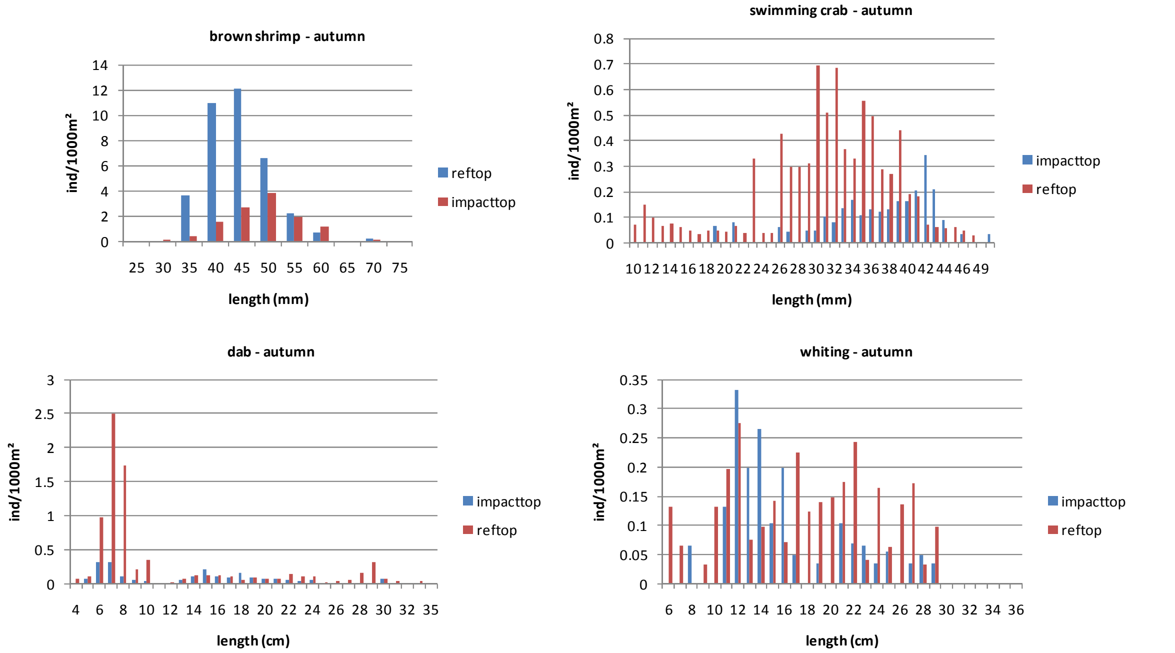


Figure 2. Continued.

7.3.2. Impact of changes in fisheries intensity

On an ecosystem component level (benthopelagic fish, demersal fish, epifauna), no persistent differences in total density could be observed between the fringe stations and the impact stations in either of the seasons (Figure 3A). The fluctuations were considerable, but could all be attributed to natural interannual and seasonal variation. The epifaunal biomass was generally lower in 2009 in the fringe stations compared to the reference stations, but this difference disappeared by 2010 (Figure 3B). The species richness fluctuated between 2 and 8 spp. for benthopelagic fish, between 5 and 13 spp. for demersal fish and between 8 and 20 spp. for epibenthos (Figure 3C). Persistent divergences between the fringe stations and the reference stations after 2008 were not observed. The same conclusion could be drawn from diversity estimates based on the Expected Number of Species method.

The autumn densities of the benthopelagic fish species horse mackerel (*T. trachurus*) were similar until 2009. In autumn 2010, the densities at the fringe stations were a lot lower (av. 10 ind/1000m²) than at the reference stations (av. 623 ind/1000m², but with considerable standard error of 553 ind/1000m²). Autumn sprat (*S. sprattus*) densities of 2009 and 2010 were a little higher in the fringe stations compared to the references. For whiting (*M. merlangus*), the density evolution was very similar in autumn for all stations. In spring 2008 to 2010, less individuals were found at the fringe stations (max av. 5 ind/1000m²) compared to the references (av. up to 38 ind/1000m²). Insufficient data were available for herring (*C. harengus*) to evaluate the density evolution since 2005. Pouting (*T. minutus*) was only encountered in the reference stations at the Thorntonbank since 2005.

For the flatfish species sole (*S. solea*), plaice (*P. platessa*) and dab (*L. limanda*), the evolution of density over the seasons and years was very similar for the fringe stations and the reference stations. For the common dragonet *Callionymus lyra*, autumn and spring densities increased drastically between 2008 and 2009 in the fringe stations but not in the reference stations, and again decreased in 2010 (no common dragonets were found in spring 2010). The density evolution of the reticulated dragonet *C. reticulatus* did not show such a pattern: the density evolution was similar for all stations.

The density patterns of the lesser weever (*E. vipera*) was very similar for all stations. The densities of solenette (*Buglossidium luteum*), however, were very variable at the fringe stations, especially in spring: densities dramatically increased between 2008 and 2009 (from av. 0.3 to 10 ind/1000m²) and then decreased again to 0.3 ind/1000m² by 2010. In autumn, densities were quite high in the fringe stations in 2008, but decreased to a level similar to the reference stations by 2010. Hooknose (*A. cataphractus*) densities were similar at all stations in autumn, but were very different between fringe and reference stations in spring. Especially in 2008, the density difference was very high, with an average of 0.1 ind/1000m² at the fringe stations and 0.6 ind/1000m² at the reference stations.

For the species *C. crangon* in both seasons *and for O. albida* in spring, the observed density evolution was virtually identical for both station types. For other species, there were quite some differences, especially in 2009:

- *O. albida* & *O. ophiura* – autumn: fringe densities higher than reference densities, but again similar values in 2010
- *O. ophiura* – spring: fringe densities lower than reference densities, but again similar values in 2010
- *L. holsatus* – spring: fringe densities higher than reference densities

Densities of *L. holsatus* were persistently higher in the fringe stations, but that was already the case in 2005, so this feature is probably not the result of changes in fisheries intensity.

Concerning the length-frequency distributions determined for 8 species, there were some differences between the fringe stations and the reference stations for the 2010 data (fig 3E):

- *Solea solea*: virtual absence of individuals smaller than 18 cm in autumn, while these were abundantly present in the reference stations. Also in spring, the absence of the smallest size classes is striking.
- *Liocarcinus holsatus*: higher densities of individuals of all size classes in autumn at the fringe stations
- *Merlangius merlangus*: striking reduction in the numbers of individuals in the size classes ranging between 21 and 26 cm at the fringe stations in spring

A. Density: benthopelagic fish, demersal fish and epibenthos

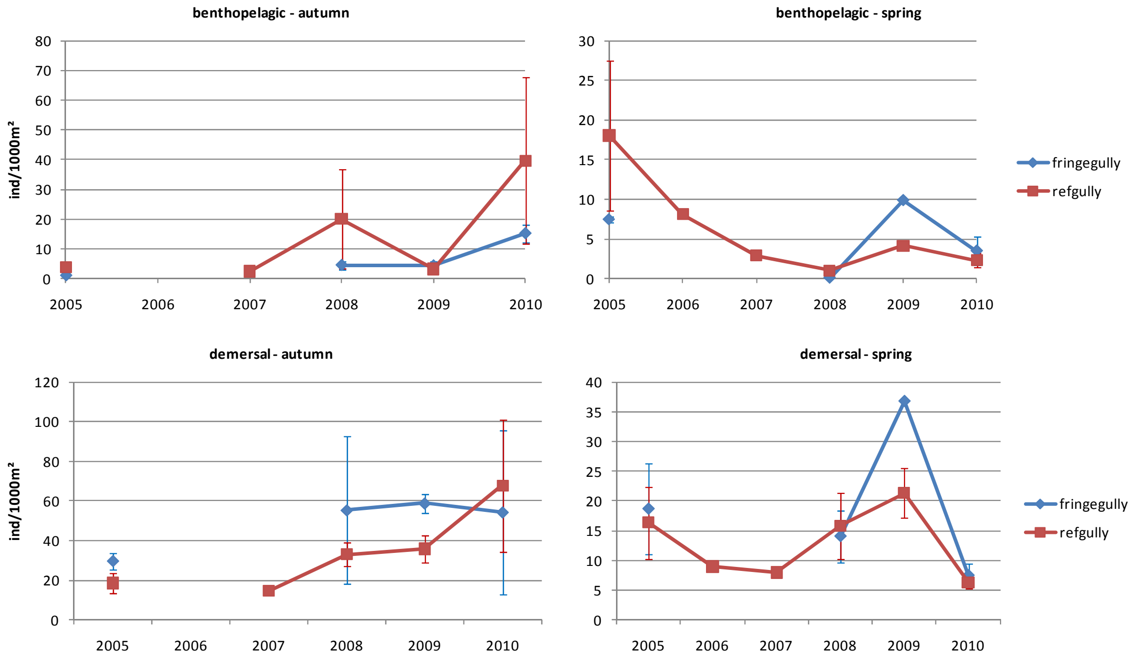
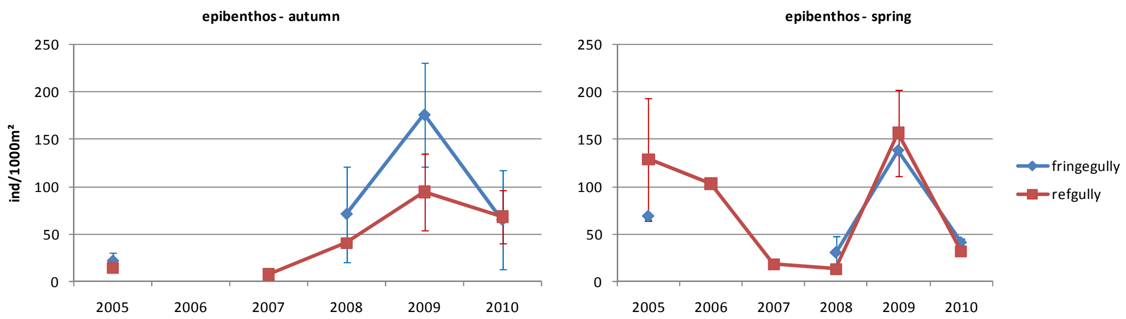
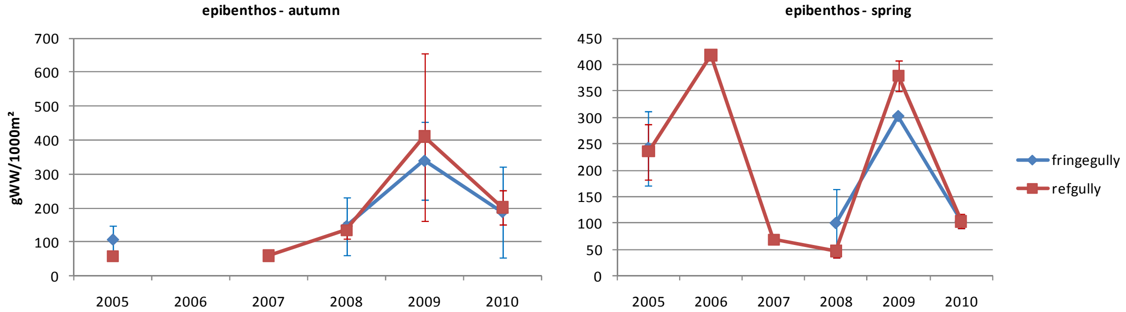


Figure 3. Charts representing differences between the fringe stations and reference stations concerning density, biomass and diversity for the species groups benthopelagic fish, demersal fish and epibenthos; differences in density for a selection of species; differences in length frequency distribution for a selection of species.



B. Biomass: epibenthos



C. Diversity: species richness of benthopelagic fish, demersal fish and epibenthos

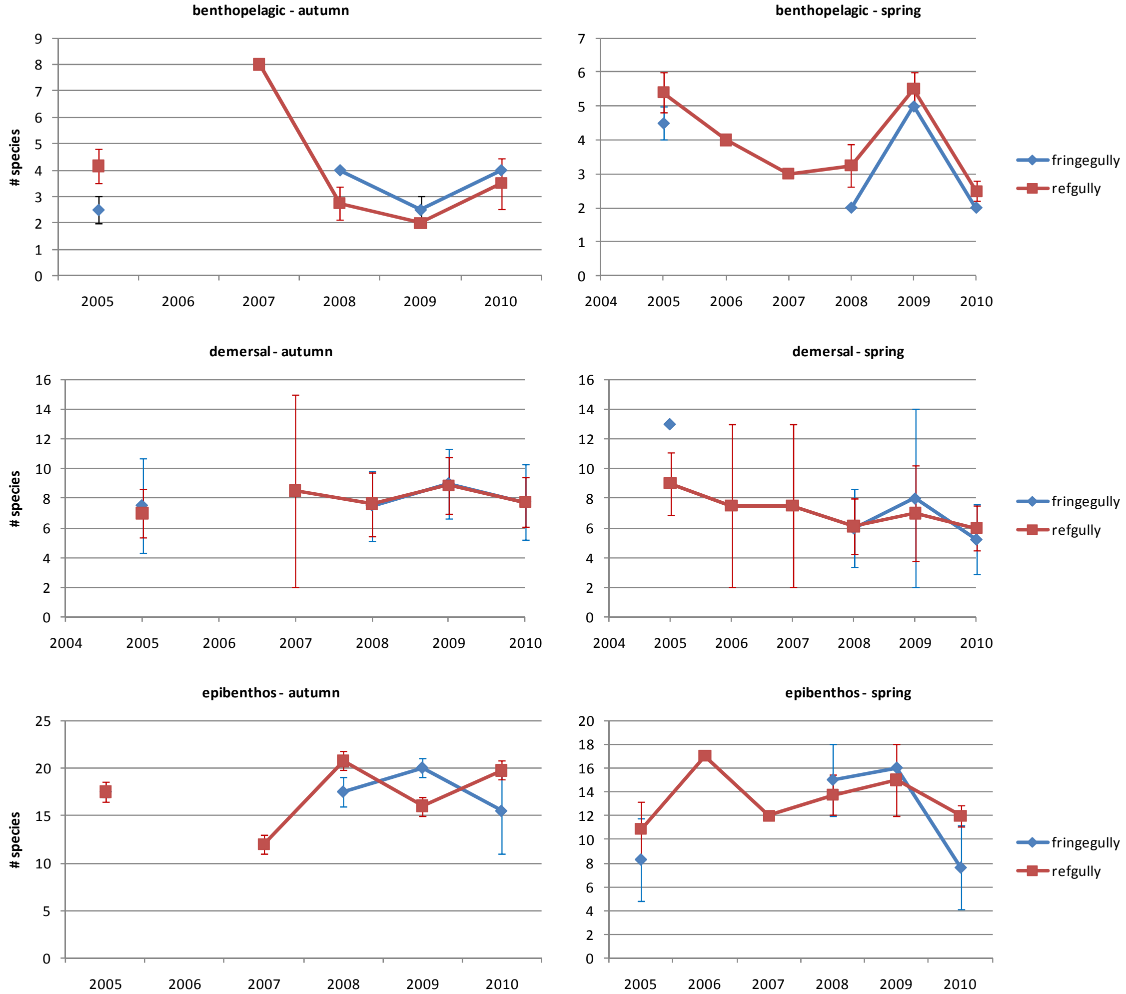


Figure 3. Continued.

D. Species selection: density evolution (only species featuring important differences between fringe stations and reference stations are shown)

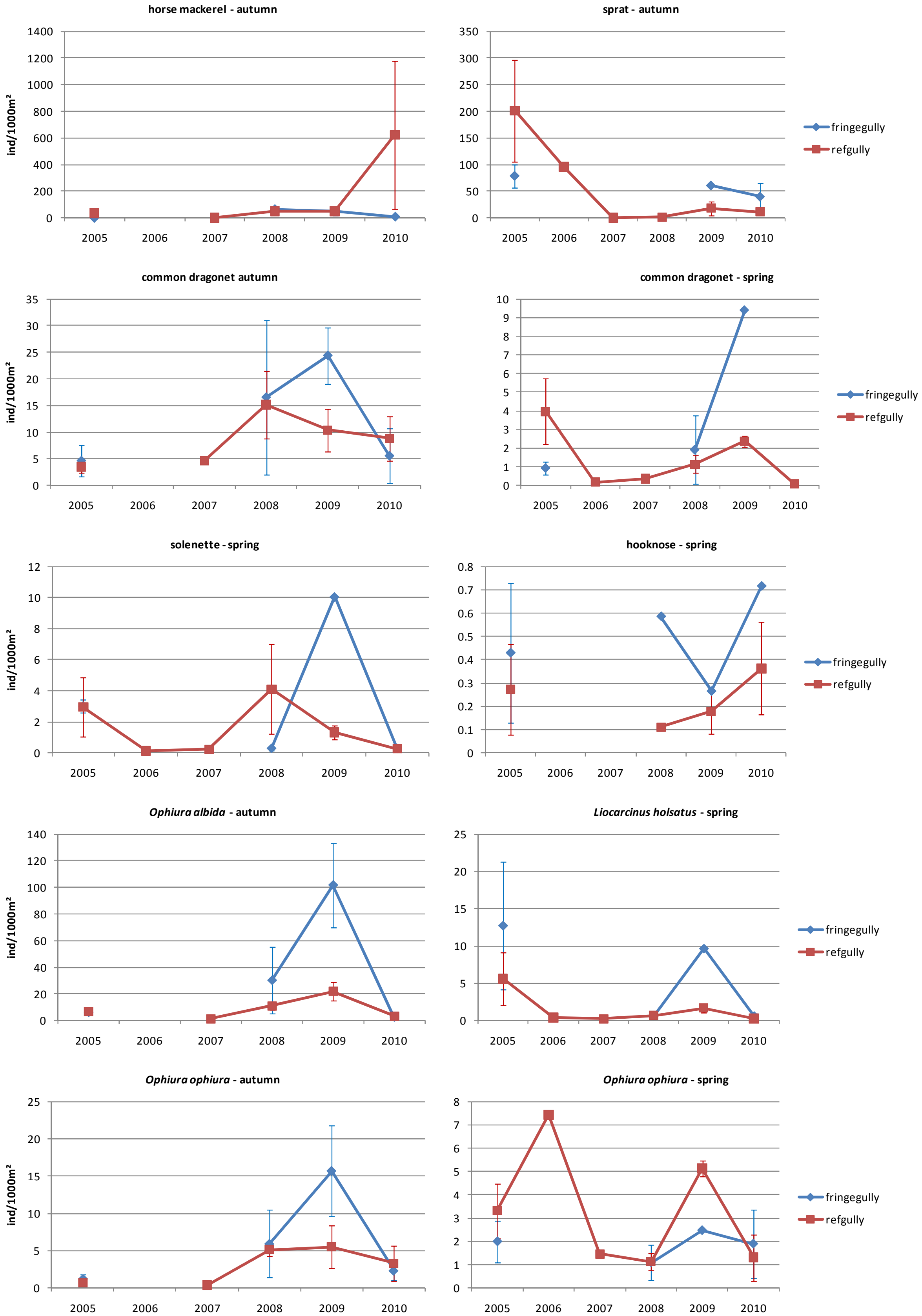


Figure 3. Continued.

E. Length-frequency distributions, data 2010 (only species featuring important differences between fringe stations and reference stations are shown)

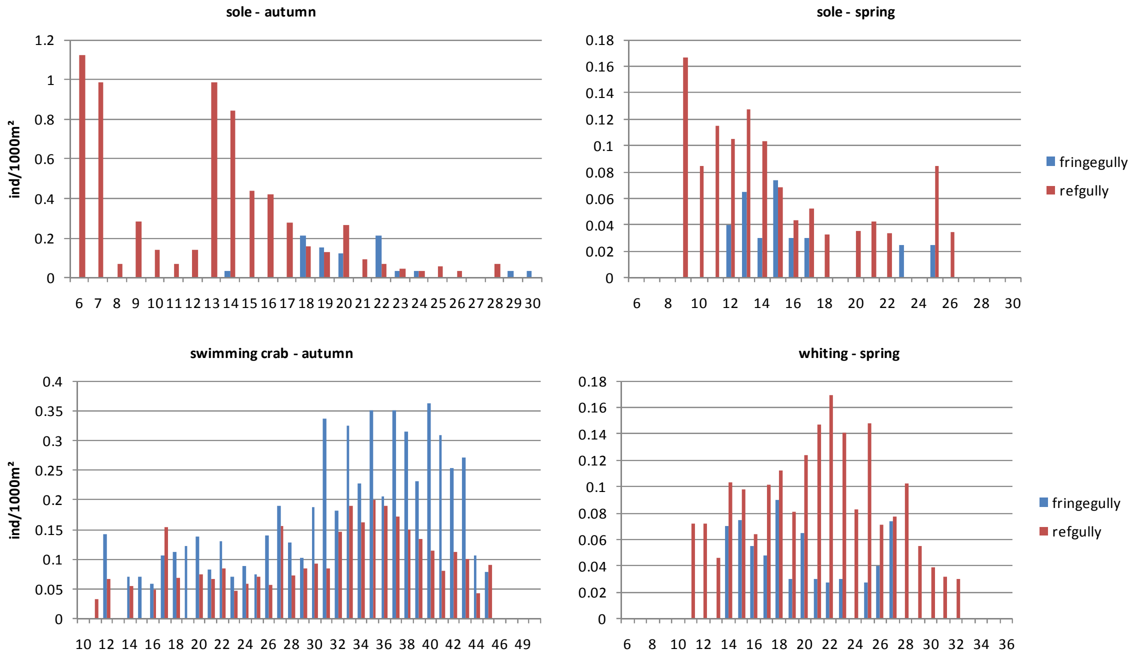


Figure 3. Continued.

7.4. Discussion

7.4.1. Impact of the presence of turbines

Since the fish track trajectories were positioned at a respectable distance (> 500 m) from the turbines due to safety precautions, only two of the effects described by Wilhelmsson *et al.* (2009) were expected to be observed by the adopted sampling design (Figure 1):

- Predation by fish and crabs associated with the turbines could negatively affect abundances of prey species.
- An artificial reef (here turbine and scour protection) can enhance abundances of pelagic fish species, and attract flatfishes to the reef.

Other effects are usually limited to a radius of 20m around the turbines, while attraction of fish may occur in a radius of 400m (Wilhelmsson *et al.*, 2009). In studies concerning other windmill farms, especially crab densities seemed to be favored by the presence of turbines, more specifically the shore crab *Carcinus maenas* (Maar *et al.*, 2009), the edible crab *Cancer pagurus* (Wilhelmsson *et al.*, 2009) and the thumbnail crab *Thia scutellata* (May, 2005). Such increased densities were not observed in the trawl samples, but the individuals of the swimming crab *Liocarcinus holsatus* were generally larger at the impact station in 2010 compared to the reference stations. The same was observed for the brown shrimp *Crangon crangon*. This may reflect either increased growth due to a high food availability or increased predation pressure eliminating smaller individuals. An increased food supply may also have caused the higher autumn densities of small whiting *Merlangius merlangus* observed in autumn 2010. Dense shoals of juvenile whiting have also been observed at the North Hoyle windmill Park (UK), where they intensively fed on the amphipod *Jassa falcata* (May, 2005). Since the Thorntonbank turbines support a substantial biomass consisting of *Jassa herdmani* (Kerckhof *et al.*, 2010) and since Reubens *et al.* (2011) described intense feeding on *J. herdmani* by pouting *Trisopterus luscus* at the Thorntonbank turbines, it is likely that a similar relationship exists between these amphipods and whiting.

The alterations within the epibenthos and fish assemblages observed in the impact area on the Thorntonbank in 2009 included (1) higher densities of horse mackerel (*Trachurus trachurus*) in autumn 2009 and (2) lower densities of sole (*Solea solea*) in spring 2009, compared to the reference areas around the Thorntonbank. These observations, however, were not confirmed by the 2010 data.

The observed differences between the impact and the reference area in 2009 and 2010 may indicate that changes within the ecosystem do occur due to the presence of the turbines. However, the lack of replication within the windmill farm (only one impact sample) and between windmill parks (no impact samples from the Bligh Bank), make it difficult to draw sound conclusions on the evolution of the epibenthos, demersal fish and benthopelagic fish in the windmill park area. This will be mediated by the planned increase of turbines on the Thorntonbank in 2011 and the planned sampling of the Bligh Bank impact area from 2011 onwards.

7.4.2. Impact of changes in fisheries intensity

An important effect of the closure of areas for fisheries is the reallocation of fishing effort to the remaining available fishing grounds, often just outside the closed area's border (Rijnsdorp *et al.*, 2001; Hiddink *et al.*, 2006). Hence, any data interpreted as showing an improved quality of benthic communities within the closure need to be nuanced because of changed post-closure fishing intensity in the "control" area outside the closure (Grizzle *et al.*, 2009). An analysis of Belgian VMS data showed increased trawling activity in the area north of the Thorntonbank. Additionally, recreational line fisheries seemed to have intensified in the same area (see Chapter 8). Consequently, the stations within this area were labeled as "fringe stations" and were no longer used as references for assessing the impact of turbine construction and operation. To evaluate possible changes due to increased fisheries intensity, the data of the fringe stations were compared with reference gully stations. Generally, we expected a general decline in diversity, a shift towards species that are more tolerant to disturbance, and higher densities of scavengers, omnivores and small-bodied organisms (Jones, 1992; Kaiser *et al.*, 2002; Finger, 2005). The results showed no effects on densities of the commercially important flatfish species sole *S. solea*, plaice *P. platessa* and dab *L. limanda*. However, the length-frequency distributions of sole showed an absence of the smallest size classes in both seasons of 2010, which could be the result of increased indirect fishing mortality (such as discards) or of changes in the local benthic community. Similarly, there was a striking reduction in the individuals in the size classes ranging between 21 and 26 cm for whiting *M. merlangus* in spring 2010 at the fringe stations. There were some differences between fringe stations and reference stations for small demersal fish (e.g. common dragonet *C. lyra*, solenette *B. luteum*, hooknose *A. cataphractus*) and for epibenthos (ophiuroids *O. ophiura* and *O. albida*, and swimming crab *L. holsatus*). Generally, these differences were highest in 2009 and more or less normalized by 2010. Whether this corresponds with a local reduction of fisheries activities in the fringe area after 2009 is unknown, since the 2010 VMS data have yet to be analyzed. For 2008-2009, the period with a confirmed increase of fishing activity by the Belgian fleet, the impact of increased fisheries activity was not drastic for fish and epibenthos, which could be expected since the fringe area already had a history of rather intensive trawling. Nevertheless, the reduction in densities of young fish might signal an increased pressure on their populations. Reiss *et al.* (2009) already stated that even in areas with high chronic fishing disturbance, further increases in fishing activity may still cause additional damage to benthic invertebrate communities, and hence to other ecosystem components.

7.5. Conclusion

The current analyses about the impact of the presence of windmill turbines did not reveal consistent patterns of changed density, biomass or diversity between the impact station and reference stations for epibenthos, demersal fish and benthopelagic fish. However, there were some new observations in 2010 concerning differences in length-frequency distributions for swimming crab, brown shrimp and whiting. Similarly, the local increase of fisheries intensity by the Belgian fleet in the area north of the Thorntonbank was accompanied by differences in the length-frequencies of sole and whiting. These differences between the impact station, fringe stations and reference stations may indicate changes in predation pressure, food supply and recruitment. Further monitoring (with increased replication) and targeted research actions are needed to confirm causal relationships between these observations and the investigated pressures.

7.6. References

Andersson, M.H., Berggren, M., Wilhelmsson, D. & Öhman, M.C., (2009). Epibenthic colonization of concrete and steel pilings in a cold-temperate embayment - a feld experiment. Helgoland Marine Research 63: 249-260.

Berkenhagen, J., Döring, R., Fock, H.O., Kloppmann, M.H.F., Pedersen, S.A. & Schulze, T., (2010). Decision bias in marine spatial planning of offshore wind farms: Problems of singular versus cumulative assessments of economic impacts on fisheries. Marine policy, Band 34 (3), 733-736.

Derweduwen, J., Vandendriessche, S. & Hostens, K., (2010). Monitoring the effects of the Thorntonbank and Bligh Bank wind farms on the epifauna and demersal fish fauna of soft bottom sediments. Thorntonbank: status during construction (T2). Bligh Bank: status during construction (T1). *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 8: 105-131.

Finger, K., (2005). The Impact of Trawling on the Benthic community - Analysis of the Epifauna in the German Bight with Imaging Methods . MSc Thesis, University of Lüneburg, 22pp.

Grizzle, R.E., Ward, L.G., Mayer, L.A., Malik, M.A., Cooper, A.B., Abeels, H.A., Greene, J.K., Brodeur, M.A. & Rosenberg, A.A., (2009). Effects of a large fishing closure on benthic communities in the western Gulf of Maine: recovery from the effects of gillnets and otter trawls Fish. Bull. 107(3): 308-317.

Hiddink, J. G., Hutton, T., Jennings, S. & Kaiser, M. J., (2006). Predicting the effects of area closures and fishing effort restrictions on the production, biomass, and species richness of benthic invertebrate communities. ICES Journal of Marine Science, 63: 822-830.

Jaworski, A., Solmundsson, J. & Ragnarsson, S.A., (2006). The effect of area closures on the demersal fish community off the east coast of Iceland. ICES Journal of Marine Science, 63: 897-911.

Jones, J.B., (1992). Environmental impact of trawling on the seabed: a review. New Zealand Journal of Marine and Freshwater Research 26:59-67.

Kaiser, M.J., Collie, J.S., Hall, S.J., Jennings, S. & Poiner, I.R., (2002). Modification of marine habitats by trawling activities: prognosis and solutions. Fish and Fisheries 3: 114-136.

Kerckhof, F., Rumes, B., Norro, A., Jacques, T.G. & Degraer, S., (2010). Seasonal variation and vertical zonation of the marine biofouling on a concrete offshore windmill foundation on the Thornton Bank (southern North Sea). p.53-68. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 5: 53-68.

Maar, M, Bolding, K, Kjerulf Petersen, J., Hansen J.L.S. & Timmermann, K., (2005). Local effects of blue mussels around turbine foundations in an ecosystem model of Nysted off-shore wind farm, Denmark. J. Sea Res. 62, 159–174.

May, J., (2005). Post-construction results from the North Hoyle offshore wind farm. Paper for the Copenhagen offshore wind international conference, Project Management Support Services Ltd, 10 pp.

Reiss, H., Greenstreet, S.P.R., Sieben, K., Ehrich, S. & others, (2009). Effects of fishing disturbance on benthic communities and secondary production within an intensively fished area. Mar Ecol Prog Ser 394:201-213.

Rijnsdorp, A.D., Piet, G.J. & Poos, J.J., (2001). Effort allocation of the Dutch beam trawl fleet in response to a temporary closed area in the North Sea. ICES Document, CM 2001/N: 01.

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

Wilhelmsson, D., (2009). Aspects of offshore renewable energy and the alterations of marine habitats. PhD Thesis, University of Stockholm, 56pp.

Chapter 8. Monitoring the effects of offshore wind farms: evaluating changes in fishing effort using Vessel Monitoring System data: targeted monitoring results

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Trawling vessel in the Belgian part of the North Sea Photo RBINS / MUMM

Abstract

This chapter reports on changes in fishing effort in the vicinity of the existing windmill parks at the BPNS based on Vessel Monitoring System (VMS) data. During the analysis, displacement of activities by Belgian trawlers of different size and engine power was evaluated. Additionally, we looked at possible changes in fisheries methods, and more precisely a shift towards passive fishing methods.

The results showed that the permanent closure of the existing windmill park concession areas for fisheries has not resulted in a major disruption of Belgian fisheries activities. For large segment trawlers, the observed evolution in fishing distribution and intensity was limited and could not be attributed to the establishment of the C-Power and Belwind windmill parks. For eurocutters, however, there was a shift in distribution from 2006 to 2009, with the abandonment of the western part of the Thorntonbank after 2006 and an increase of fisheries activities between the Thorntonbank and the Bank Zonder Naam in 2009. This might indicate a local increase in the availability of commercially interesting fish species. A change in fisheries methods from active (trawling) to passive (trammel netting) gears could not be observed with the currently available data.

In the current analysis, realistic maps of fishing effort and distribution could not be drafted due to the lack of VMS data on foreign vessels fishing in the windmill park area and on vessels smaller than 15m. This was partly mediated by analysing data gathered during visual surveys. However, the integration of VMS data of all vessels fishing within the study area is indispensable for future monitoring of fisheries activities of windmill parks and other closed areas.

Samenvatting

Dit hoofdstuk geeft de resultaten weer van een analyse betreffende veranderende visserijdruk in de buurt van de bestaand Belgische windmolenparken. Deze analyse is gebaseerd op “Vessel Monitoring System” (VMS) gegevens van Belgische vaartuigen van verschillende categorieën in grootte en motorvermogen. Er werd tevens nagegaan of er een verschuiving kon waargenomen worden in het gebruik van actief en passief vistuig. De resultaten toonden aan dat de sluiting van de windmolenparken voor de visserij geen grote verstoring heeft teweeg gebracht in de Belgische visserij-activiteiten. De evolutie van de verspreiding van het groot segment was beperkt en kon niet in verband worden gebracht met de bouw van de windmolenparken. Bij eurokotters was er wel een verschuiving in de verspreiding in de periode 2006-2009, waarbij het westelijke gedeelte van de Thorntonbank grotendeels werd verlaten na 2006, maar waarbij een toenemende activiteit werd waargenomen in het gebied tussen de Thorntonbank en de Bank Zonder Naam in 2009. Dit zou een indicatie kunnen zijn van een toename in densiteiten van commercieel interessante vissoorten. Een verschuiving van actief naar passief vistuig kon niet worden waargenomen op basis van de beschikbare gegevens.

De beschreven analyse betreft enkel de Belgische vloot (schepen > 15m) en geeft dus geen realistisch beeld van de werkelijke visserij-inspanning in het gebied. Het ontbreken van gegevens betreffende kleine vaartuigen en vaartuigen varend onder een vreemde vlag werd deels opgevangen door de analyse van gegevens afkomstig van visuele waarnemingen. Het is echter van het grootste belang om alle VMS gegevens afkomstig uit het studiegebied te integreren voor de toekomstige monitoring van windmolenparken en andere gesloten gebieden.

8.1. Introduction

In the Belgian part of the North Sea (BPNS), the construction of offshore windmill parks gave rise to the establishment of areas closed for fisheries. After such a closure, different effects on both the ecosystem as on fishing activities have been observed (e.g. Murawski *et al.*, 2000; Grizzle *et al.,* 2009) and can be thus also be expected to manifest themselves in the BPNS. These effects comprise (1) the establishment or recovery of spawning and nursing grounds, (2) the recovery of benthic communities and diversity within the area, and (3) edge effects along the borders resulting from displacement of fisheries activities and changes in fishing intensity (MUMM, 2004). The latter effect can be evaluated using VMS data originating from the Belgian part of the North Sea.

VMS data originate from a fishing vessel monitoring system (VMS), which is a program of fisheries surveillance, in which satellite transmission equipment that is installed on fishing vessels, provides information about the vessels' position and activity. This is different from traditional monitoring methods, such as using surface and aerial patrols, on-board observers, logbooks or dockside interviews. VMS data constitute a cost-effective tool for the successful monitoring, control and surveillance of fisheries activities. In this respect, they are an excellent tool for monitoring compliance with closed-area regulations and for investigating changes in fisheries distribution and effort in the vicinity of such closed areas.

Recently, Vessel Monitoring System (VMS) data have been made available by the Belgian Sea Fisheries Service[1] for scientific research related to fisheries management. Unfortunately, only VMS data of Belgian vessels were provided. The lack of data concerning foreign vessels on the BPNS hampers the drafting of realistic maps on fishing effort in the vicinity of Belgian offshore windmill parks. Nevertheless, an analysis of the available Belgian data can already give an indication of the extent of the changes in fisheries activities following the construction of offshore windmill parks and the subsequent closure of the concession zones for bottom disturbing fisheries.

The aim of the described analysis was to investigate changes in fishing effort in the vicinity of the existing windmill parks at the BPNS based on Vessel Monitoring System (VMS) data. During the analysis, displacement of activities by Belgian trawlers of different size and engine power was evaluated. Additionally, we looked at possible changes in fisheries methods, and more precisely a shift towards passive fishing methods.

8.2. Material and Methods

VMS data were available for the years 2006 to 2009, for vessels > 15m (EG 2244/2003). These data encompass specifications concerning the identity of the vessel, and the position, time of registration, speed and heading at 2 hour intervals.

All VMS registrations originating from the BPNS were assigned to vessel groups defined by engine power and gear, as derived from the yearly published "Official List of Belgian Fishing Vessels" (Anonymous, 2006 to 2009). Ten combinations of engine power class (eurocutters EC, large segment vessels LS) and gear (beam trawl B, otter trawl OT, trammel net W, shrimp trawl KO, Twin Rig T) were encountered in the database, of which EC B and LS B were most abundant and constituted over 95% of the data.

The activity of a vessel at the time of the VMS registration was derived from the recorded speed, by applying a speed filter. According to Fock (2008), speed filters for data with long interval length (2 hours at the BPNS) are best developed by calculating mean fishing speed (MFS) values. For the BPNS data, these values were calculated per ship category, based on engine power and registered gear. Average speed was calculated based on all "at sea" values smaller than 8 knots (all trawlers) or 5 knots (trammel netters). Fishing activity was then defined as all activity at speeds lower than MFS + 2 knots (Fock, 2008).

Ten combinations of engine power and gear were encountered in the database. Since data on some power and gear combinations (e.g. EC B/KO) were too limited to calculate a representative mean fishing speed, only 4 groups were retained: EC trawlers / EC W/ LS trawlers/ LS W. During a quality check of the vessel list per group, it appeared that the vessel group "EC W" did not exist in real life. This vessel group was in fact subject to administrative actions related to quotum transfer and did not actually fish with trammel nets. The registrations of these vessels were removed from the geodatabase.

Based on the calculated mean fishing speed per vessel category, a selection was made of all VMS registrations representing presumed fishing activity. These data were plotted on BPNS maps representing the number of VMS registrations (fishing) per 3km² grid cell, since this proved to be an

[1] All primary data were supplied by the Department of Agriculture and Fisheries – Sea Fisheries Service / Departement Landbouw en Visserij – Dienst Zeevisserij.

adequate resolution for VMS data with a 2 hour interval (Mills *et al.*, 2007). Maps were generated per vessel group and per year.

The data were processed, filtered and visualized using Microsoft Access and ArcView 10.0 (ESRI Inc, 2010).

8.3. Results

Maps were generated for the three vessel groups per year, by plotting the VMS registrations representing presumed fishing activity as the number of registrations per 3km² grid cell. Since the vessel group "LS W" consisted of only one vessel, the generated maps cannot be published in the light of confidentiality regulations concerning VMS data (BS, 8/12.1992). Consequently, only maps on trawling activity are shown, while trammel net activity is only vaguely described in terms of intensity and geographic distribution.

- **EC trawl**

  Eurocutters mainly fishing for flatfish (there were only a few registrations for shrimp fisheries, and only in 2006) concentrated their activities in the Vlaamse Banken and south of the Gootebank, with a maximum of 438 VMS registrations per grid cell per year. Within the windmill park area, the Thorntonbank area was less intensively, but regularly trawled in 2006 (up to 13 VMS registrations per grid cell), but the western section was abandoned during 2007 and 2008. In 2009, a lot of trawling activity appeared in the zone between the Thorntonbank and the Bank Zonder Naam (up to 22 registrations per grid cell). This is the zone where Rentel has been given a domain concession for another future wind farm. The borders of the windmill park concessions were well respected by Belgian eurocutters: not a single VMS registration was observed within their limits after 2006.

- **LS trawl**

  Large beam trawlers in the BPNS fished more widely distributed but with lower intensity than eurocutters. In 2006, registrations were observed throughout the Belgian windmill zone, but fisheries effort was mostly limited to single events per grid cell per year. Throughout the offshore area of the BPNS, the dispersion of registrations decreased in 2007 and 2008, which was also the case in the windmill zone. In these years, the highest numbers of VMS registrations were observed in the vicinity of the Gootebank, while the rest of the zone remained virtually untrawled by Belgian vessels. In 2009, the number of fished grid cells again increased, but still with low intensity (maximally 6 registrations per grid cell at the Gootebank and single events in the rest of the windmill zone). The borders of the windmill park concessions were well respected by Belgian large segment trawlers: only a single VMS registration was observed within the Belwind concession area in 2009. None were seen in the Thorntonbank concession areas.

- **LS W**

  The single large trammel net vessel operating on the BPNS did not fish within the Belgian windmill zone. Only a single registration was observed within the zone in 2009, but outside the existing windmill concessions.

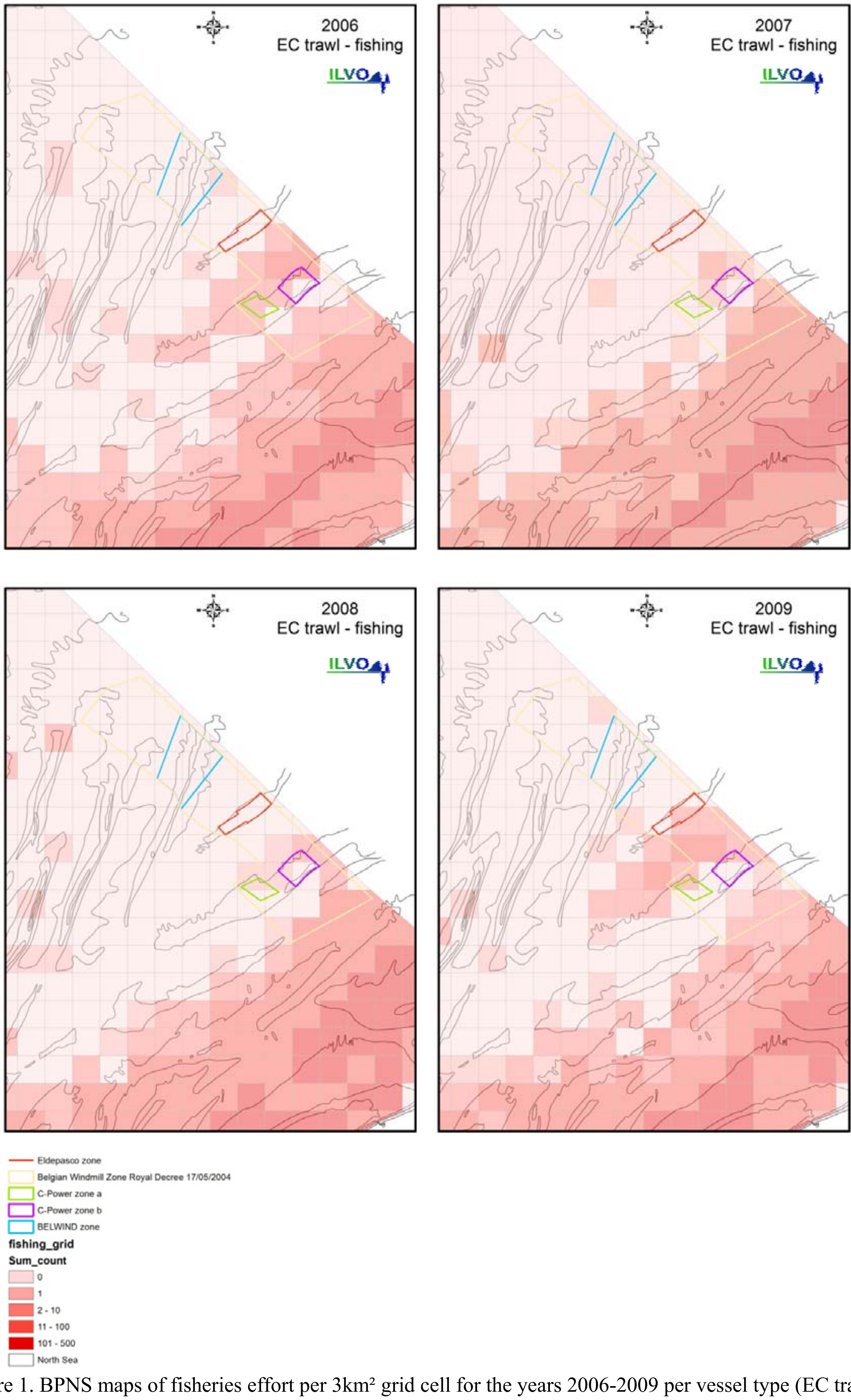

Figure 1. BPNS maps of fisheries effort per 3km² grid cell for the years 2006-2009 per vessel type (EC trawl : trawlers ≤ 221kW, LS trawl: trawlers > 221kW). Colors represent a gradient in numbers of VMS registrations per grid cell representing fishing activity.

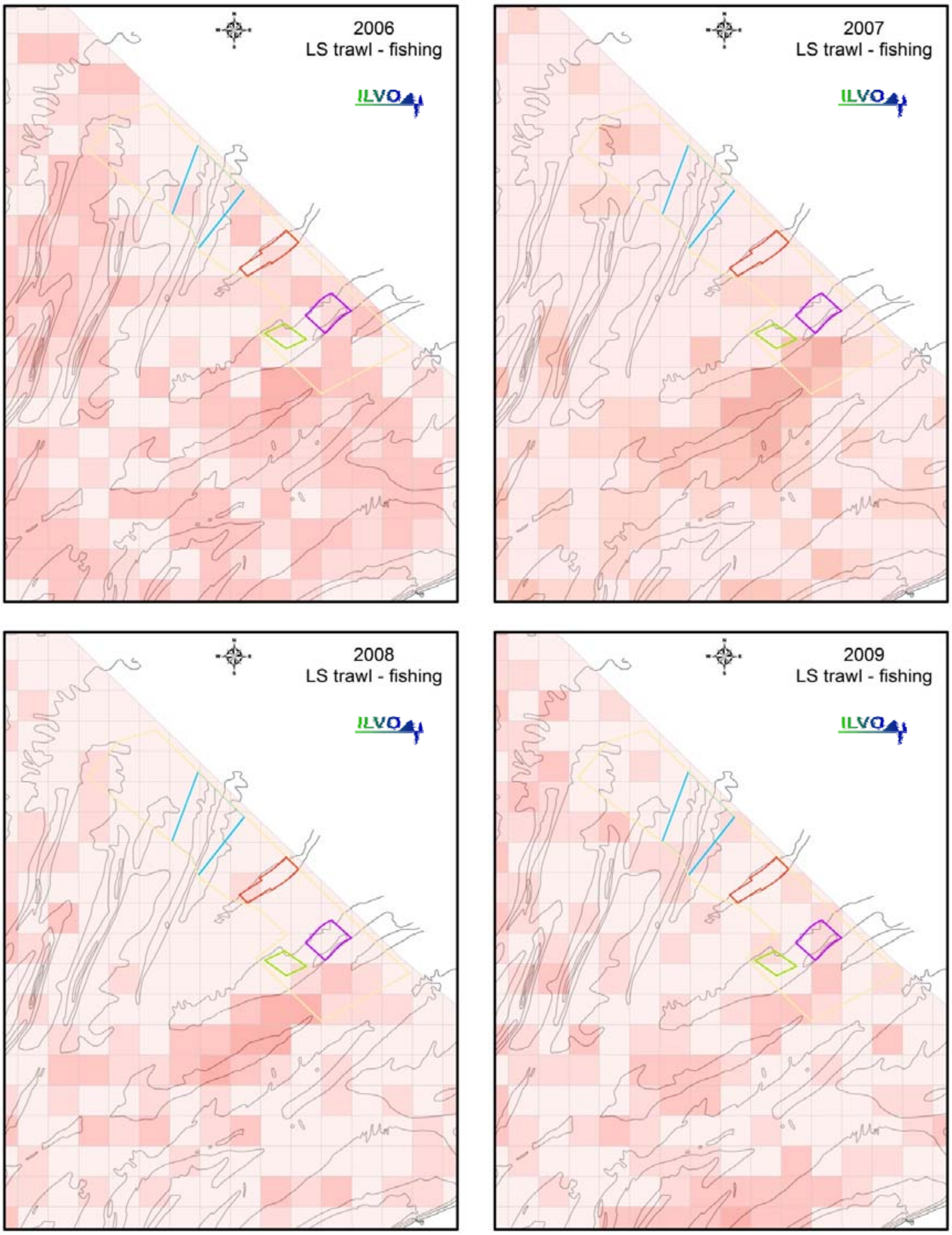

Figure 1. continued.

8.4. Discussion

8.4.1. Windmill parks and fisheries

As far as can be derived from the available VMS data, it seems that the permanent closure of the existing windmill park concession areas for fisheries has not resulted in a major disruption of Belgian fisheries activities. For large segment trawlers, the observed evolution in fishing distribution and intensity was limited and could not be attributed to the establishment of the C-Power and Belwind windmill parks. For eurocutters, however, there was a shift in distribution from 2006 to 2009, with the abandonment of the western part of the Thorntonbank after 2006 and an increase of fisheries activities between the Thorntonbank and the Bank Zonder Naam in 2009. This might indicate a local increase in the availability of commercially interesting fish species. This hypothesis could be tested by an integrated analysis of VMS data and logbook data on landings. Linking these datasets is however still in progress for Belgian fisheries data. The increased trawling activity may also result in effects with regard to soft-bottom macrobenthos, epibenthos and demersal fish. Although sampling stations have been assigned to study edge effects resulting from a shift in fisheries activity, these are generally situated very close to the concession (see WT6 and WT8 for epibenthos and demersal fish in Chapter 7, and see WTC4, WTC6, WTB16, WTB18 for macrobenthos in Chapter 6). The increased fisheries activities are, however, situated closer to the gully between the Thorntonbank and the Bank Zonder Naam, so it might be useful to move these “fringe stations” to this area, or to assign new monitoring stations.

A change in fisheries methods from active (trawling) to passive (trammel netting) gears could not be observed with the currently available data.

8.4.2. Usability of VMS data for monitoring the distribution and intensity of fisheries activities near windmill parks

The maps generated using the available VMS data only represented fishing activities of vessels fishing under a Belgian flag. If VMS data of Dutch, French , Danish and British vessels fishing in the Belgian windmill park area would be overlaid, the trends observed in Figure 1 would change drastically. Although all VMS data of vessels fishing in the Belgian EEZ are present at the administrative level, sharing VMS data for non-CFP[2] purposes is constrained by a combination of human rights law; data protection law; the law of confidence, and EU law - in particular the EU confidentiality obligation under Article 113 of EC Regulation 1224/2009 (the “Control Regulation”). When sharing VMS data outwith the sphere of the CFP, compliance with the EU confidentiality obligation cannot be guaranteed. However, it is arguable that sharing anonymized and aggregated VMS data for marine planning and management purposes is not contrary to human rights law, data protection law or the EU confidentiality obligation if certain safeguards are put in place to protect the commercial value of VMS data and preserve confidentiality (ICES, 2010). Consequently, the need for integration of data from all flag states operating in a single EEZ can and should be tackled as soon as possible. Such an integration was already possible for the Irish, German and Dutch EEZ’s (Fock, 2008; Anonymous, 2009; Deerenberg *et al.*, 2010; Oostenbrugge *et al.*, 2010; ICES, 2011), including data of the Belgian fleet, and proved to significantly increase the utility of VMS data in providing a spatially and temporally explicit understanding of fishing activities.

Other than the lack of data on foreign vessels, the current analysis suffers from an underestimation of actual fishing effort due to the lack of data on vessels under 15 m of length. Since small-scale commercial fisheries and all recreational fisheries have been estimated to represent a meaningful proportion of total fishing effort in the BPNS (Depestele *et al.*, 2008), VMS data do not suffice to get a correct and detailed view of the total effort. Ideally, all commercial fishing vessels regardless of their size should be equipped with a VMS transmitter or a similar device. Installing VMS devices for recreational fisheries is however not realistic, so other ways of estimating fishing effort by these small vessels have to be considered. In that perspective, visual surveys are complementary to VMS data, since they can provide an estimate of the spatial distribution and the presence of hot spots of small scale fishing activities (Maes *et al.*, 2005; Goffin *et al.*, 2007; Depestele *et al.*, 2008). In the Belgian windmill park area, intensive ship-based seabird surveys are performed by the Research institute for Nature and Forest (INBO) (see chapter on seabird monitoring), during which observations of vessels of any size are being recorded in a standardized way. These data clearly showed a concentration of recreational fisheries (mostly anglers) north of the existing C-Power turbines in 2008-2009 (fig 2), in the area where VMS data also showed a concentration of eurocutter

[2] CFP: Common Fisheries Policy

activity in 2009. Such a cluster was not observed in 2006-2007, but this may partly be due differences in sampling intensity between the periods. Still, the co-occurrence with higher eurocutter activity (as derived from VMS data, which are not subject to differences in sampling intensity) is striking, so increased angler activity likely is a reality. This angler activity usually targets pelagic and bentho-pelagic species, of which high densities have already been observed in the vicinity of the turbines (Reubens *et al.*, 2010; Reubens *et al.*, 2011). Hence, it is likely that the increased activity is a direct result of the presence of pelagic and bentho-pelagic fish species near the turbines.

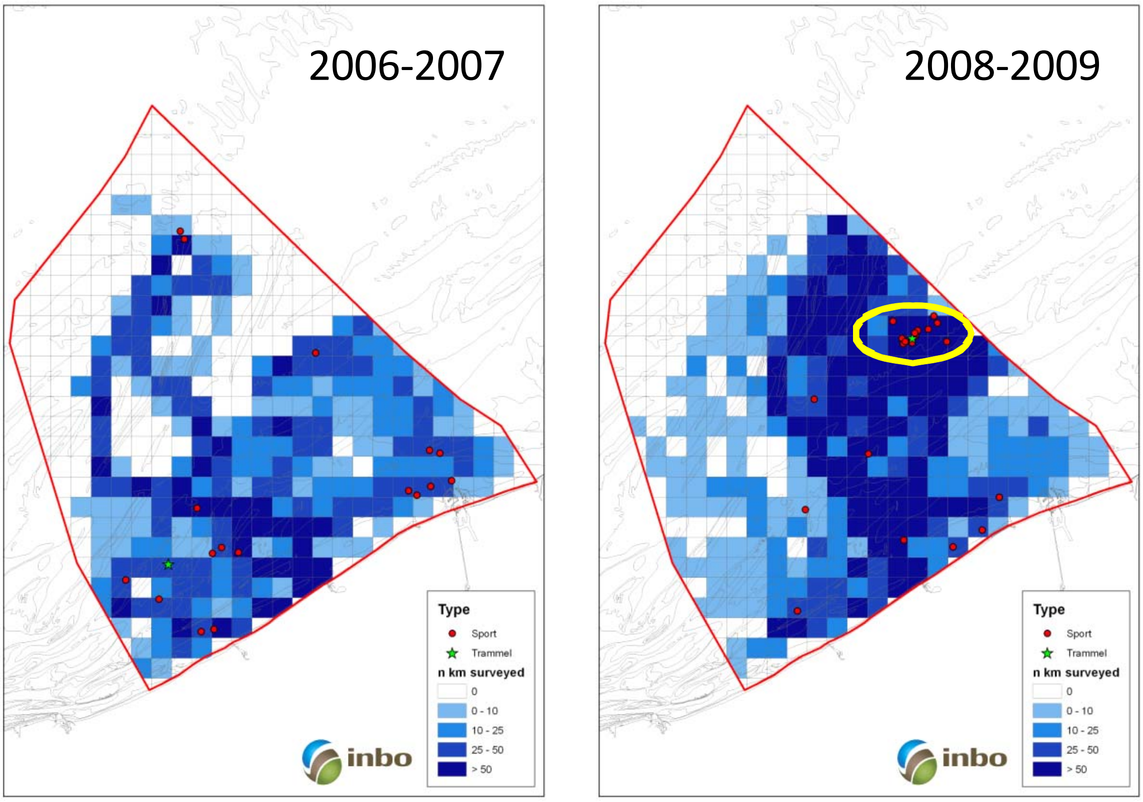

Figure 2. Point observations of trammel net activity (green stars) and recreational fisheries (red dots) for the years 2006-2007 and 2008-2009, based on vessel observations during seabird surveys. The underlying blue grid (3 km²) represents the survey intensity as the number of kilometers effectively sailed in each grid cell.

8.5. Conclusion

The permanent closure of the existing windmill park concession areas for fisheries has not resulted in a major disruption of Belgian fisheries activities. VMS data analyses showed that for eurocutters, there was a shift in distribution from 2006 to 2009, with the abandonment of the western part of the Thorntonbank after 2006 and an increase of fisheries activities between the Thorntonbank and the Bank Zonder Naam in 2009. For recreational fisheries, mapping observations from visual surveys by INBO revealed a concentration of activity in the same region north of the Thorntonbank. These observations might indicate a local increase in the availability of commercially interesting fish species, and the existence of fringe effects with regard to the state of soft-bottom fauna in the area north of the existing C-Power turbines. The state of commercial fish, and of non-commercial fish and invertebrates can be investigated by means of the analysis of logbook data and of (re-)assigned sampling stations for macrobenthos, epibenthos and demersal fish.

The observed increase in fisheries activities by Belgian eurocutters and by recreational fisheries may be altered in the near future following the construction of new wind mill parks in the area, more precisely the park planned between the C-Power and the Eldepasco concessions. Additionally, windmill park construction is also planned in the area south of the C-Power concession, which is an area that is traditionally intensively fished.

VMS data show to be very useful in providing a spatial and temporal understanding of fisheries activities. In the current analysis however, overall fishing activities in the area could not accurately be mapped due to the lack of VMS data on foreign vessels fishing in the windmill park area and on vessels smaller than 15m. This was partly mediated by analysing data gathered during visual surveys. However, the integration of VMS data of all vessels fishing within the study area is indispensable for future monitoring of fisheries activities of windmill parks and other closed areas. Hence, scientists and administrators should strive for an integration of all data, taking into account confidentiality regulations and national and European laws.

8.6. References

Anonymous, (2006). Officiële lijst der Belgische Vissersvaartuigen. Federale overheidsdienst Mobiliteit en Vervoer, Maritiem Vervoer. 24 pp.

Anonymous, (2007). Officiële lijst der Belgische Vissersvaartuigen. Federale overheidsdienst Mobiliteit en Vervoer, Maritiem Vervoer. 29 pp.

Anonymous, (2008). Officiële lijst der Belgische Vissersvaartuigen. Federale overheidsdienst Mobiliteit en Vervoer, Maritiem Vervoer. 31 pp.

Anonymous, (2009). Officiële lijst der Belgische Vissersvaartuigen. Federale overheidsdienst Mobiliteit en Vervoer, Maritiem Vervoer. 30 pp.

Anonymous, (2009). Atlas of the Commercial Fisheries Around Ireland, Marine Institute, December 2009. ISBN 978 1 902895 46 8. 58 pp.

Deerenberg, C.M., Teal, L.R., Beare, D.J. & van der Wal, J.T., (2010). FIMPAS project - Pre - assessment of the impact of fisheries on the conservation objectives of Dutch marine protected areas. IJmuiden : IMARES, 2010 (Report C071/10).

Depestele, J., Courtens, W., Degraer, S., Derous, S., Haelters, J., Hostens, K., Moulaert, I., Polet, H., Rabaut, M., Stienen, E. & Vincx, M., (2008). Evaluatie van de milieu-impact van WArrelnet- en boomKOrvisserij op het Belgisch deel van de Noordzee (WAKO). Eindrapport. ILVO Visserij: Oostende, Belgium. 185 pp.

ESRI, Inc., (2010). Arcview, version 10.0. www.esri.com.

Fock, H.O., (2008). Fisheries in the context of marine spatial planning: defining principal areas for fisheries in the German EEZ. Marine Policy 2008;32:728–39.

ICES, (2010). Report of the Study Group on VMS data, its storage, access and tools for analysis (SGVMS), 8-9 September 2010, Hamburg, Germany. ICES CM 2010/SSGSUE:12. 46 pp.

Goffin, A., Lescrauwaet, A.-K., Calewaert, J.-B., Mees, J., Seys, J., Delbare, D., Demaré, W., Hostens, K., Moulaert, I., Parmentier, K., Redant, F., Mergaert, K., Vanhooreweder, B., Maes, F., De Meyer, P., Belpaeme, K., Maelfait, H., Degraer, S., De Maersschalck, V., Derous, S., Gheskiere, T., Vanaverbeke, J., Van Hoey, G., Kuijken, E., Stienen, E., Haelters, J., Kerckhof, F., Overloop, S. & Peeters, B., (2007). MIRA Milieurapport Vlaanderen, Achtergronddocument 2006, Kust & zee, Vlaamse Milieumaatschappij, Erembodegem, Belgium, www.milieurapport.be, 180 pp.

Grizzle, R.E., Ward, L.G., Mayer, L.A., Malik, M.A., Cooper, A.B., Abeels, H.A., Greene, J.K., Brodeur, M.A. & Rosenberg, A.A., (2009). Effects of a large fishing closure on benthic communities in the western Gulf of Maine: recovery from the effects of gillnets and otter trawls Fish. Bull. 107(3): 308-317.

ICES, (2011). Fisheries Measures in Protected Areas (FIMPAS) within the Exclusive Economic Zone (EEZ) of the Dutch part of the North Sea: areas outside the 12 nautical miles zone: Proposals, Dates, Venue. FIMPAS Steering Group. 33 pp.

Maes, F., Schrijvers, J., Van Lancker, V., Verfaillie, E., Degraer, S., Derous, S., De Wachter, B., Volckaert, A., Vanhulle, A., Vandenabeele, P., Cliquet, A., Douvere, F., Lambrecht, J. & Makgill R., (2005). Towards a spatial structure plan for sustainable management of the sea, (GAUFRE) research in the framework of the BSP programme ‘Sustainable Management of the Sea’, PODO II, Gent. 539 pp.

Mills, C.M., Townsend, S.E., Jennings, S., Eastwood, P.D. & Houghton, C.A., (2007). Estimating high resolution trawl fishing effort from satellite-based vessel monitoring system data. ICES J. Mar. Sci. 64(2): 248–255. doi:10.1093/icesjms/fsl026.

MUMM, (2004). Milieueffectenbeoordeling van het project ingediend door de n.v. C-Power. Rapport van het Koninklijk Belgisch Instituut voor Natuurwetenschappen, Departement Beheerseenheid van het Mathematisch Model van de Noordzee (BMM), 155 pp.

Murawski, S.A., Brown, R., Lai, H.-L., Rago P.J. & Hendrickson, L., (2000). Large scale closed areas as a fishery-management tool in temperate marine systems: the georges bank experience. Bulletin of marine science, 66(3): 775–798.

Oostenbrugge, J.A.E., Bartelings, H. & Buisman, F.C., (2010). Distribution maps for the North Sea Fisheries: methods and application in Natura 2000 areas. LEI report 2010-067, 122pp.

Reubens, J., Degraer, S. & Vincx, M., (2010). The importance of marine wind farms as artificial hard substrata for the ecology of ichthyofauna. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 6: 69-82.

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

ICES, (2010). Report of the Study Group on VMS data, its storage, access and tools for analysis (SGVMS), 8-9 September 2010, Hamburg, Germany. ICES CM 2010/SSGSUE:12. 46 pp.

Verordening (EG) nr. 2244/2003 van de Commissie van 18 december 2003 tot vaststelling van uitvoeringsbepalingen inzake satellietvolgsystemen (VMS). Publicatieblad Nr. L 333 van 20/12/2003 blz. 0017 – 0027.

Chapter 9. Seabirds & offshore wind farms: Power and impact analyses 2010

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Black-legged kittiwake near a C-Power wind turbine © Karl Van Ginderdeuren – ILVO-Fisheries

Abstract

Seabird count results exhibit extremely high variation in counted numbers, a high proportion of zero counts, and strong auto-correlation effects. This inevitably results in low statistical power regarding the use of these data in impact assessment. Therefore, in our BACI monitoring set-up, count data are spatially aggregated per reference and impact area, thus minimizing variation, and avoiding autocorrelation. We studied the expected power of our monitoring study by performing power calculations for several scenarios of decrease in numbers, monitoring intensity and monitoring duration. We found that for most species we will be able to detect changes in numbers of 30-70% relatively easy for most seabird species within a period of 10 years after the impact. Species that combine common occurrence (>1 bird/km²) with moderate over-dispersion (factor < 10) are most suitable for monitoring. We cannot control local seabird occurrence, but by carefully delineating a control area and maximizing monitoring intensity, the power of our impact analysis is strongly enhanced. Ideally, the control area holds equal numbers of seabirds compared to the impact area.

Surprisingly, we already found some significant effects. More precisely, tern activity in the Thorntonbank wind farm area significantly increased since the first turbines were built, and the same holds true for Common and Herring gull densities at the Bligh Bank wind farm. Enhanced seabird activity inside the wind farms may be induced by mere attraction to artificial structures as a stepping stone, a resting place or a 'reference' in the wide open seascape, but also by enhanced foraging conditions. While this counters the worries of habitat loss due to avoidance or habitat deterioration, increased bird activity increases the risk of collision mortality.

The reference study already revealed increased activity of Common and Sandwich tern at the Thorntonbank study area during migration periods. Considering their high protection status and fragile populations, the area was therefore indicated to be of particular importance to these birds. While both tern species are already exposed to wind farm induced mortality at their breeding sites at Zeebrugge (Everaert & Stienen, 2006), they will now be exposed to the same threat during their migration far out at sea. The occurrence of terns at the Thorntonbank study area should therefore receive maximum attention in the coming monitoring years.

As mentioned, we found significant attraction effects in Common and Herring gull at the Bligh Bank. Again, these results are highly preliminary, especially considering the limited time frame in which impact data at the Bligh Bank could be collected. Future monitoring will inevitably result in more firm conclusions. Nevertheless, these early findings already indicate that attraction effects may be more apparent than avoidance effects, which stresses the need for proper radar research, to study flight activity inside the wind farms, and to model collision risks.

Samenvatting

Een typische zeevogeldataset wordt gekenmerkt door een hoge variatie in waargenomen aantallen, een hoog aantal nultellingen, en sterke autocorrelatie. Bij het gebruik van dit soort gegevens in impactanalyses valt de statistische 'power' daarom normaal gezien laag uit. In plaats van punttellingen te gebruiken, hebben wij daarom onze telresultaten gegroepeerd per gebied en per maand, om zo de variantie te drukken en negatieve effecten van autocorrelatie te vermijden. We bestudeerden de te verwachten power van onze impactstudie door verschillende scenario's na te gaan, en we varieerden de afname in aantallen, alsook de monitoringsintensiteit en monitoringsduur. Uit onze resultaten blijkt dat we voor de meeste soorten een afname van 30 tot 70% kunnen detecteren binnen een periode van 10 jaar na de impact. Sommige soorten presteren duidelijk beter dan andere, door toedoen van hun hogere abundantie, en/of lagere overdispersie.

Verrassend genoeg vonden we nu reeds significante effecten als gevolg van de aanwezigheid van offshore windturbines. Met name op de Thorntonbank blijken de aantallen Visdief en Grote stern binnen het impactgebied te zijn toegenomen sinds de eerste turbines er werden gebouwd. Hetzelfde geldt voor Stormmeeuw en Zilvermeeuw op de Bligh Bank. Terwijl we oorspronkelijk vooral vreesden voor habitatverlies, blijkt uit onze zeer voorlopige resultaten dat vogels eerder aangetrokken worden door de windparken dan dat ze ze vermijden. Aantrekking kan het gevolg zijn van de voorkeur voor artificiële objecten als pleisterplaats of als referentiebaken binnen het open zeegebied,

maar kan evengoed het gevolg zijn van verbeterde voedselcondities. Hoedanook stelt dit de vogels voor een ander probleem, namelijk dat van verhoogde mortaliteit als gevolg van aanvaring.

Reeds tijdens de referentiejaren werd de verhoogde aanwezigheid van sterns in de omgeving van de Thorntonbank aangemerkt als aandachtspunt, gezien hun hoge beschermingsstatus en kwetsbare populaties. Terwijl beide soorten in hun broedgebieden al vaak bloot staat aan de risico's van windmolen gerelateerde mortaliteit, lijkt ditzelfde probleem zich nu ook op open zee te gaan stellen.

De recente bevindingen onderstrepen ook het belang van degelijk radaronderzoek, om de aantallen vliegbewegingen binnen de windparken in kaart te kunnen brengen, als input voor aanvaringsmodellen. Anderzijds zijn nog steeds slechts 6 van de 54 geplande windmolens op de Thorntonbank aanwezig, en zijn de hier gepresenteerde resultaten hoedanook zeer voorlopig te noemen.

9.1. Introduction

Despite its limited surface, the Belgian Part of the North Sea (BPNS) holds internationally important numbers of seabirds. The area is exploited by birds in a number of ways, and its specific importance varies throughout the year. During winter, maximum numbers are present with an average of 42 000 seabirds (Vanermen & Stienen, 2009). The offshore bird community is dominated by auks and kittiwakes, while important numbers of grebes, scoters and divers reside inshore. In summer, fewer birds are present (on average 17 000 birds), but large numbers of terns and gulls exploit the area in support of their breeding colony located in the port of Zeebrugge. Furthermore, the BPNS is part of a very important seabird migration route through the southern North Sea: each autumn, an estimated 1.0 to 1.3 million seabirds migrate through this 'migration bottleneck' (Stienen *et al.*, 2007).

The near future will see large scale exploitation of offshore wind energy, and a concession zone comprising almost 10% of the waters under Belgian jurisdiction is reserved for wind farms. Presently, six wind turbines have already been installed at the Thorntonbank (C-Power), while 55 turbines are present at the Bligh Bank (Belwind). Inevitably, this will affect the local seabird community and effects of wind turbines on birds range from direct mortality through collision, to more indirect effects like habitat change, habitat loss and barrier-effects (Desholm, 2005; Drewitt & Langston 2006;…).

A monitoring study was set up to assess to what extent local densities of seabirds are affected by the presence of the turbines. It may be expected that some birds will avoid the wind farms, while others may be attracted to them due to an increase in food availability and roosting possibilities.

In the previous monitoring report (Vanermen *et al.*, 2010) we presented our modelling set-up for the future impact analyses. Here we present an update of the results based on the data gathered over the year 2010. Secondly, to learn more about the statistical value of our count data we performed an extensive power analysis based on the data gathered during reference years.

9.2. Material and Methods

9.2.1. Reference areas

The study is based on a Before-After Control-Impact comparison (BACI design). Migrating birds show deflections in flight orientation from up to a distance of 1-5 km (Petterson *et al.*, 2005; Petersen *et al.*, 2006) but little is known about the avoidance of swimming birds. However, a significant post-construction decrease in densities of divers, scoters and Long-tailed ducks was shown by Petersen *et al.* (2006) out to a distance of 3 km away from the Nysted wind farm in Denmark.

Therefore, we applied a buffer zone of at least 3 km around the future Belwind and C-Power wind farms to define our 'impact areas'. Following, we delineated two control areas based on the comparability in numbers and seasonality of seabirds occurring (see previous reports, e.g. Vanermen *et al.*, 2010). Considering the large day-to-day variation in observation conditions and seabird densities, the distance between impact and control area had to be small enough to be able to count them both on the same day by means of a research vessel. The resulting control and impact areas are 1.5 km apart, equalling the geographical error on our transect counts. The control areas' surface spreads out from at least 4.5 to almost 20 km away from the nearest turbine, an area in which we do not expect overall densities of seabirds to be affected by the presence of turbines in the impact areas.

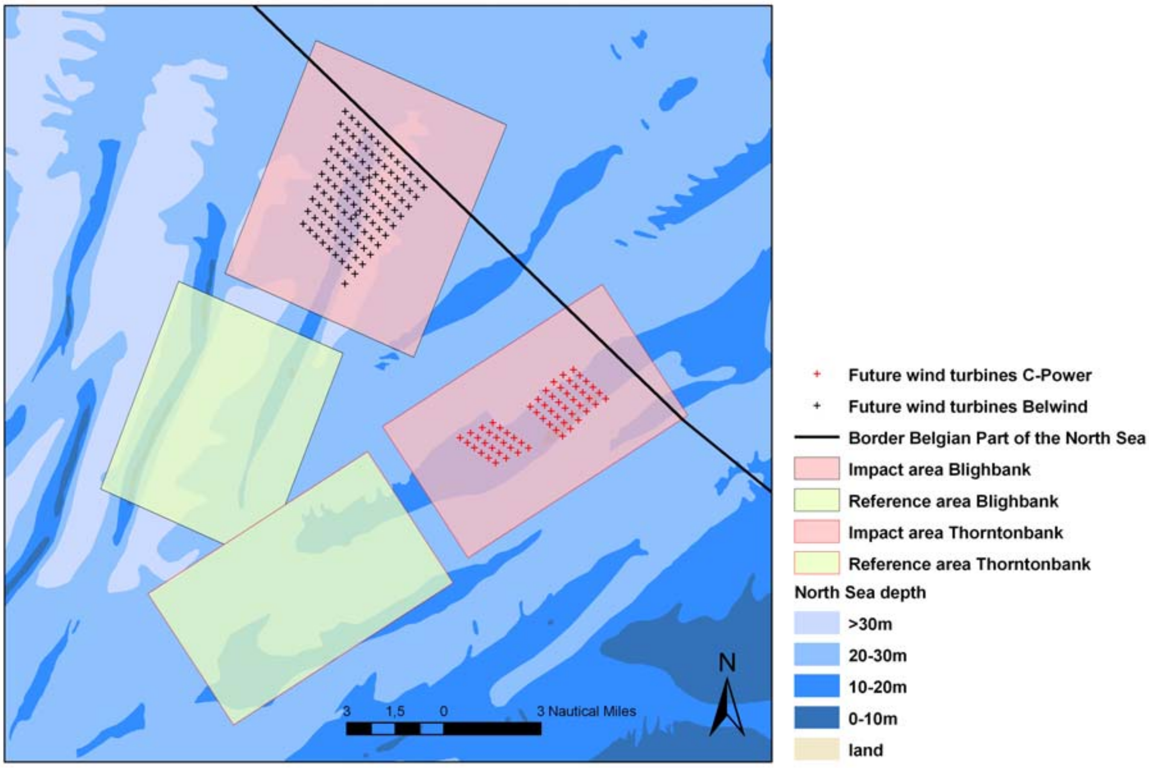

Figure 1. Control and impact areas for both future wind farms at the Thorntonbank and Bligh Bank.

9.2.2. Ship-based seabird counts

In the study areas, intensive monitoring took place through ship-based seabird counts from 2005 onwards. These are conducted according to a standardized and internationally applied method, as described by Tasker *et al*. (1984). While steaming, all birds in touch with the water (swimming, dipping, diving) located within a 300 m wide transect along one side of the ship's track are counted ('transect count'). For flying birds, this transect is divided in discrete blocks of time. During one minute the ship covers a distance of approximately 300 m, and at the start of each minute all birds flying within a quadrant of 300 by 300 m are counted ('snapshot count'). Taking the travelled distance into account, the count results can be transformed to seabird densities.

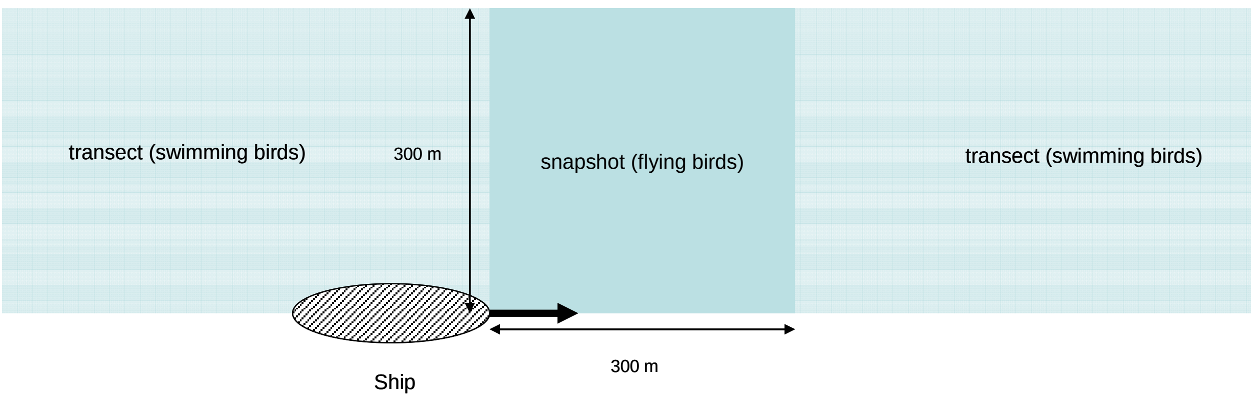

Figure 2. Methodology of standardized seabird counts using a 300 m wide transect for swimming birds, and 'snapshot' counts (each minute) for flying birds.

Our count method is in accordance to the ESAS-prescriptions, but the way of dealing with the count results is different. While the ESAS-database collects the results of ten-minute tracks, we lumped the count results per area (control/impact) and per monitoring month. This way, we avoided auto-correlation effects, and we minimized overall variance. To further minimize variation due to short-term temporal changes in seabird abundance and in weather and observation conditions, we included only those days at which both the impact and reference area were visited. Naturally, the current monitoring routes always include both of these areas, but this was not always the case in our historical data.

9.2.3. Monitoring species

Based on the reference data, Vanermen & Stienen (2009) concluded that the wind farm area at the Thorntonbank:

- has no particular value to Red-throated diver, Great crested grebe, Northern fulmar, Common scoter, Great skua and Herring gull
- is not particularly valuable to the following species, although high densities may occur: Northern gannet, Common gull, Lesser black-backed gull, Great black-backed gull, Black-legged kittiwake, Common guillemot, Razorbill
- is of particular value to <u>Little gull</u>, <u>Sandwich tern</u> and <u>Common tern</u>

A similar study on the Bligh Bank reference data resulted in the conclusions that the Bligh Bank wind farm area:

- is of no particular value to Red-throated diver, Great crested grebe, Northern fulmar, Common scoter, Common gull, Herring gull, Great black-backed gull, Sandwich tern, Common tern and Razorbill
- is not particularly valuable to the following species, although increased or high densities may occur: Northern gannet, Lesser black-backed gull, Black-legged kittiwake, Common guillemot
- is probably of particular value to <u>Great skua</u> and <u>Little gull</u>

Of course, special focus should go to those species for which the wind farm area is indicated to be of particular value. But also, we are interested in the general displacement effects caused by the presence of offshore wind farms. This includes avoidance by species that were present during the reference situation, as well as attraction of species that were uncommon or even absent during reference years. To anticipate on the full spectrum of possible displacement effects, we investigate a broad range of species, listed in Table 1.

Because of their almost complete absence and clear coast bound distribution, Red-throated diver, Great crested grebe and Black scoter are left out of the analyses in this report. For the Bligh Bank this also accounts for the Annex I species Common tern and Sandwich tern, and for the Thorntonbank we did not include Great skua due to its rarity. Of course, all birds are counted during monitoring surveys, and if necessary, we may include any species in the analysis at any time.

Table 1.
Species included in the monitoring study at the Thorntonbank & Bligh Bank wind farms.

Species	Thorntonbank	Bligh Bank
Northern fulmar	X	X
Northern gannet	X	X
Great skua		X
Little gull	X	X
Common gull	X	X
Herring gull	X	X
Lesser black-backed gull	X	X
Great black-backed gull	X	X
Black-legged kittiwake	X	X
Sandwich tern	X	
Common tern	X	
Common guillemot	X	X
Razorbill	X	X

9.2.4. Monitoring scheme and count effort

Since 1993, the Research Institute for Nature and Forest (INBO) carries out standardised seabird counts at the BPNS. From 2002 onwards, this was performed on a monthly base along three fixed monitoring routes, sailed by the research vessel 'Zeeleeuw'. In the course of time, monitoring effort shifted from an integral monitoring of the BPNS to an actual wind farm monitoring program. The period 2005-2007 was a transition period, in which two routes were partly dedicated to the monitoring of the Thorntonbank wind farm site and the nearby Gootebank. Since 2008 however, all three monthly monitoring routes focus on the wind farm concession zone and adjacent control areas, also including the Oosthinderbank, Bligh Bank and Bank zonder Naam (Figure 3).

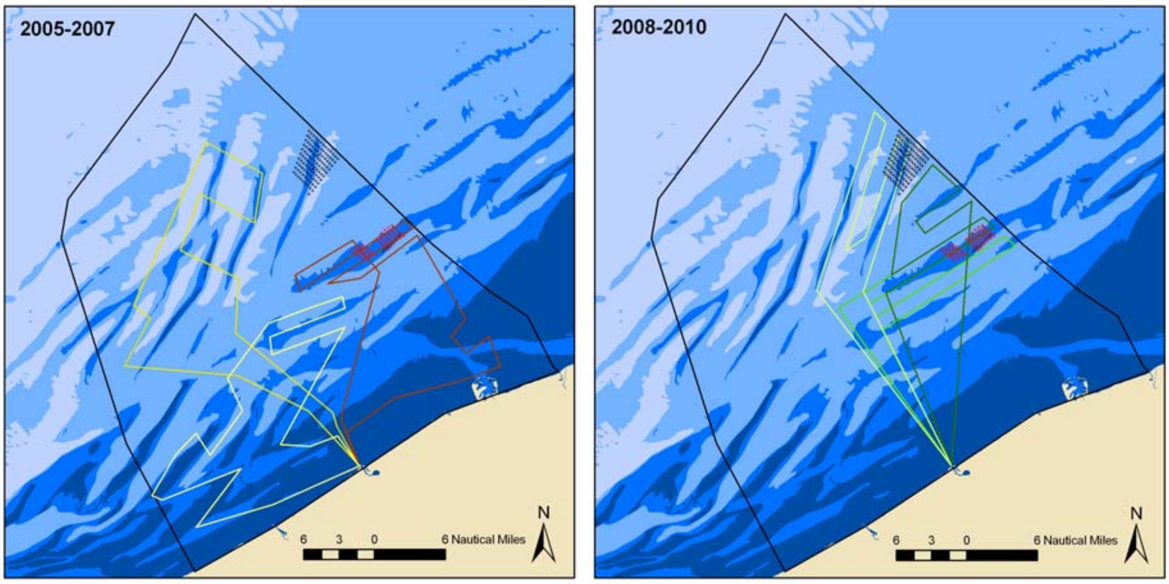

Figure 3. Monitoring routes sailed during the periods 2005-2007 (left) and 2008-2010 (right), with indication of the (future) location of the turbines of C-Power (Thorntonbank) and Belwind (Bligh Bank).

9.2.4.1. Count effort Thorntonbank

Figure 4 displays the count effort in the impact and control areas at the Thorntonbank study area. Hereby, count effort is expressed as the mean number of square kilometres of transect that was counted per monitoring month, equalling the number of kilometres sailed multiplied by the transect width (0.3 km). Average monitoring intensity has more than doubled after the turbine impact (from 6.4 to 14.2 km²), and was consistently higher in the impact area compared to the reference area.

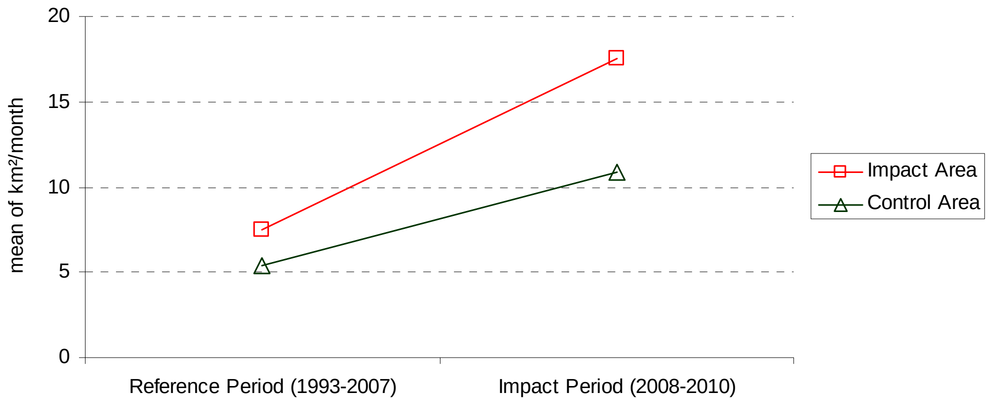

Figure 4. Count effort in the Thorntonbank study area, expressed as the mean number of km² of transect counted per monitoring month.

Figure 5 shows the number of 'monitoring months' before and after the first turbines were erected. During the reference period (1992-2007), visits were irregular, and count effort is therefore not equally distributed throughout the year (o). Our dataset also includes data resulting from three years of impact monitoring. Since turbine impact took place, we planned at least one monitoring route per month, which should have resulted in a total of 36 'monitoring months'. However, due to weather conditions or ship repair, some surveys were cancelled, explaining why there was only one 'monitoring month' in January & February, and two in March & November (x), thus totalling 30 'monitoring months'.

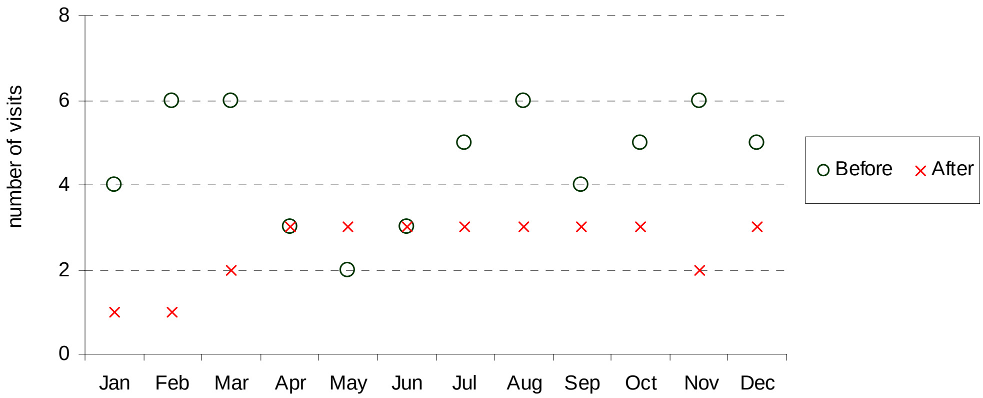

Figure 5. Number of 'monitoring months' before and after the construction of the first turbines at the Thorntonbank in 2008.

9.2.4.2. Count effort Bligh Bank

At the Bligh Bank study area too, monitoring intensity strongly increased since the first turbines were built (from 6.7 to 11.9 km² - see Figure 6). As in the previous paragraph, we observe an erratic distribution of the number of 'monitoring months' during reference years (o in Figure 7). The impact period started off quite recently in September 2009, explaining the poor number of 'monitoring months' (x).

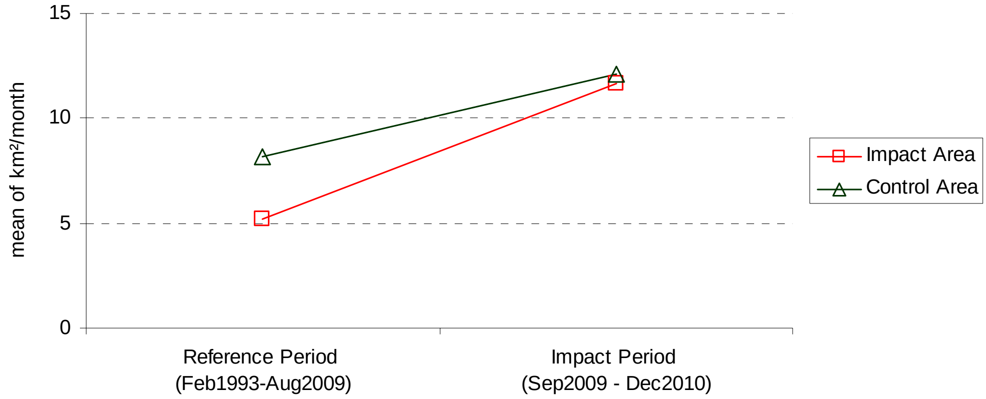

Figure 6. Count effort in the Bligh Bank study area, expressed as the mean number of km² of transect counted per monitoring month.

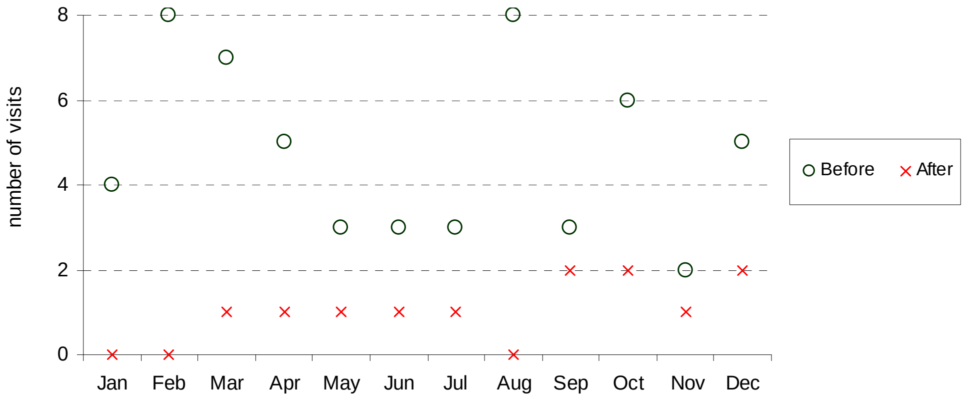

Figure 7. Number of 'monitoring months' before and after the construction of the first turbines at the Bligh Bank in September 2009.

9.2.5. Data-analysis: modelling the reference data

9.2.5.1. Quasi-Poisson model

The monitoring results of the reference period were modelled through a 'generalised linear' approach, in which the relationship between the response and the linear equation is defined by a 'link-function', noted as follows:

$$g(E(y)) = \alpha + \sum_{j=1}^{p} \beta_j x_j$$

In the above equation, the function g(.) is the 'link-function', E(y) the expected value of the response variable y, α the intercept, x_j a vector of j explanatory variables and β_j a vector of j coefficients (Yee & Mitchell, 1991; Clarke *et al.*, 2003).

When the counted subject is randomly dispersed, count results respond to a poisson-distribution and can thus be linked to the linear predictors using a logarithmic transformation:

$$\ln(E(y)) = \alpha + \sum_{j=1}^{p} \beta_j x_j$$

This model is referred to as a standard Poisson regression (McCullagh & Nelder, 1989; Potts & Elith; 2006). To allow for over-dispersion caused by aggregated distribution of seabirds, we applied a quasi-poisson model (quasi-likelihood estimation with a logarithmic link-function) (McDonald *et al.*, 2000; Potts & Elith, 2006). In quasi-poisson modelling, coefficient estimation is equal to the results of a poisson regression. However, the standard errors on the predicted coefficients are much higher, and explanatory variables are less likely to contribute significantly to the model.

Whether counts were performed in the control or the impact area, is defined in the models by the factor variable 'CI' (Control-Impact). Since seabird occurrence is subject to large seasonal fluctuations, we included 'month' as an explanatory variable. Seasonal density patterns can be described through a sine curve, which can be defined by a linear sum of a sine and a cosine term (Onkelinx *et al.*, 2008), including 'month' as a continuous variable:

$$\ln(density) = a_1 \times \sin\left(2 \times \Pi \times \frac{month}{p}\right) + a_2 \times \cos\left(2 \times \Pi \times \frac{month}{p}\right)$$

Here, p is the period of the sine curve, and a_1 and a_2 are the coefficients to be predicted.

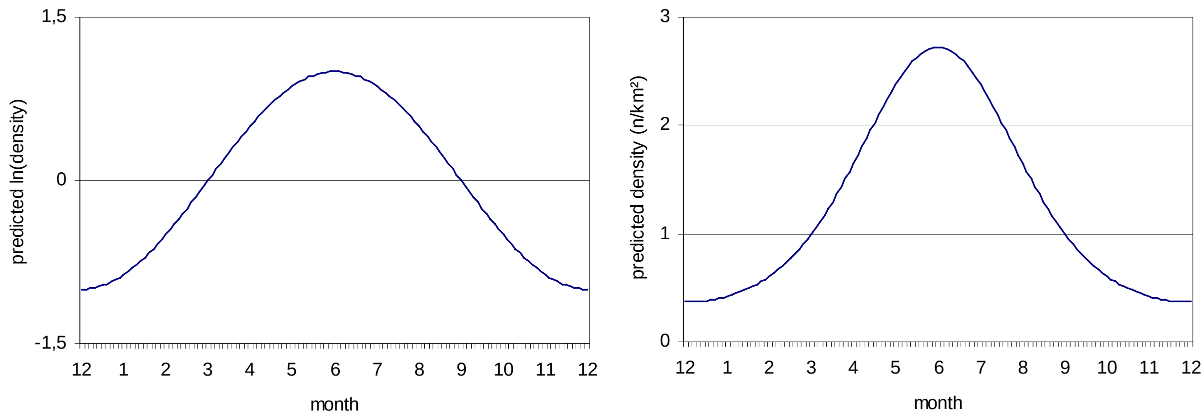

Figure 8. Example of a sine curve in logarithmic scale (left) and the same curve transformed into the linear scale.

Figure 8 presents a fictitious example of a summer visitor, in which the period of the seasonality curve is one year with peak numbers in June. Of course, seasonal occurrence might be much more complex, and needs to be described by adding up several linear sums, as for example in:

$$\ln(density) = a_1 \times \sin\left(2 \times \Pi \times \frac{month}{12}\right) + a_2 \times \cos\left(2 \times \Pi \times \frac{month}{12}\right) + a_3 \times \sin\left(2 \times \Pi \times \frac{month}{6}\right) + a_4 \times \cos\left(2 \times \Pi \times \frac{month}{6}\right)$$

Here, a sine curve with a period of 12 months is added up with a curve with a period of 6 months. This situation might arise when a bird is present only during summer months (period of one year), but occurs in increased numbers during migration periods, for example March & September (period of 6 months) (Figure 9).

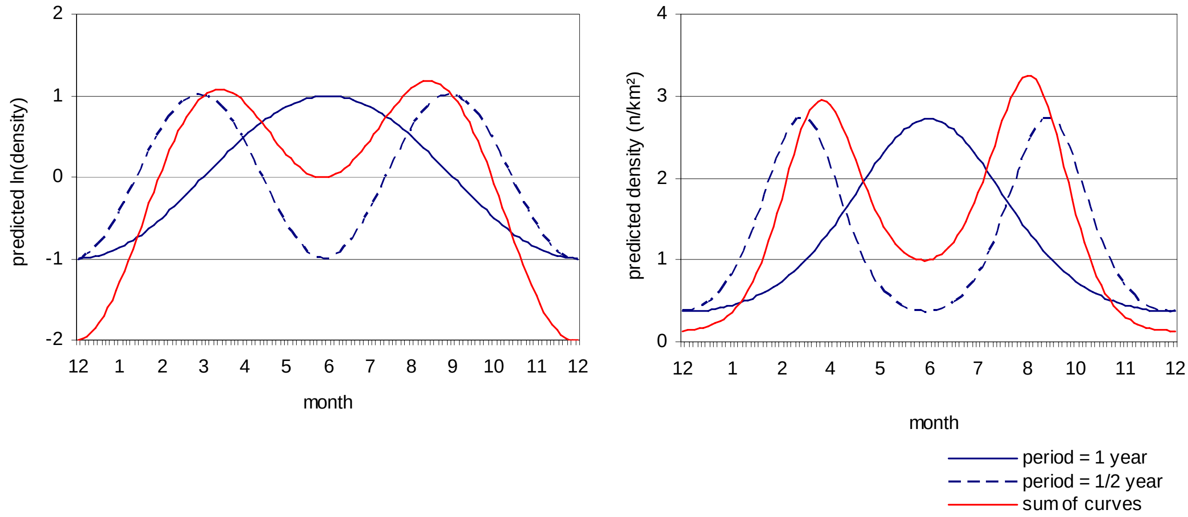

Figure 9. Example of combining two sine curves with different periods, in the logarithmic scale (left) and after transformation into the linear scale (right).

9.2.5.2. Model selection

To test the contribution of the explanatory variables, we ran several models, successively dropping one variable, and comparing these models with each other using ANOVA. During this process, the linear sum of sine and cosine terms is always treated as one undividable term, called ‘Seasonality’ from hereon.

We performed backward selection by starting from the most complex model, including an interaction term. The first test investigates whether there is a difference in seasonality pattern between both areas. If so ($p<0.05$), we need to hold on to the interaction model, if not, we may drop the interaction term and we continue the testing procedure. The next step is to investigate whether there is an additive effect of ‘CI’, which would indicate a difference between the control and impact area. For most species, we do not expect there to be an area effect, since the control area is supposed to holds more or less equal numbers of seabirds compared to the impact area, at least during reference years. In contrast, we do expect ‘Seasonality’ to explain a major deal of the variance in our data, and hence was tested for last, forming the base of our model.

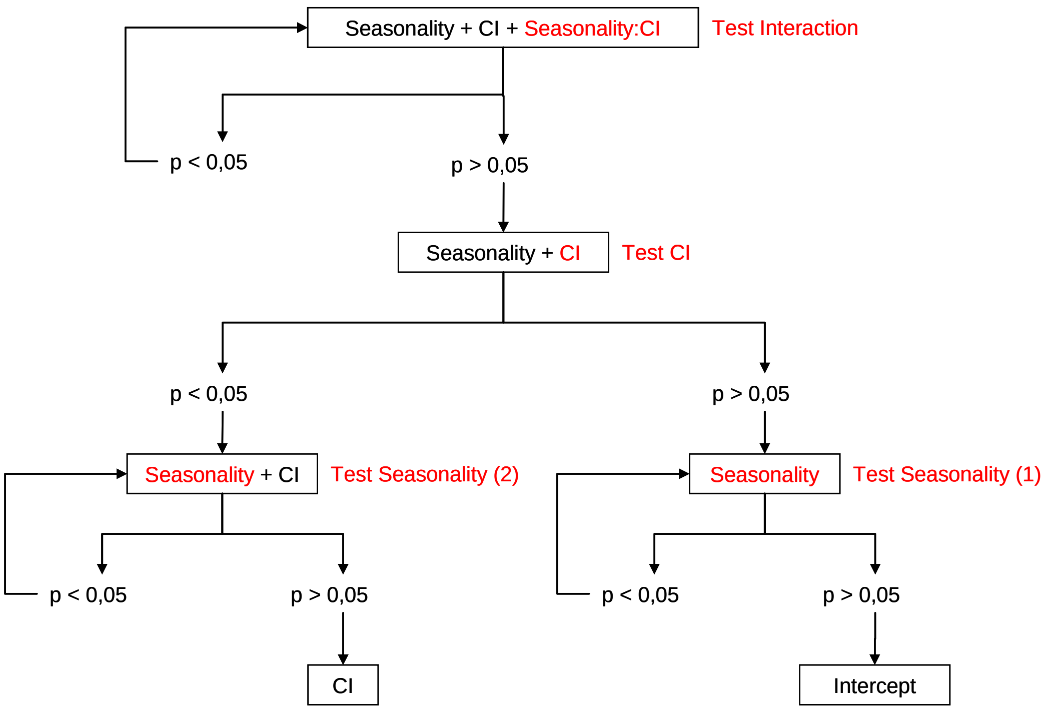

Figure 10. Flowchart of tests performed to select a reference model (the terms indicated in red are those tested for).

9.2.6. Impact analysis

The applied impact analysis depends on the selected reference model. If we observed an interaction- or area-effect during the reference years, the model is added only with a 'Before-After' (BA) factor variable:

- *impact model 1*: BA * (Seasonality + CI + Seasonality:CI)
- *impact model 2*: BA * (Seasonality + CI)
- *impact model 3*: BA * (CI)

In case 'CI' is not included in the reference model, we also need to include the factor variable 'T', indicating turbine presence:

- *impact model 4:* (BA + T) * (Seasonality)
- *impact model 5*: (BA + T) * (Intercept)

There is no interaction possible between 'BA' & 'T', since the level of 'BA' is fixed when 'T' equals 1 (indicating that turbines are present).

Table 2.
Overview of the unique combinations of factor variables used in the impact analysis (green=reference data / red=impact data).

Control/Impact Area	Before/After Impact	BA - CI	BA - T
Control Area	Before	0 – 0	0 – 0
Impact Area	Before	0 – 1	
Control Area	After	1 – 0	1 – 0
Impact Area	After	1 – 1	1 – 1

In the first place, we want to know if there is an additive effect of the turbines' presence on seabird densities, and therefore we need to test for the effect of the interaction term 'BA:CI' in impact models 1, 2 & 3 (e.g. tests 2' in Figure 11), and for the effect of 'T' in impact models 4 & 5 (e.g. test 2'' in Figure 11). When the higher degree interaction terms appears to contribute significantly to the model (tests 1' & 1'' in Figure 11), it is no longer possible to test for the main effects included in these interaction terms. Following, interpretation of a possible turbine effect is – unfortunately – no longer possible.

Since changes in numbers in the study area are not necessarily related to the turbine presence, subsequent tests are performed to investigate the effect of 'BA:Seasonality' and 'BA'.

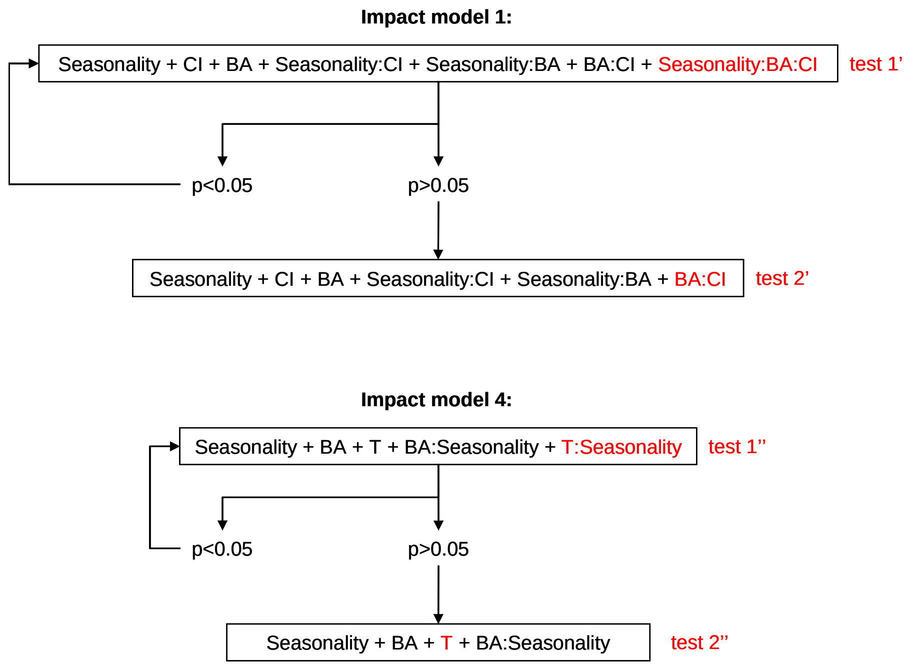

Figure 11. Graphic scheme on how to tests for turbine effects based on impact models 1 & 4 (the terms indicated in red are those tested for).

9.2.7. Power analysis

We performed power analyses to investigate the statistical value of our data. Crucial in this respect are the reference models, which form the base for the generation of random datasets.

For random data simulation based on a quasi-poisson distribution, we applied a gamma distribution, which is described by two variables: shape *a* and scale *s*. The mean and variance are defined as:

$\mu = a * s$
$\sigma = a * s^2$

Imagine λ being the mean, and θ the over-dispersion parameter describing a quasi poison distribution, then we should define shape and scale as follows:
$a = \lambda / \theta$
$s = \theta$

And thus:
$\mu = a * s = (\lambda / \theta) * \theta = \lambda$
$\sigma = a * s^2 = (\lambda / \theta) * \theta^2 = \theta * \lambda$

First, we calculated the power for a number of theoretical scenarios, with varying monitoring set-up characteristics and different types of seabird occurrence. Both the reference and impact data are simulated, and put into the modelling set-up as set out in the above chapters.

For each scenario, 10 000 random datasets were simulated, for which we calculated the p-value of the turbine effect. The resulting power equals the percentage of p-values below the significance level of 0.05 (see §9.2.7.1).

Secondly, we calculated powers based on the actual reference count results, only simulating the impact data. Again, we worked out several scenarios regarding monitoring set-up and several levels in decrease in numbers. For each scenario, the power was calculated based on 1 000 simulations (see § 9.2.7.2).

9.2.7.1. Scenario-based power calculations

As already mentioned, we produced a number of imaginary scenarios, in order to obtain insight in the way the power of our impact analysis is affected by the monitoring set-up and the kind of seabirds involved.

During the reference period already, seabird occurrence can strongly differ between control and impact area. As such, we regarded following scenarios (see Figure 12) of occurrence, resulting in three different reference models:

- No 'CI'-effect: Density ~ Seasonality
- 'CI'-effect: Density ~ CI + Seasonality
- Interaction-effect: Density ~ CI + Seasonality + CI:Seasonality

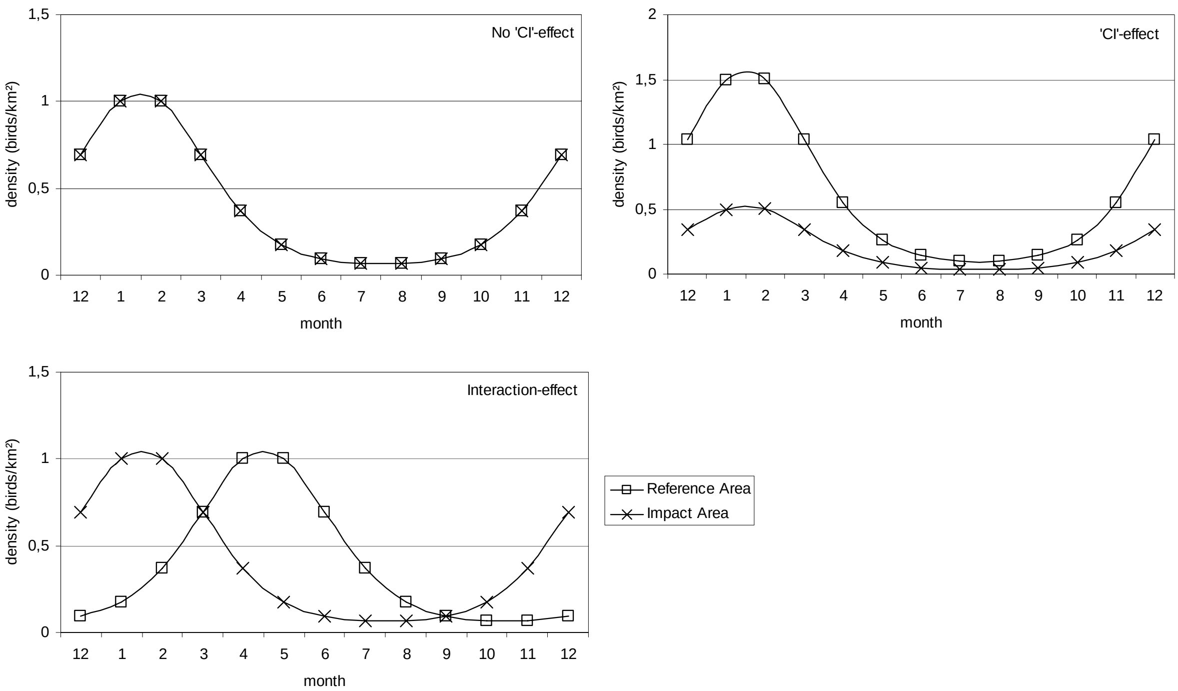

Figure 12. Three scenarios of seabird occurrence used as a base for the power analysis.

While in Figure 12, the maximum abundance averaged over both areas equals 1 bird/km², we varied the abundance by multiplying the numbers in the above graphs with four factors (1/5, 1, 5 & 25). The resulting range of abundances obtained as such is a realistic reflection of the actual observed reference situation, as modelled according to the methodology described in §9.2.5.

Another bird distribution characteristic is the over-dispersion factor. When the over-dispersion equals 1, this means that numbers are randomly dispersed (either in time or in space), thus following a poisson distribution. Count results of seabirds are always over-dispersed to some extent and this variable is varied with five levels (factors 1.2, 2, 10, 50 & 250). Again, these levels reflect the range of actual observed over-dispersion factors in the reference data of both wind farm study areas (see Table 4 & Table 7).

The variation in scenarios described above is fully determined by the distribution characteristics of the seabirds involved, and cannot be ‘controlled’. But we *can* control our monitoring intensity (km²), equalling the number of kilometres sailed per month per area, multiplied by the transect width (generally 300 m). Monitoring intensity is varied by three levels, being 5, 10 and 15 km²/month.

Resulting, we regarded 180 different scenarios, for which power was calculated based on 10 000 simulations, assuming a decrease in numbers of 50%, after a monitoring period of 10 years (5 years before & 5 years after the impact, totalling 120 ‘monitoring months’). For a few of these scenarios, we extended the analysis by calculating the power for varying lengths of the impact monitoring (5 years before the impact, versus 5, 10 & 15 years after).

9.2.7.2. Reference data based power calculations

For both study areas, the mean monitoring intensity during the impact period was at least 10 km² per area per monitoring month (see Figure 4 & Figure 6), which is taken as a base for the power calculations. To study the effect of doubling our monitoring intensity, powers were also calculated for a mean of 20 km² counted per area per month. Thus, we regarded following scenarios:

- varying decrease: 30, 50 & 70%
- varying monitoring intensity: 10 & 20 km² per month per area
- varying monitoring period: 1, 3, 5, 7, 9, 11, 13 & 15 years *after* impact

For each of these 48 scenarios and for each seabird species included in the analysis (Table 1), we simulated 1 000 impact datasets, on which the turbine effect was tested. Comparing the resulting p-values with two levels of significance (0,05 & 0,10) results in 2 power values per scenario per species.

9.3. Results

9.3.1. Scenario-based power analysis

There are striking differences in power results, and while bird abundance has a positive effect on the resulting power, the opposite is true for the over-dispersion parameter.

Figure 13 shows that for birds occurring in densities of 1 to 25 birds/km², the power may exceed 99%, given that the over-dispersion stays *below* a certain ‘critical level’. Hence, a relatively low abundance of 1 bird/km² can easily be compensated by a small over-dispersion factor (≤ 2), while birds occurring in densities of 5 or 25 birds/km² may exhibit strong over-dispersion up to factors of respectively 10 & 50, and still reach such high power.

Nevertheless, under the assumptions of the example in Figure 13, in case of low bird abundance (0.2 bird/km²) power remains below 80% for all levels of over-dispersion. On the other extreme is a extremely high over-dispersion factor of 250, for which none of the investigated abundance levels result in satisfactory powers, remaining below 60%.

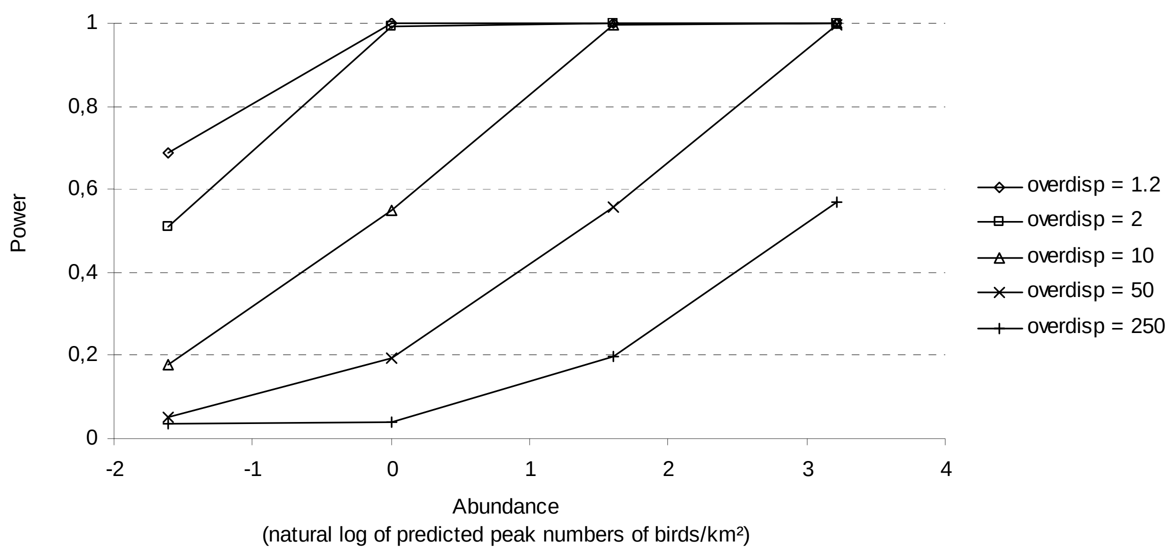

Figure 13. Calculated power (10 000 simulations) for a 50% decrease in numbers after 10 years of monitoring (5 years before + 5 years after the impact), in relation to abundance (0,2 – 1 – 5 – 25 birds/km²) for five categories of over-dispersion (factors 1,2 – 2 – 10 – 50 – 250).

When considering the variation in power results due to on the applied reference model, we see that the 'No Effect'-scenario shows the highest power levels, and the outcome is considerably lower for simulations based on the other two reference models (Figure 14).

The variation in scenarios described above is fully determined by the (uncontrollable) characteristics of seabird distribution during reference years. Figure 14 however shows that the power is also increased with increasing monitoring intensity, as the calculated powers range between 51–88% for a monitoring intensity of 5 km², while tripling the intensity results in powers ranging between 93–100%. Increasing monitoring intensity can be achieved by counting both sides of the ship, thus doubling the transect width, or by travelling more distance per month in both reference and impact area. Importantly, along with the increasing monitoring intensity, differences due to a different reference situation become increasingly smaller.

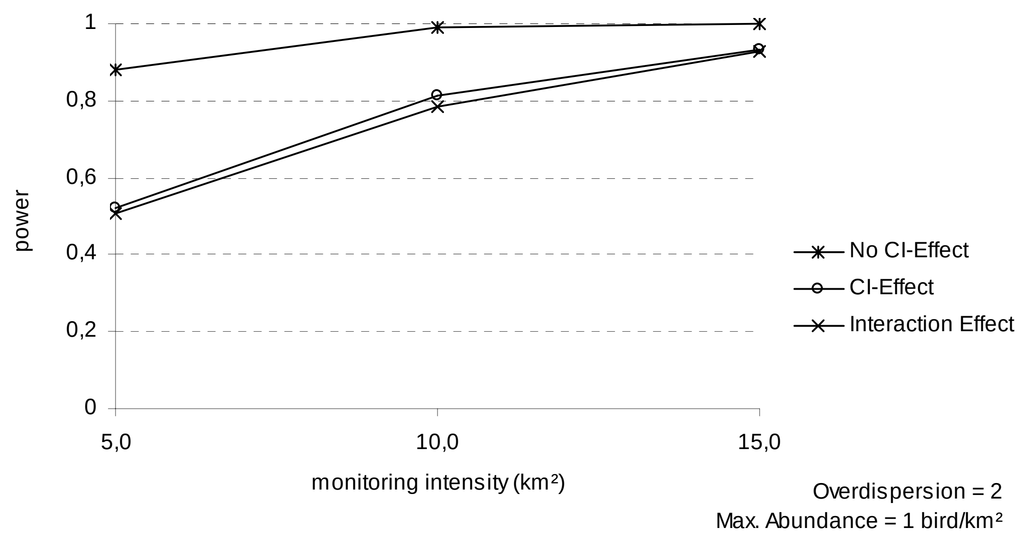

Figure 14. Calculated power (10 000 simulations) for a 50% decrease in numbers after 10 years of monitoring (5 years before + 5 years after the impact), based on three different reference models, and with varying monitoring intensity (5 – 10 – 15 km²).

Finally, instead of *intensifying the monitoring* by counting more square kilometres per month, power can be increased by *extending the monitoring period* and thus increasing the sampling size. We compared the power increase induced by doubling or tripling the total survey effort, through either one of these methods. Figure 15 proves that slightly better results are obtained when prolonging the monitoring period instead of intensifying the counts. However, the differences are negligible and if one has to choose, intensifying the surveys is preferred over prolonging the survey, since of course, the effects should to be detected as soon as possible.

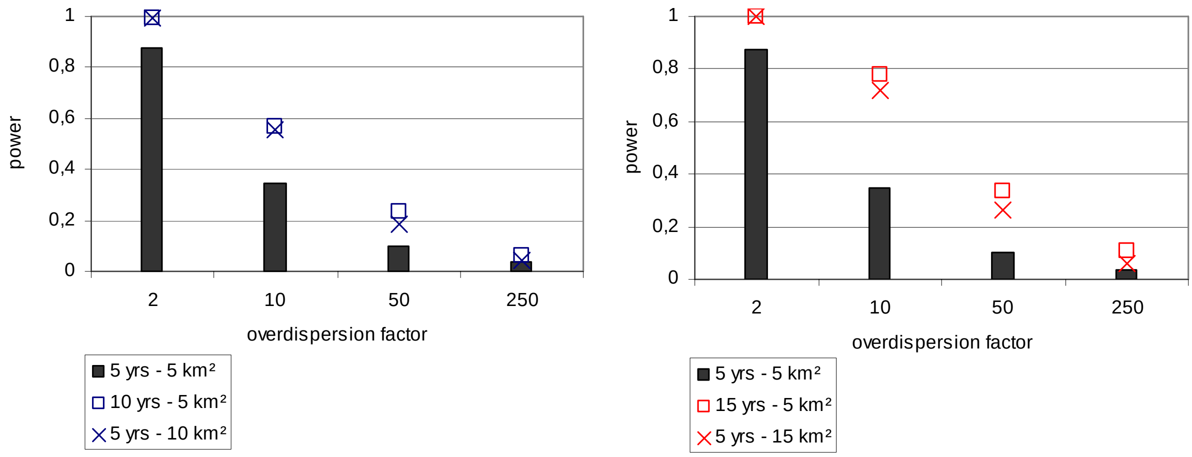

Figure 15. Power level when doubling (left) of tripling (right) the total survey effort, either by increasing the length of impact monitoring (□ : from 5 → 10 / 15 years) or by increasing the monitoring intensity (**X** : from 5 → 10 / 15 km²) assuming a decrease in numbers of 50% (max. abundance 1 bird/km²).

9.3.2. Thorntonbank

9.3.2.1. Reference situation

We modelled seabird occurrence at the impact & control site at the Thorntonbank using quasi-likelihood estimation, resulting in species-specific reference models (test results are displayed in Table 3).

For most species, only 'Seasonality' contributed significantly to the models' performance, resulting in a reference model without an area effect. Mostly, seasonality was modelled using a sine curve with a period of 12 months. Except for both tern species, in which the models performed much better when combining a 12-month period curve with a 6-month period curve. For the terns, including interaction resulted in over-fitting and extremely high standard errors, and the interaction model was therefore not included in the selection process.

For the gull species Little gull, Common gull and Black-legged kittiwake, there was a significant effect of the interaction term, indicating that their occurrence differed strongly between impact and reference area. Reference modelling in Great black-backed resulted in a model including the area factor as well 'Seasonality', but without an interaction term.

Table 3.
Test results for the reference model selection (based on flowchart in Figure 10) for the Thorntonbank study area.

	Test Interaction	Test CI	Test Seasonality (1)	Test Seasonality (2)
Northern gannet	0.26	0.37	0.00	
Northern fulmar	0.72	0.82	0.01	
Little gull	0.02			
Common gull	0.02			
Lesser black-backed gull	0.77	0.92	0.00	
Herring gull	0.07	0.72	0.00	
Great black-backed gull	0.23	0.01		0.00
Black-legged kittiwake	0.01			
Sandwich tern		0.62	0.00	
Common tern		0.96	0.00	
Common guillemot	0.31	0.56	0.00	
Razorbill	0.73	0.48	0.00	

The resulting reference models, predicted maximum densities and the over-dispersion factors are summarised in Table 4. Count data of Lesser black-backed, Great black-backed gull and Black-legged kittiwake exhibit extremely high over-dispersion, and these same species were recorded in very high densities. On the other extreme are the tern species, with low over-dispersion in the count data, and relatively low densities.

Table 4.
Predicted maximum abundances in the control and impact area, and the over-dispersion in the count data for twelve seabird species at the Thorntonbank study area during reference years.

	Reference Model	Max Abundance (n/km^2) (Control Area)	Max Abundance (n/km^2) (Impact Area)	Overdispersion factor
Northern gannet	Seasonality	1.4	1.4	20.0
Northern fulmar	Seasonality	0.5	0.5	10.6
Little gull	CI * Seasonality	1.1	1.0	8.8
Common gull	CI * Seasonality	0.3	2.8	6.4
Lesser black-backed gull	Seasonality	16.6	16.6	88.6
Herring gull	Seasonality	0.4	0.4	7.2
Great black-backed gull	CI + Seasonality	1.7	8.3	44.3
Black-legged kittiwake	CI * Seasonality	1.9	10.6	33.9
Sandwich tern	Seasonality	0.6	0.6	1.3
Common tern	Seasonality	0.5	0.5	1.1
Common guillemot	Seasonality	6.3	6.3	13.1
Razorbill	Seasonality	1.0	1.0	9.7

While Little gull fits in the Interaction-effect scenario (§9.2.7.1) due to a clear phase shift in the seasonality pattern, the occurrence of Great black-backed gull illustrates the 'CI'-effect scenario (§9.2.7.1), with higher numbers in the impact area compared to the reference area (Figure 16). For Sandwich tern and Common guillemot, the reference modelled did not reveal any 'CI'-related effect, and predicted values are the same in both areas (Figure 17).

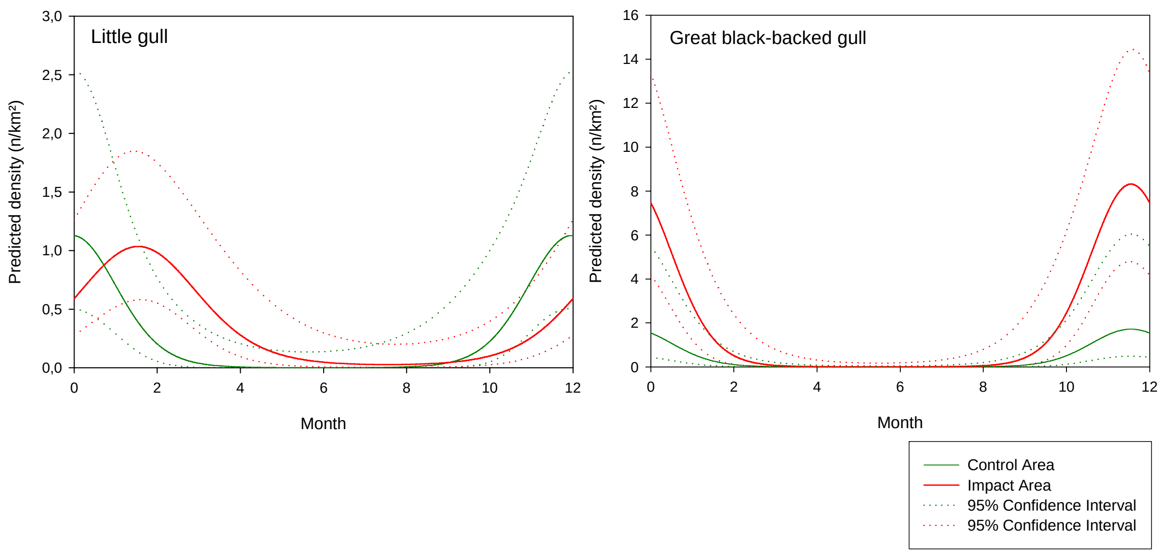

Figure 16. Predicted densities of Little gull and Great black-backed gull for the control and impact area at the Thorntonbank, with indication of the 95% point-wise confidence interval.

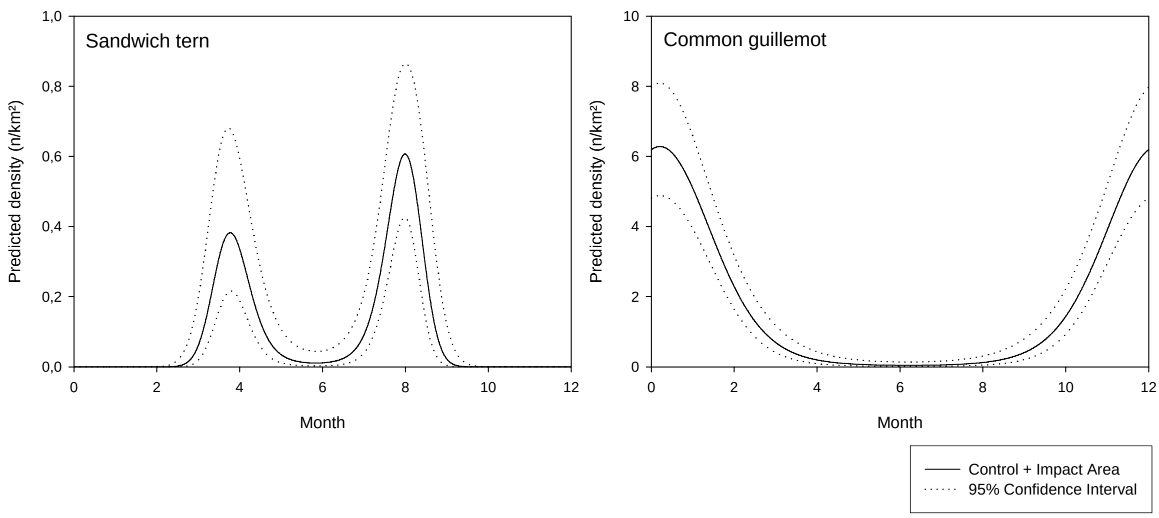

Figure 17. Predicted densities of Sandwich tern and Common guillemot for the control and impact area at the Thorntonbank, with indication of the 95% point-wise confidence interval.

9.3.2.2. Results Power analysis

Figure 18 displays the calculated powers based on the available reference data gathered at the Thorntonbank, assuming a 50% decrease and a monitoring period of five years after impact. The effect of increasing monitoring intensity from 10 to 20 km² appears to be highly relevant, as within 5 years a 50% decrease can be detected in 4 instead of 2 species. Power results can also be increased by pulling up the significance level from 5 to 10%, which is justified based on the need for the monitoring program to function as an early warning system (see §9.4.1).

Concluding, for four species, being Common guillemot, Sandwich tern, Common tern and Lesser black-backed gull, we will be able to detect a 50% change in numbers after 5 years, with a chance of more than 80%, given a monitoring intensity of 20 km². Presently, monitoring intensity at the Thorntonbank study area ranges from 10.9 km² in the control area to 17.5 km² in the impact area, averaging 14.2 km². By applying a significance level of 0.10 instead of 0.05, we can also include Razorbill in this selection.

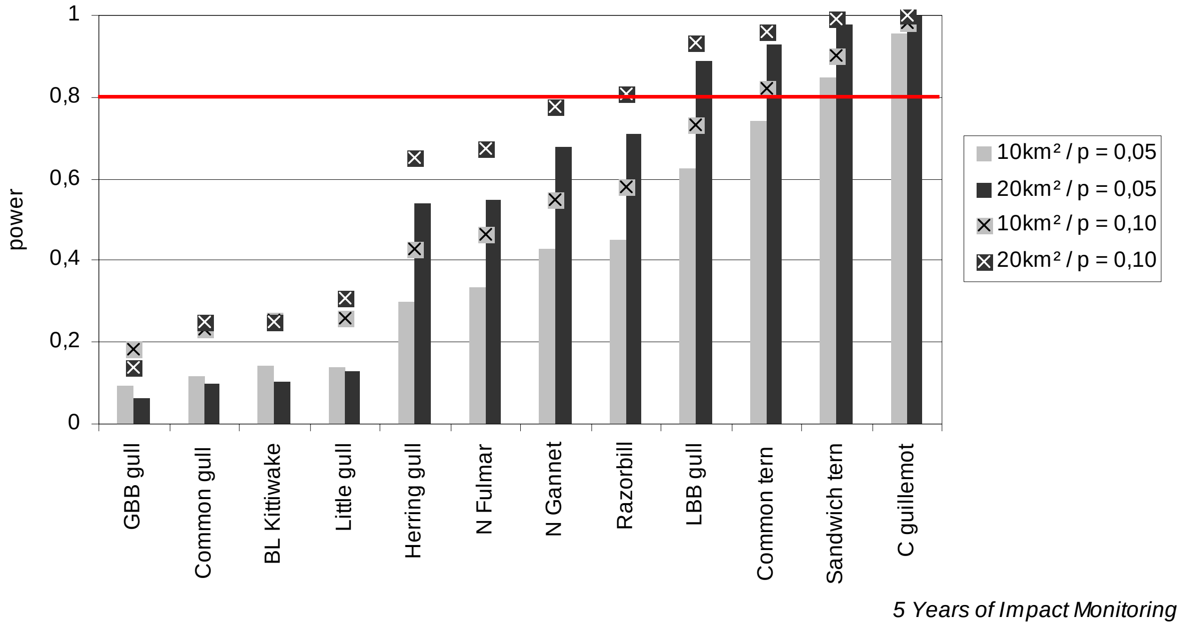

Figure 18. Calculated powers (1 000 simulations) for twelve species of seabird 5 years after the impact and a change in numbers of 50%, for varying monitoring intensities (10 versus 20 km²/month) and significance levels (0.05 versus 0.10), based on data gathered at the Thorntonbank.

To gain insight in how long monitoring should hold on, we calculated time series of power. This was done for three levels of decrease (30, 50 and 70%), assuming a monitoring intensity of 20 km² and applying a significance level of 0.10.

For a decrease of 30%, we reach a sufficient power (80%) after ten years for four seabird species, i.e. Common guillemot, Sandwich tern, Common tern and Lesser black-backed gull (Figure 19). Within the same period, it should be possible to detect a 50% change in four more species, namely Razorbill, Northern gannet, Northern fulmar and Herring gull. When a 70% decrease in numbers is simulated we may add Little gull, Common gull and Black-legged kittiwake to this selection, while for Great black-backed gull, the power does not reach 80% even after 15 years of impact monitoring.

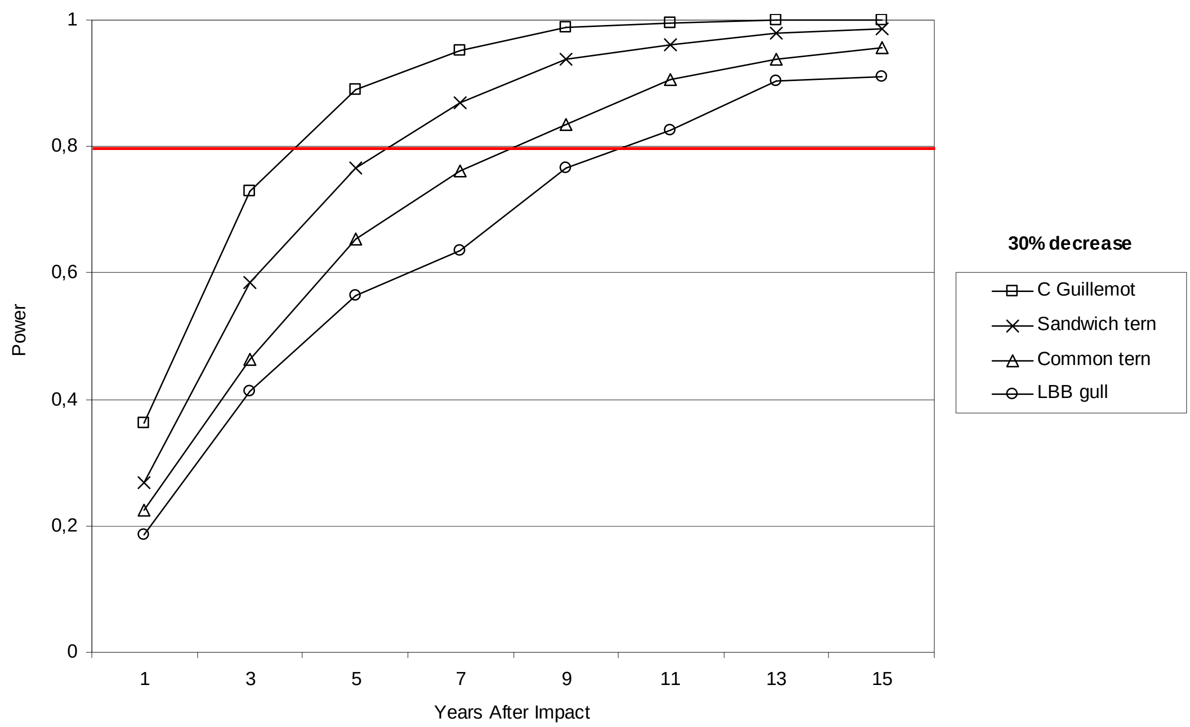

Figure 19. Time series of power results (significance level = 0.10 / 1 000 simulations) at the Thorntonbank wind farm area for four seabird species assuming a monitoring intensity of 20 km² per area per month, and a decrease in numbers of 30%.

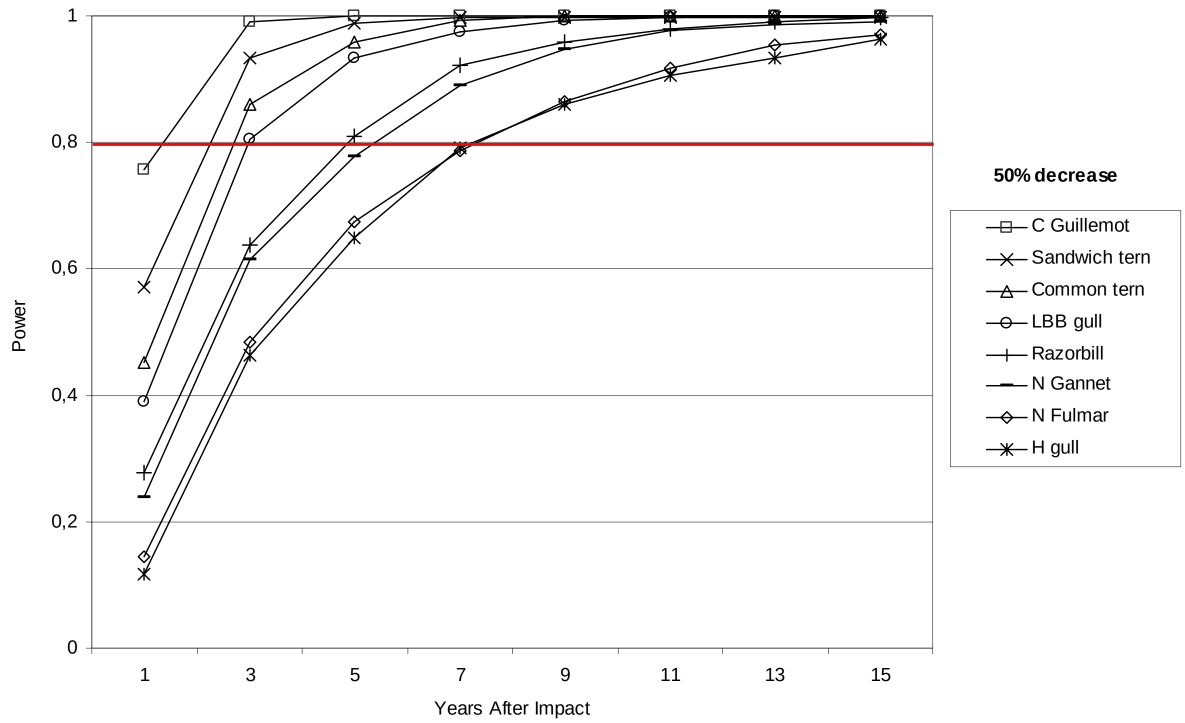

Figure 20. Time series of power results (significance level = 0.10 / 1 000 simulations) at the Thorntonbank wind farm area for eight seabird species assuming a monitoring intensity of 20 km² per area per month, and a decrease in numbers of 50%.

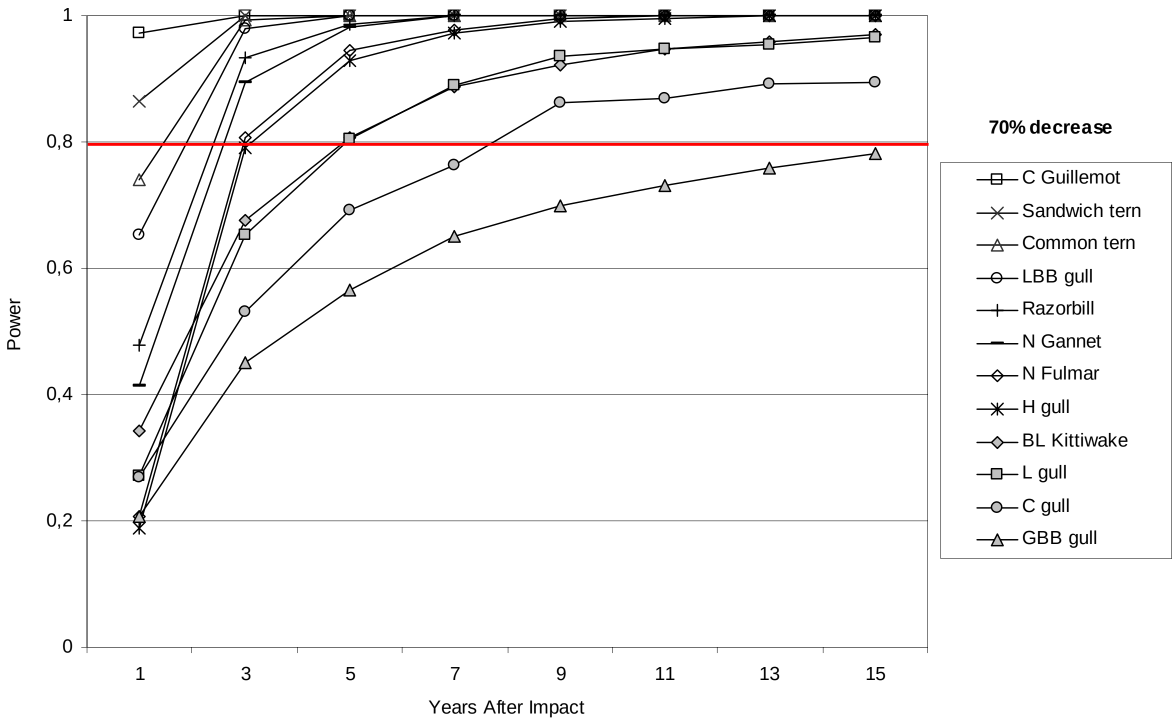

Figure 21. Time series of power results (significance level = 0.10 / 1 000 simulations) at the Thorntonbank wind farm area for twelve seabird species assuming a monitoring intensity of 20 km² per area per month, and a decrease in numbers of 70%.

9.3.2.3. Results impact analysis

Table 5 summarizes the test results of our impact analysis, while Figure 24 & Figure 25 offer a graphical view of the BACI results.

The only effects of turbine presence on bird densities that we have found are attraction effects in Sandwich and Common tern (Table 5). Numbers in the impact area increased with respectively 30 and 77%, while they dropped in the control area. For both species, we also detected a significant interaction between 'BA' and 'Seasonality', indicating a shift in seasonality pattern. After the impact, Sandwich tern was observed comparatively less during spring migration, while spring numbers of Common tern increased compared to the reference period (Figure 22).

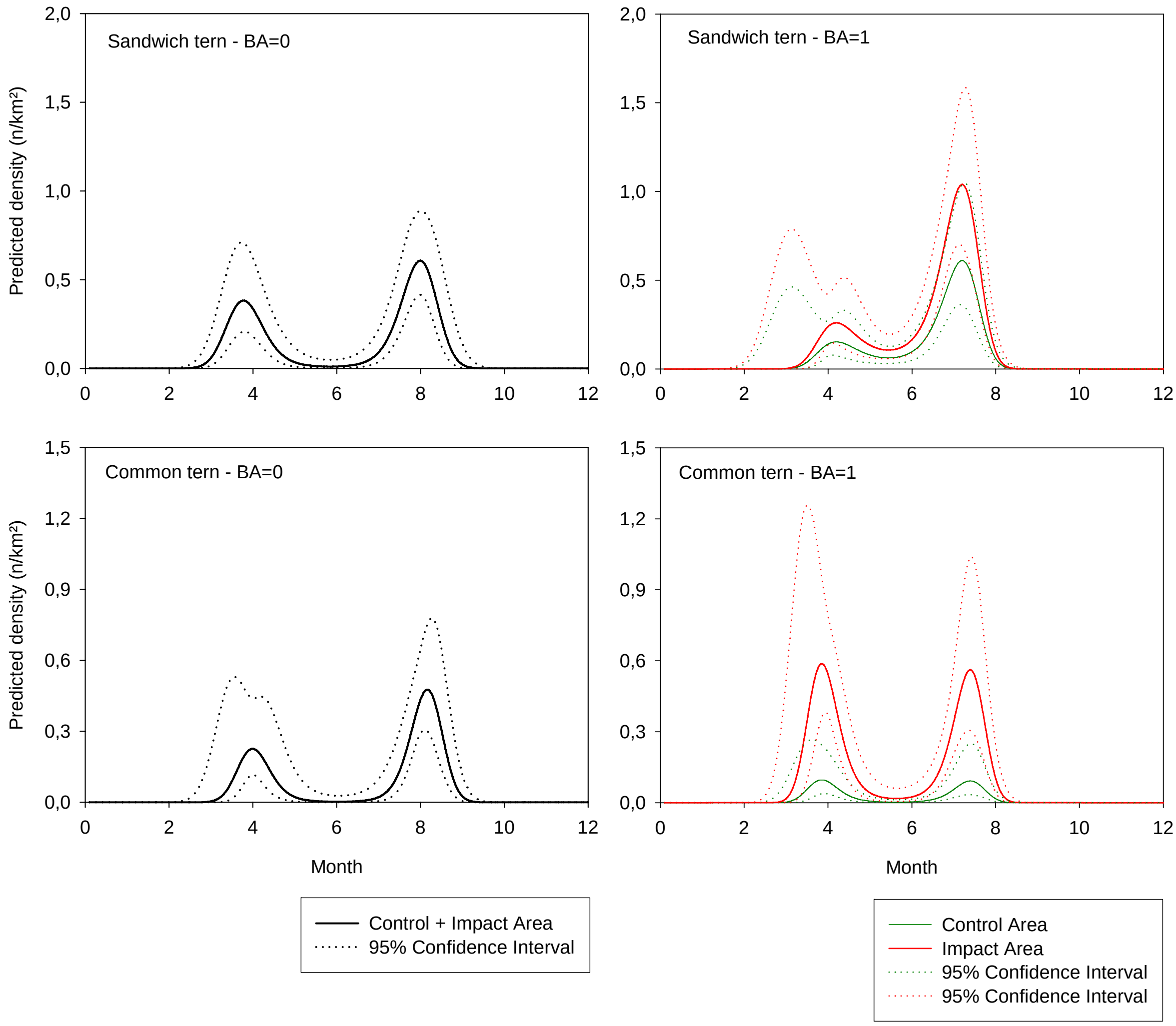

Figure 22. Predicted numbers for Sandwich and Common tern at the Thorntonbank study area according to the impact model.

Interaction effects were also detected in Little gull and Herring gull (Table 5). Peak numbers of Little gull have shifted from January/February to March/April. For Herring gull, numbers in the both areas have increased strongly, with a slight shift in seasonality between impact and reference area after impact (Figure 23). However, none of these effects can be addressed to the turbines' presence.

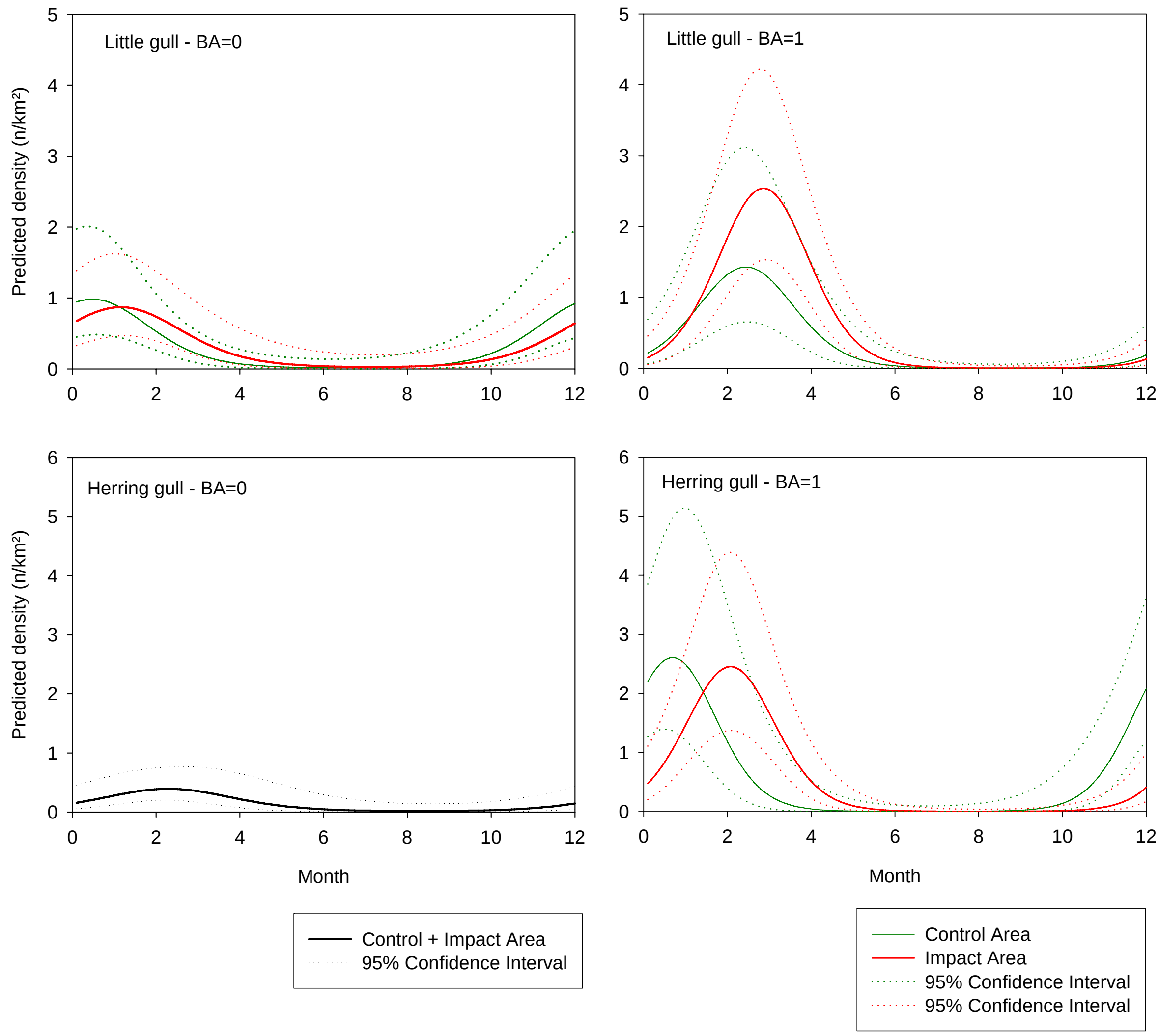

Figure 23. Predicted numbers for Little and Herring gull at the Thorntonbank study area according to the impact model.

In four other seabird species, numbers in the wind farm area have dropped significantly since the turbines' construction, but a comparable decrease was observed in the control area ('BA'-effect, see Table 5). This was the case for the 'true' seabirds, i.e. Northern fulmar, Northern gannet and both auk-species (Figure 25).

For Lesser and Great black-backed gull as well as Black-legged kittiwake, the models were not able to discern any effect (Table 5). This is more or less confirmed by the parallel BACI-graphs in Figure 24 in case of Great black-backed gull & Black-legged kittiwake, while a positive turbine effect could be suspected in Lesser black-backed gull.

In Common gull, the impact modelling resulted in highly unreliable predictions. Despite this, the geometric mean densities displayed in the BACI graph (Figure 24) suggest a possible avoidance effect.

Table 5.
Overview of the impact analysis results for the Thorntonbank wind farm area, including a hypothesis concerning displacement effect based on the preliminary impact dataset.

Species	**Turbine**	**p - value**	**Other effects**	**p - value**	**Hypothesis**
Sandwich tern	T	0.038	BA:Seasonalit	0.000	Attraction
Common tern	T	0.000	BA:Seasonalit	0.000	Attraction
Herring gull	T:Seasonality	0.001	BA:Seasonalit	0.014	No effect
Little gull	-	-	BA:Seasonalit	0.000	No effect
Northern Gannet	-	-	BA	0.014	No effect
Northern Fulmar	-	-	BA	0.011	No effect
Common guillemot	-	-	BA	0.000	No effect
Razorbill	-	-	BA	0.016	No effect
Lesser Black-backed gull	-	-	-	-	No effect
Great Black-backed gull	-	-	-	-	No effect
Black-Legged kittiwake	-	-	-	-	No effect
Common gull	/	/	/	/	?Avoidance?

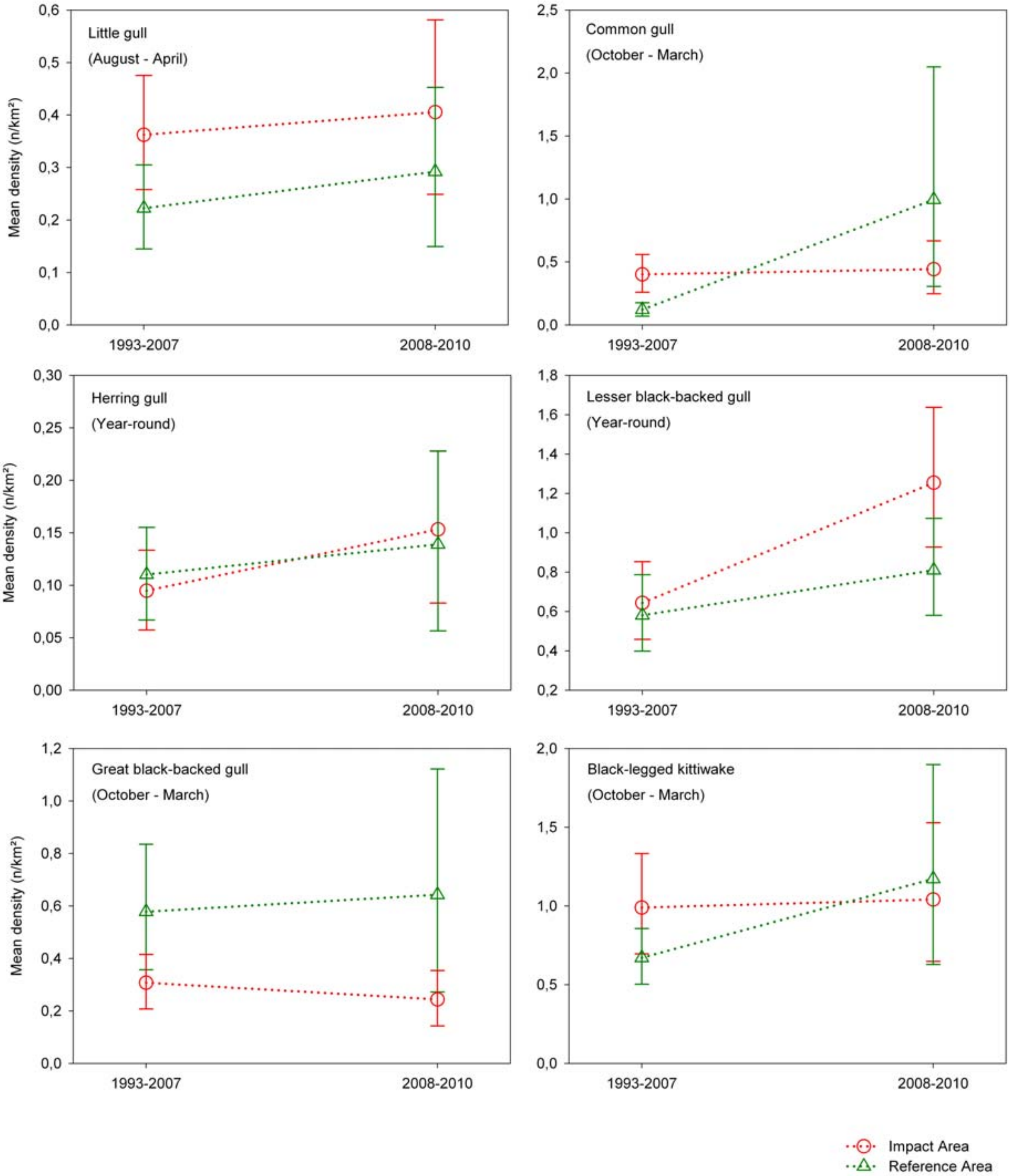

Figure 24. Geometric mean gull densities (+/- std. error) in the reference and impact area before and after the first turbines were built at the Thorntonbank.

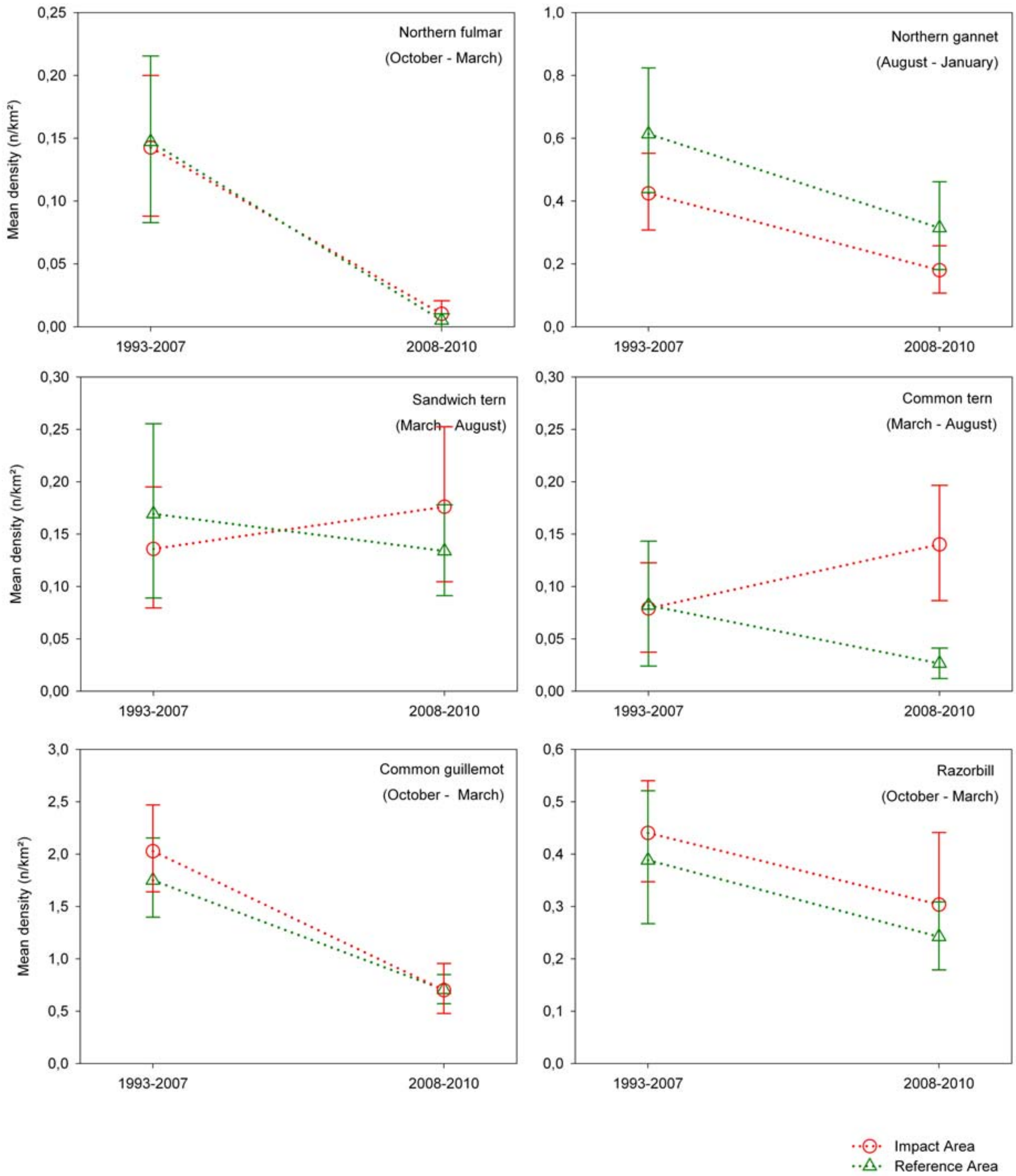

Figure 25. Geometric mean seabird densities (+/- std. error) in the reference and impact area before and after the first turbines were built at the Thorntonbank.

9.3.3. Bligh Bank

9.3.3.1. Reference situation

A significant seasonal pattern was found in four species, i.e. Northern gannet, Common gull, Black-legged kittiwake and Common guillemot. In the count results of Razorbill we detected an interaction effect (CI*Seasonality), while for Little gull there appears to be a 'CI'- as well as a

'Seasonality'-effect. For the five remaining study species, i.e. Northern fulmar, Great skua, Lesser black-backed, Herring and Great black-backed gull, the reference model is limited to the intercept (Table 7).

Table 6.
Test results for the reference model selection (based on the flowchart in Figure 10) for the Bligh Bank study area.

	Test Interaction	**Test CI**	**Test Seasonality (1)**	**Test Seasonality (2)**
Northern gannet	0.60	0.52	0.02	
Northern fulmar	0.68	0.81	0.08	
Great skua	0.25	0.67	0.16	
Little gull		0.00		0.00
Common gull	0.57	0.97	0.00	
Lesser black-backed gull	0.39	0.69	0.18	
Herring gull	0.79	0.85	0.29	
Great black-backed gull	0.98	0.23	0.67	
Black-legged kittiwake	0.31	0.31	0.04	
Common guillemot	0.63	0.19	0.00	
Razorbill	0.02			

As was the case at the Thorntonbank, we observed very high over-dispersion in some gull species (Great black-backed gull & Black-legged kittiwake), whereas Great skua and Herring gull were observed in very low densities (<0.1 birds/km²).

Table 7.
Predicted maximum abundances in the control and impact area, and the over-dispersion in the count data for eleven species of seabird at the Bligh Bank study area during reference years.

	Reference Model	**Max Abundance (n/km²) (Control Area)**	**Max Abundance (n/km²) (Impact Area)**	**Overdispersion factor**
Northern fulmar	Intercept	0.20	0.20	18.5
Northern gannet	Seasonality	0.84	0.84	13.5
Great skua	Intercept	0.04	0.04	2.0
Little gull	CI + Seasonality	0.10	0.97	1.35
Common gull	Seasonality	0.25	0.25	1.6
Lesser black-backed gull	Intercept	0.32	0.32	13.5
Herring gull	Intercept	0.08	0.08	3.6
Great black-backed gull	Intercept	0.30	0.30	224.0
Black-legged kittiwake	Seasonality	1.76	1.76	50.9
Common guillemot	Seasonality	3.60	3.60	13.4
Razorbill	CI * Seasonality	1.11	0.35	5.3

9.3.3.2. Results Power analysis

Figure 26 displays the calculated powers based on the available reference data gathered at the Bligh Bank, assuming a 50% decrease and a monitoring period of five years after impact. The results are less favourable than at the Thorntonbank (Figure 26). Again Common guillemot shows the best outcome, as this species occurs in moderately high densities with moderate over-dispersion. When monitoring intensity is increased to 20 km² per month, and the applied significance level is 0.10, power in Common gull and Northern gannet also reaches 80%. On the other extreme is Great black-backed gull with extremely low power due to low densities and extremely high over-dispersion. Surprisingly, Razorbill too shows poor power.

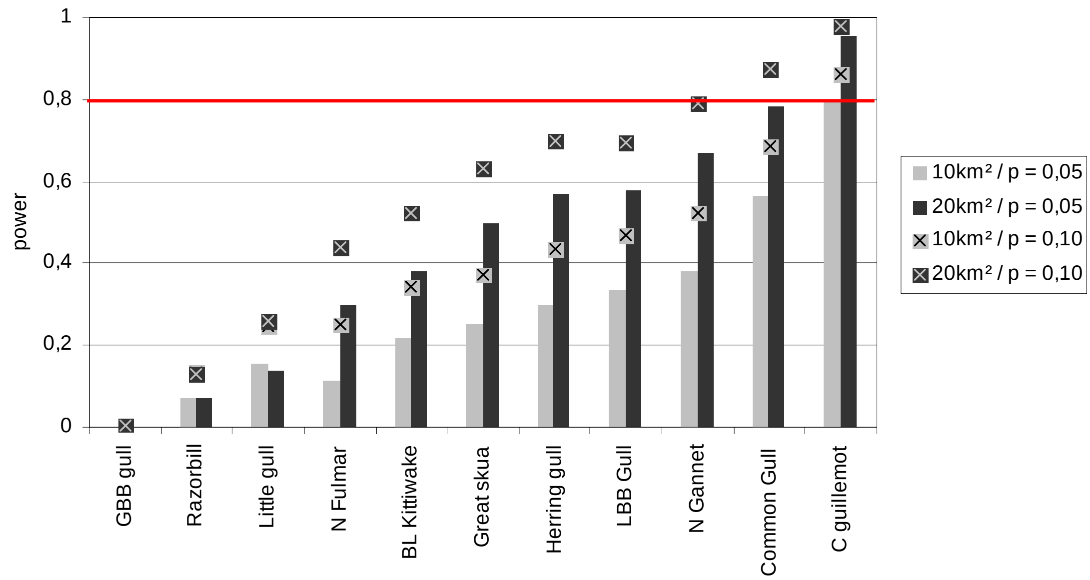

Figure 26. Calculated powers (1 000 simulations) for eleven species of seabird 5 years after the impact and a change in numbers of 50%, for varying monitoring intensities (10 versus 20 km²/month) and significance levels (0.05 versus 0.10), based on data gathered at the Bligh Bank.

When simulating a decrease in numbers of 50%, and given a monitoring intensity of 20 km² and a significance level of 0.10, our results show that only after ten years of monitoring, sufficient power (80%) is reached for six seabird species, being Common guillemot, Northern gannet, Great skua, Common, Lesser black-backed and Herring gull (Figure 28). To reach an 80% power level, we need 3 more years for Black-legged kittiwake and 5 more for Northern fulmar.

For Little gull, we observe a power of 80% after 7 years, assuming a drop in numbers of 70%, while for Razorbill this limit is reached only after fifteen years (Figure 29). Again, Great black-backed gull proves to be the worst monitoring species.

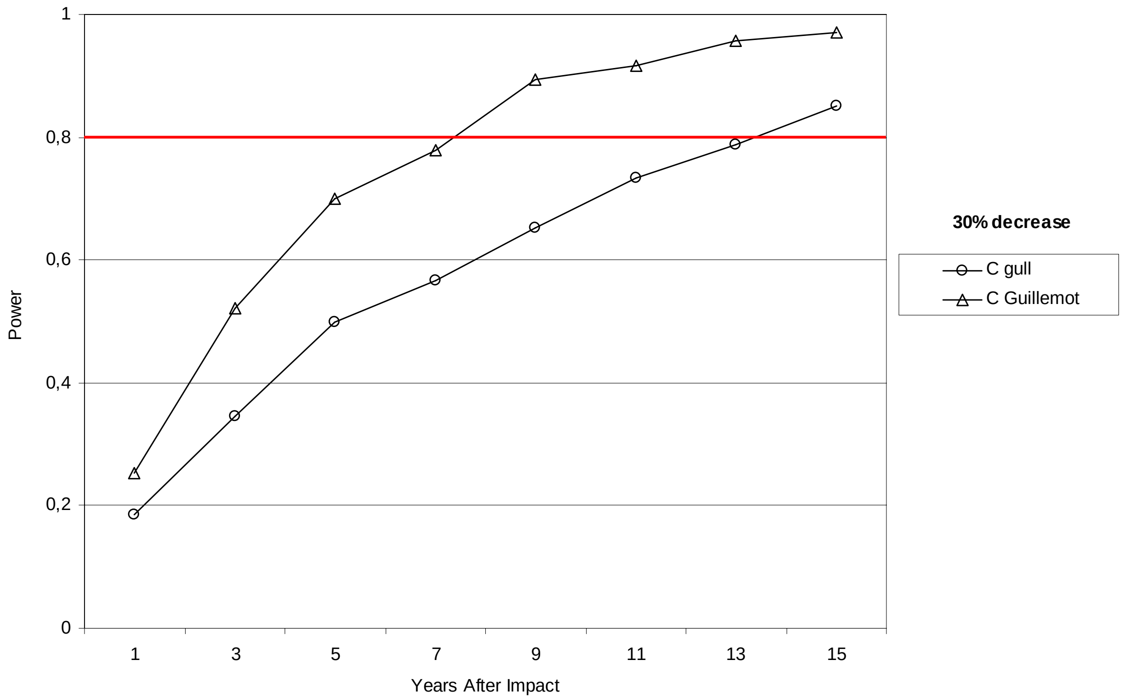

Figure 27. Time series of power results (significance level = 0.10 / 1 000 simulations) at the Bligh Bank wind farm area for two seabird species assuming a monitoring intensity of 20km² per area per month, and a decrease in numbers of 30%.

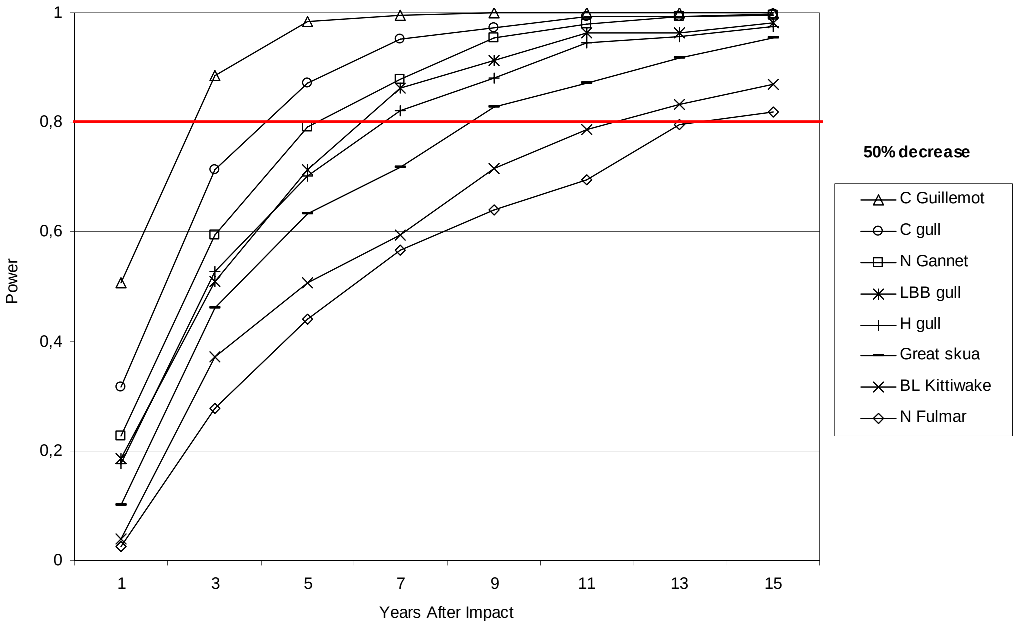

Figure 28. Time series of power results (significance level = 0.10 / 1 000 simulations) at the Bligh Bank wind farm area for eight seabird species assuming a monitoring intensity of 20km² per area per month, and a decrease in numbers of 50%.

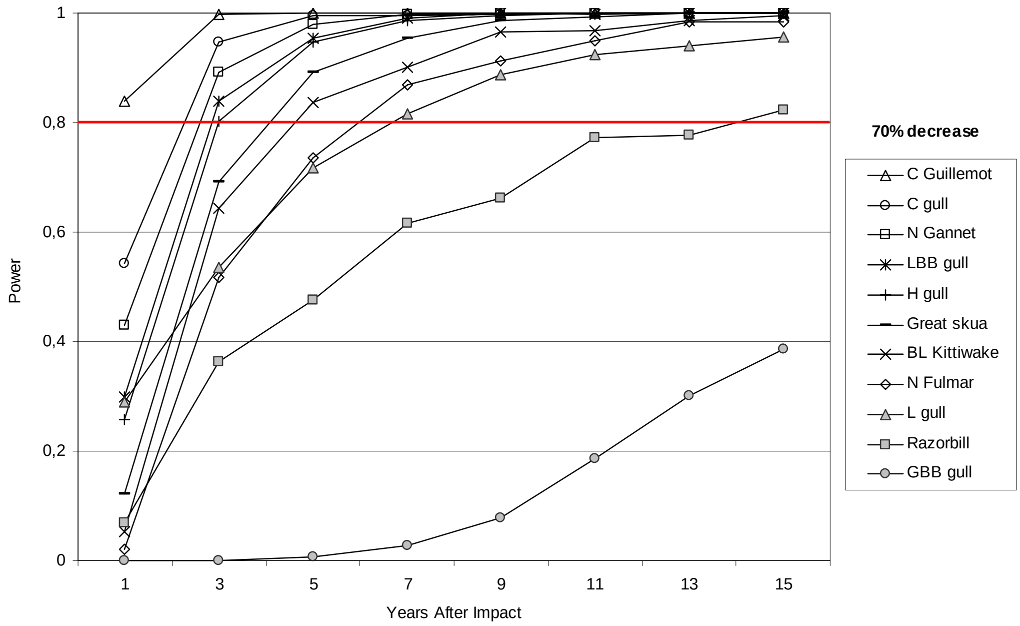

Figure 29. Time series of power results (significance level = 0.10 / 1 000 simulations) at the Bligh Bank wind farm area for eleven seabird species assuming a monitoring intensity of 20km² per area per month, and a decrease in numbers of 70%.

9.3.3.3. Results Impact analysis

Since we do not dispose of year-round data since the beginning of the impact period (see Figure 7), we could not perform reliable impact modelling for two species, i.e. Little gull and Razorbill. The BACI-graphs in Figure 31 & Figure 32 do suggest avoidance of Little gull and no effect in Razorbill.

Analysis of the impact data of the remaining species does show significant turbine effects in three species, being Common gull, Herring gull & Lesser black-backed gull. The BACI-graphs (Figure 31) learn that in case of Common and Herring gull this is due to a very high increase in numbers (with a factor 22 and 6 respectively) in the impact area as opposed to the reference area, indicating attraction to the wind farm. This pattern is mainly due to the results of the December campaign in 2010, when numbers of both species in the wind farm were extremely high, not only compared to the control area but compared to all other areas at the BPNS visited during three days of seabird monitoring (Figure 30).

In contrast, numbers of Lesser black-backed gull in the impact area remained more or less the same while they increased strongly in the control area, suggesting avoidance (explaining a negative 'T'-effect combined with a positive 'BA'-effect) (Figure 31).

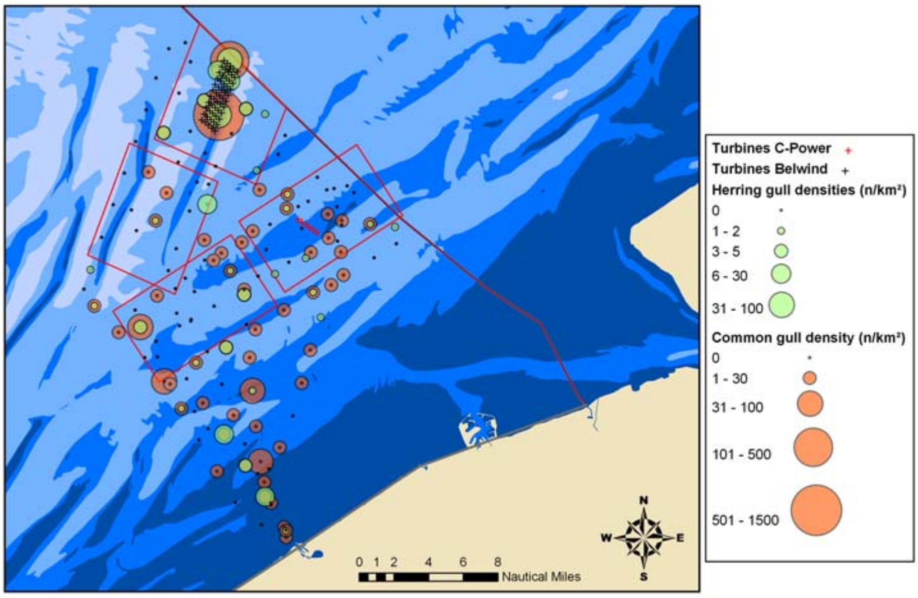

Figure 30. Distribution of Herring and Common gull during three monitoring days in December 2010.

Count results of Northern fulmar, Great skua, and Common guillemot only revealed a 'BA'-effect. As expected based on this result, the BACI-graphs of these species (Figure 32) display a general drop in observed numbers after construction, with a parallel trend in the impact and control area.

For the remaining three species no effects could be discerned, which seems plausible based on the BACI-graphs in case of Great black-backed gull and Black-legged kittiwake. In case of Northern gannet however, we observed a clear drop in numbers in the impact area, opposed to a slight increase in the control area (Figure 32), suggesting avoidance of the wind farm area.

Table 8.
Overview of the impact analysis results for the Bligh Bank wind farm area, including a hypothesis concerning displacement effect based on the preliminary impact dataset

Species	Turbine Effect	p-value	Other Effect	p-value	Hypothesis
Common gull	T	0.000			Attraction
Herring gull	T	0.001	-	-	Attraction
Lesser Black-backed gull	T	0.001	BA	0.000	Avoidance
Northern Fulmar	-	-	BA	0.021	No effect
Great skua			BA	0.010	No effect
Common guillemot	-	-	BA	0.001	No effect
Great Black-backed gull	-	-	-	-	No effect
Northern Gannet	-	-	-	-	?Avoidance
Black-legged kittiwake	-	-	-	-	No effect
Little gull	/	/	/	/	?Avoidance
Razorbill	/	/	/	/	?No effect?

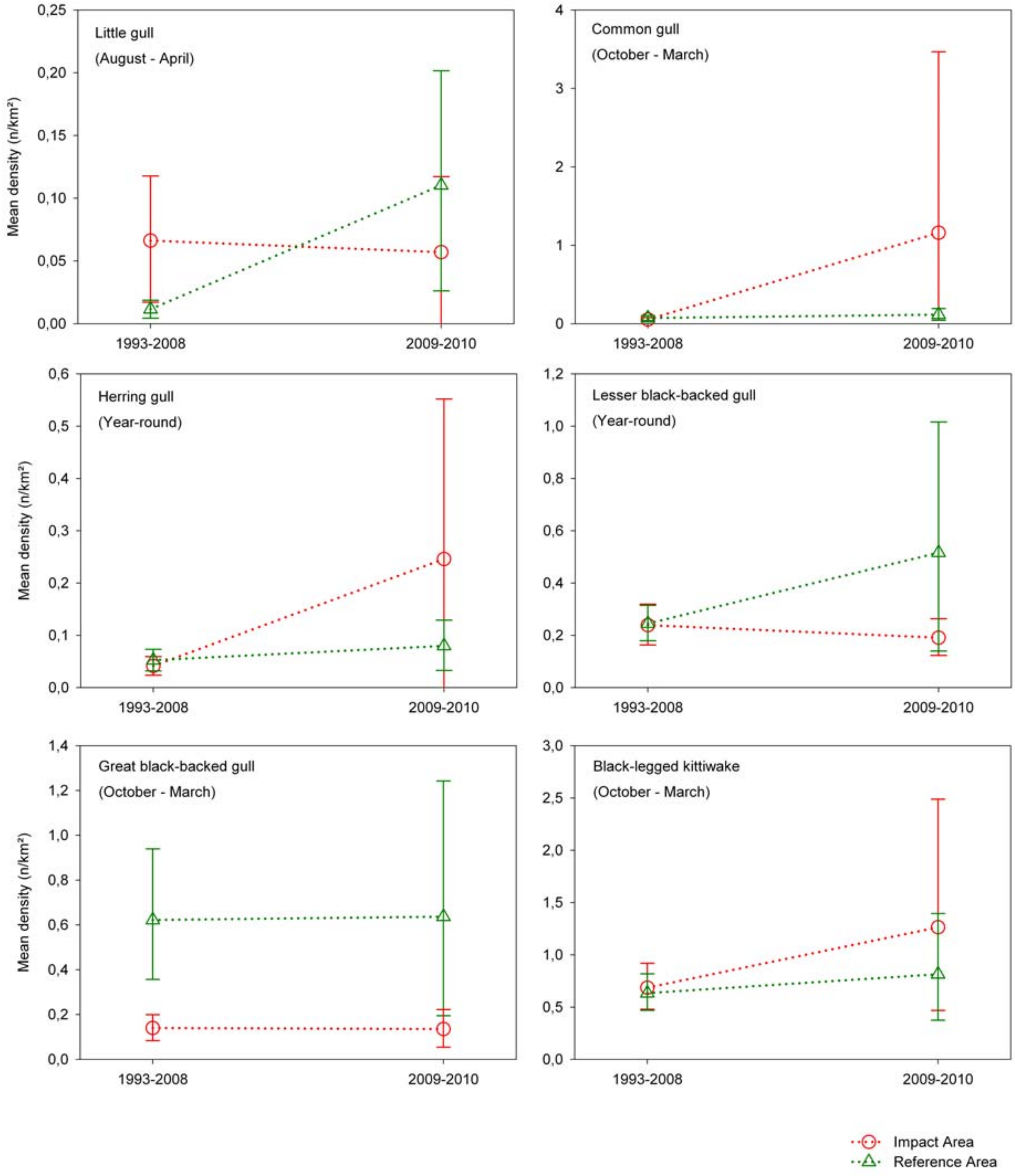

Figure 31. Geometric mean gull densities (+/- std. error) in the reference and impact area before and after the first turbines were built at the Bligh Bank.

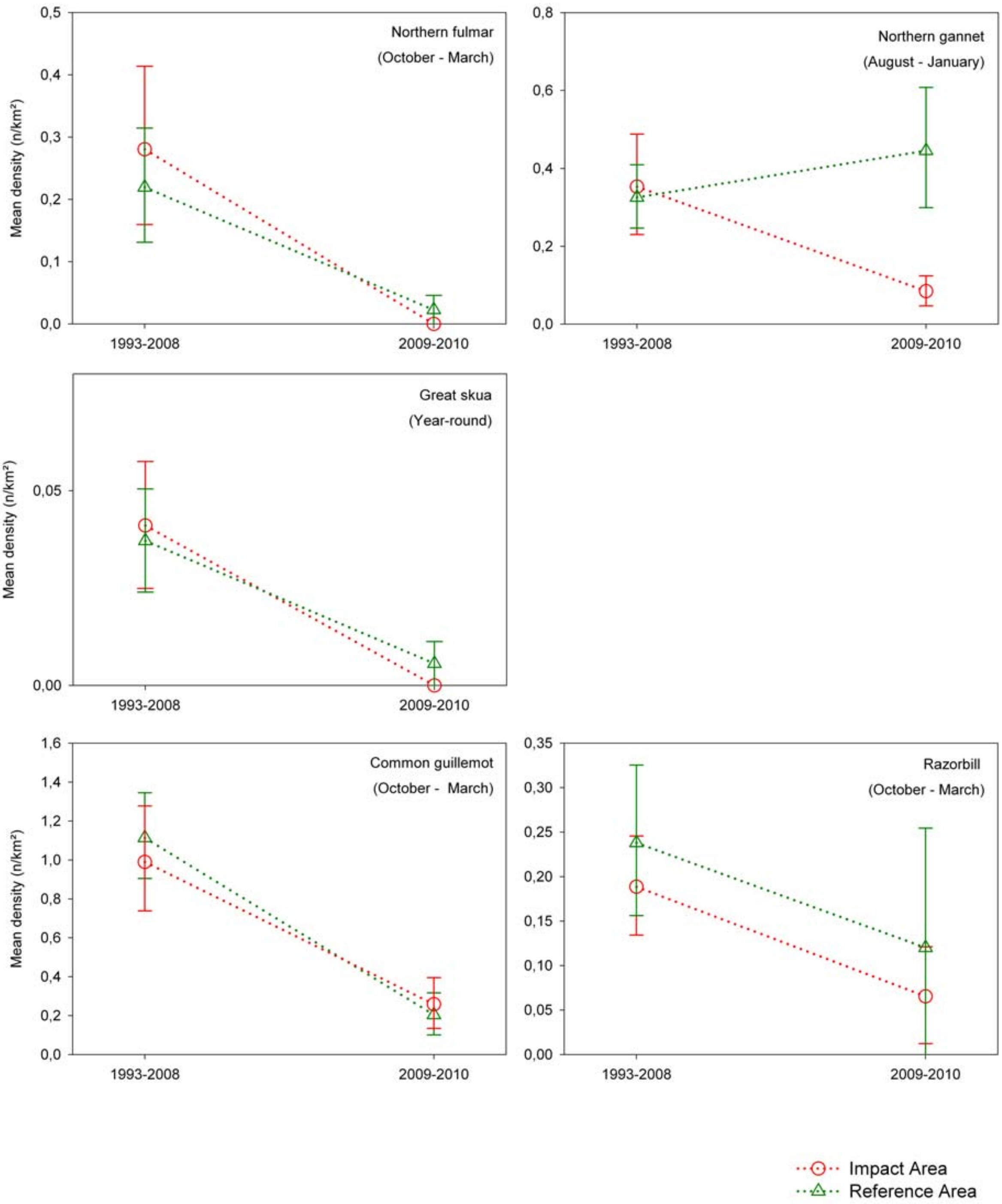

Figure 32. Geometric mean seabird densities (+/- std. error) in the reference and impact area before and after the first turbines were built at the Bligh Bank.

9.3.4. Synthesis of Impact modelling

Three years after the first construction works at the Thorntonbank wind farm area, we detected a significant increase in numbers of Sandwich and Common terns in the impact area as opposed to the reference area. Impact modelling was due to high unreliability not possible in Common gull, but the BACI-graph suggests an avoidance effect (indicated by question marks in Table 9). For none of the other species a turbine effect could be discerned, neither by the impact modelling, nor by visual interpretation of the geometric mean densities as displayed in the BACI-graphs (Figure 24 & Figure 25).

At the Bligh Bank study area, impact modelling showed a significantly positive effect in Common gull and Herring gull, while the opposite accounts for Lesser black-backed gull. Impact modelling did not detect any effect in Northern gannet, despite a clear drop in numbers in the impact area as opposed to the control area (see BACI-graph in Figure 32), which is why we do hypothesise avoidance by this species.

While impact modelling was not possible for Little gull and Razorbill due to lack of data, BACI-graphs suggest avoidance by Little gull and no effect in Razorbill (indicated by the question marks in Table 9).

Table 9.
Hypotheses on the displacement effects based on the preliminary impact datasets for the Thorntonbank and Bligh Bank wind farm areas.

Species	**Thorntonbank**	**Bligh Bank**
Northern Fulmar	No effect	No effect
Northern Gannet	No effect	?Avoidance?
Great skua		No effect
Little gull	No effect	?Avoidance?
Common gull	?Avoidance?	Attraction
Herring gull	No effect	Attraction
Lesser Black-backed gull	No effect	Avoidance
Great Black-backed gull	No effect	No effect
Black-legged kittiwake	No effect	No effect
Sandwich tern	Attraction	
Common tern	Attraction	
Common guillemot	No effect	No effect
Razorbill	No effect	?No effect?

9.4. Discussion

9.4.1. Power analysis

Underwood & Chapman (2003) state that the power in impact studies is affected by:

- the variability in the measurements
- the probability of a type I error
- the amount of sampling
- the effect size

In the scenario-based analysis we investigated the effect of the variability in the data by varying the over-dispersion factor. Also we tested how bird abundance and type of reference model affects the resulting power.

Next we calculated powers based on our actual observed reference data. Here, the variability is determined by the data records themselves, but we varied the effect size, the amount of sampling (number of years) and we calculated the power based on two levels of significance (0.05 & 0.10).

Indeed, our power results are negatively influenced by the over-dispersion factor (Φ), which expresses the way the data variance is related to the expected response value ($E(y)=\Phi * \sigma$). Since we spatially aggregated our count results per area, the over-dispersion will be largely due to the year-to-year variation, rather than a reflection of the clustering behaviour of the bird species involved. Also, when the model leaves a great deal of variance unexplained, this is inevitably reflected in the factor of over-dispersion. Therefore, it might not always be the best solution to ‘force’ a simple sine curve to the data. While for some species it is probably a true reflection of the actual field situation this does not necessarily hold true for *all* species. It might be interesting to additionally perform GAM modelling, since GAM's are data-driven rather than model-driven (Yee & Mitchell, 1991). This way, an asymmetric seasonal pattern for example, will be fitted better and far more easily than with an a priori defined sine curve. Preliminary tests already showed that GAM modelling in a quasi-poisson context resulted in consistently lower over-dispersion factors.

The more birds present per monitoring month, the higher the power. Hence there is a strong positive correlation between species abundance and the resulting power. But, more importantly, the same effect is obtained when monitoring intensity is increased, also resulting in more birds observed per monitoring month. Thus, counting more will result in better power, despite the fact that in our methodology, the data are condensed to only one record per area per month. By increasing monitoring intensity we may include more species of which we desire to detect certain changes within a certain time frame.

It is also possible to extent this time frame to increase the power. For equal total survey efforts, we found that prolonging the impact monitoring period (for example 5 km² / 10 years) gives slightly better results, as compared to intensifying the counts (10 km² / 5 years). Since time is of crucial importance in impact studies aiming to function as early warning systems, intensifying the counts should nevertheless be preferred over prolonging the survey.

Finally, we tested how the power of our impact analysis reacted on different types of seabird occurrence during the reference years, resulting in three different reference models ('Seasonality', 'CI+Seasonality' & 'CI*Seasonality').

The model without an area effect performed best, while the other two models resulted in much lower powers. This finding shows the importance of delineating a control area which is highly comparable to the impact area regarding seabird numbers and seasonality. Underwood & Chapman (2003) state that to detect 'press' impacts it requires a maximum number of control locations. Within the BPNS however, each area hosts its own characteristic seabird community, varying throughout the year, and delineating other suitable control areas is therefore very difficult.

For both wind farms, we calculated powers based on the characteristics of the true reference data. At the Thorntonbank, a monitoring period of 5 years after impact should be enough (power >= 80%) to detect a 50% change in numbers of 3 species, being Common guillemot, Sandwich tern and Common tern, given a monitoring intensity of 10 km² and a significance level of 0.05. Common guillemot is a common species occurring in predictable and high numbers throughout the winter season, and was expected to perform best as a monitoring species. We are happy to also be able to include Annex I species Common and Sandwich tern, for both of which the area was found to be of particular importance during the reference study (Vanermen and Stienen, 2009). Both species occur in relatively low numbers, but since the data exhibit low over-dispersion, power scores high.

Doubling the monitoring intensity from 10 to 20 km², adds only one more species to this selection, being Lesser black-backed gull. This species often shows extremely high spatial over-dispersion, and may therefore not be the promising monitoring bird it appears to be based on the power results presented here.

When we want to add more species of which we desire to detect a 50% change, we should prolong the monitoring period to at least eight years and apply a significance level of 0.10, thus adding Razorbill, Northern gannet, Northern fulmar and Herring gull.

Power scores very low for the remaining four species, caused by the type of reference model (including an area and/or interaction effect) that is applied to simulate the random impact data sets. Interestingly, when we perform the simulations with a model *without* an area effect, powers score much higher, even when still applying the same complex impact model to test for the turbine effect (BA:CI). Hence the poor outcome results from 'extending' the area effect observed in the reference period into the impact period, which may not always be a true reflection of the field situation. Indeed, in case of a shift in seasonality as observed in Little gull (see Figure 16) one can wonder if this is in fact a true reflection of reality. Observed seasonality patterns result from the large scale migration phenomenon, and it seems unlikely that differences occur at such a small scale if not induced by coincidence. Still, care is needed, since within the scale of the BPNS, Little gull does shows different seasonality patterns offshore compared to onshore areas. We cannot change our reference data, but for the purpose of random impact data simulation, it may be better to use a more general reference model.

At the Bligh Bank, observed numbers of seabirds are generally lower than at the Thorntonbank, resulting in lower statistical power. Assuming a monitoring intensity of 10 km², Common guillemot is the only species for which we will be able discern a decrease in numbers of 50% after 5 years. After 8 years, we may add 4 more species, being Common gull, Northern gannet, Lesser black-backed and Herring gull, provided that monitoring intensity equals 20 km² and that we apply a significance level of 0.10.

At first sight, the power results in this study seem to be rather low, and one can argue if we should be satisfied with these outcomes. Extremely important in this respect is to realise that not being able to detect a certain change *does not mean that there is no effect*!

McLean *et al*. (2006 and 2007) conducted a comparable study on long-time series of aerial survey counts of five seabird species (Red-throated diver, Common scoter, Sandwich tern, Lesser & Great black-backed gull). The (hypothetical) monitoring set-up in this study is quite different from the one presented here. The authors calculate the power of detecting changes within a study area of varying size (2x2 km², 5x5 km² etc.), with the hypothetical wind farm located in the centre. The study investigates the effect of the gradient of decline (uniform, or gradually), spatial scale, survey intensity, survey duration, inclusion of spatial variables and inclusion of reference areas. McLean *et al*. (2007) concluded that "the statistical power to detect a 50% change in birds numbers remains low (<85%) for all species irrespective of the length of time over which monitoring is carried out", for significance levels of 0.20.

Indeed, the cheapest and easiest way to pull up the power of any impact analysis is to apply a higher significance level than the conventional 0.05. Here, the significance level represents the chance wrongly concluding that the turbines are causing an impact, while in fact they are not ('type I error'). As is known, a stringent significance level goes at the expense of the power, resulting that potential impacts may go unnoticed (Underwood and Chapman, 2003). This of course is not advisable, as we wish our study to function as an early warning system, and slightly increasing the significance level from 0.05 to 0.10 is therefore perfectly justified.

Concluding, by maximizing monitoring intensity and monitoring period, we can increase the power of our impact study to an acceptable level for most seabird species. However, there are clear logistic limitations. During the intensive monitoring program of the last few years, monitoring intensity was about 14 km² per area per month at the Thorntonbank and 12 km² at the Bligh Bank. Unfortunately, regarding the use of research vessels we are now at the top of our possibilities. One possible solution is to focus all energy on one wind farm area, which however would be a pity since a monitoring set-up with two impact and two control sites is clearly more valuable. Otherwise it could be possible - whenever visibility allows so - to increase the transect width, and to count along both sides of the ship. This way monitoring intensity could possibly be increased with 50%.

9.4.2. Impact study Thorntonbank

The only two species in which we detected a significant turbine effect were Sandwich tern and Common tern. Since 2008, numbers of both species increased in the impact area, which was not the case in the control area, indicating attraction to the turbines. Presently, only 6 out of 54 turbines are in place, and it would be too easy and too soon to address this increase to the turbines' presence. On the other hand, clear positive effects on fish communities are already visible (Reubens *et al*., 2010), possibly also affecting higher trophic levels.

For none of the other species a turbine effect could be proven, despite slight indications of avoidance in Common gull.

As mentioned, 48 more turbines still have to be built in the impact area, but ironically, 'impact' monitoring is already going on for three years. Continuing to apply a two-level factor variable simply indicating turbine presence or absence is therefore not feasible. In order to be able to compare the effect of 6 with that of 54 turbines, we may include the turbine effect as a continuous variable, representing the number of turbines actually in place.

9.4.3. Impact study Bligh Bank

Significant turbine effects were detected in three species, being Common gull, Herring gull, Lesser black-backed gull. In case of Common and Herring gull this is a positive effect suggesting attraction to the wind farm. We need to say that this finding is mainly based on the results of one monitoring month (December 2010) when numbers of both species in the wind farm were extremely high, not only compared to the control area but compared to all other areas visited during three days of seabird monitoring. In January 2011, almost no birds were present in the wind farm, while in February, we again observed increased numbers of gulls. Considering the limited impact dataset, it is too soon to draw any firm conclusions, but the near future should reveal if these gulls are in fact attracted by the turbines' presence.

For Lesser black-backed and Little gull, the BACI graphs show that numbers in the impact area remained more or less the same while numbers in the control area increased strongly. Again, it is too soon to state that this is due to avoidance of the wind farm area. For none of the other species, the impact analysis detected a turbine effect, which is confirmed by the BACI graphs, displaying parallel trends in numbers in the impact and control area.

9.5. References

Clarke, E.D., Spear, L.B., McCracken, M.L., Marques, F.F.C., Borchers, D.L., Buckland, S.T. & Ainley D.G., (2003). Validating the use of generalised additive models and at sea surveys to estimate size and temporal trends of seabird populations. Journal of Applied Ecology 40: 278-292.

Desholm, M., (2005). Wind farm related mortality among avian migrants – a remote sensing study and model analysis. PhD thesis. Dept. of Wildlife Ecology and Biodiversity, NERI, and Dept. of Population Biology, University of Copenhagen. National Environmental Research Institute, Denmark.

Drewitt A.L. & Langston R.H.W., (2006). Assessing the impact of wind farms on birds. Ibis 148: 29-42.

Everaert, J. & Stienen, E.W.M., (2006). Impact of wind turbines on birds in Zeebrugge – significant effect on breeding tern colony due to collisions. Biodiversity and Conservation 15 (10): 3345-3359.

Lapeña, B.P., Wijnberg, K.M., Hulscher, S.J.M.H. & Stein A., (2010). Environmental impact assessment of offshore wind farms: a simulation-based approach. Journal of Applied Ecology 47: 1110-1118.

McCullagh, P. & Nelder, J.A., (1989). Generalised linear models (2nd edition), London, Chapman and Hall.

McDonald, T.L., Erickson, W.P. & McDonald, L.L., (2000). Analysis of Count Data from Before-After Control-Impact studies. Journal of Agricultural, Biological and Environmental Statistics 5(3): 262-279.

McLean, I.M.D., Skov, H., Rehfisch, M.M. & Piper, W., (2006). Use of aerial surveys to detect bird displacement by offshore wind farms. BTO Research Report No. 446 to COWRIE. BTO, Thetford.

McLean, I.M.D., Skov, H. & Rehfisch, M.M., (2007). Further use of aerial surveys to detect bird displacement by offshore wind farms. BTO Research Report No. 482 to COWRIE. BTO, Thetford.

Onkelinx, T., Bauwens, D. & Quataert, P., (2008). Potentie van ruimtelijke modellen als beleidsondersteunend instrument met betrekking tot het voorkomen van watervogels in de Zeeschelde – Statistisch luik. Unpublished report.

Pettersson, J., (2005). The impact of offshore wind farms on bird life in Kalmar Sound, Sweden. A final report based on studies 1999-2003. Ecologiska Institutionen, Lunds Universitet, Sweden. 128 pp.

Petersen, I.K., Christensen, T.K., Kahlert, J., Desholm, M. & Fox, A.D., (2006). Final results of bird studies at the offshore wind farms at Nysted and Horns Rev, Denmark. Report Request.

Commissioned by DONG energy and Vattenfall A/S. National Environmental Research Institute, Ministry of the Environment, Denmark. 79 pp.

Potts, J.M. & Elith, J. (2006). Comparing species abundance models. Ecological Modelling 199: 153-163.

Reubens, J.T., Degraer, S. & Vincx, M. (2010). The importance of marine wind farms, as artificial hard substrata, for the ecology of the ichtyofauna. *In:* Degraer, S., Brabant, R. & Rumes, B., (2010). Offshore wind farms in the Belgian part of the North Sea. Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 6: 69-82.

Stienen, E.W.M., Van Waeyenberge, J., Kuijken, E. & Seys, J. (2007). Trapped within the corridor of the Southern North Sea: the potential impact of offshore wind farms on seabirds. In: Birds and Wind Farms - Risk assessment and Mitigation (eds. de Lucas M., Janss G.F.E. & Ferrer M.), p71-80. Quercus, Madrid, Spain.

Tasker, M.L., Jones, P.H., Dixon, T.J. & Blake, B.F., (1984). Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardised approach. Auk 101: 567-577.

Underwood, A.J. & Chapman, M.G., (2003). Power, precaution, Type II error and sampling design in assessment of environmental impacts. Journal of Experimental Biology and Ecology 296: 49-70.

Vanermen, N. & Stienen, E.W.M., (2009). Seabirds & Offshore Wind Farms: Monitoring results 2008. Report INBO.R.2009.8, Research Institute for Nature and Forest, Brussels. *In:* Degraer S. & Brabant R. (Ed.), (2009). Offshore wind farms in the Belgian part of the North Sea: State of the art after two years of environmental monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 8: 151-221.

Vanermen, N., Stienen, E.W.M., Onkelinx, T., Courtens, W., Van de walle, M. and Verstraete, H. (2010) Monitoring seabird displacement: a modelling approach. Report INBO.R.2010.12, Research Institute for Nature and Forest, Brussels. *In:* Degraer S., Brabant R. & Rumes B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea. Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 9: 133-152.

Yee, T. & Mitchell, N.D., (1991). Generalised additive models in plant ecology. Journal of Vegetation Science 2: 587-602.

Chapter 10. Offshore wind farm impact assessment: monitoring of marine mammals during 2010

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View on one of the bubble windows of the aerial surveillance aircraft.

Photo J. Haelters / RBINS / MUMM

Abstract

As in previous years, the temporal and spatial distribution of marine mammals was monitored in the framework of the assessment of possible environmental effects of the construction and exploitation of offshore wind farms. As the only common marine mammal in Belgian waters is the harbour porpoise *Phocoena phocoena*, monitoring focused on this species. A combination of methods was used to obtain information on harbour porpoises. Aerial surveys allow to make snapshots of the distribution and density of marine mammals, relative to the location of the wind farm areas and planned activities. The use of passive acoustic monitoring (PAM) devices can reveal local mid- to long-term changes in the presence of harbour porpoises at selected locations, occurring naturally or due to human activities. Finally, the use of strandings data allow for assessing yearly and seasonal patterns in the presence of the harbour porpoise in Belgian waters. As virtually no pile driving, considered as of particular concern to marine mammals, took place in 2010, the monitoring focused on the seasonal variation and the geographical distribution of harbour porpoises, particularly in relation to the timing of future piling activities and the location of the current wind farm projects, and on ecological parameters.

The results of the 2010 monitoring confirmed that the harbour porpoise is common in Belgian waters during late winter and early spring, both inshore and offshore. However, they also demonstrated a relatively high number of animals in the area outside Belgian (12 nm) territorial waters during early summer. Strandings were more evenly distributed over the year than during the first years of the 21st century. Peaks in strandings occurred in spring and late summer-early autumn, and low numbers of porpoises washed ashore in June-July and between November and February.

The results indicated that it remains difficult to predict the occurrence of harbour porpoises in Belgian waters outside the late winter-early spring period, in which their presence has been fairly stable over the last decade. Erratic invasions of a relatively large number of animals in Belgian waters can occur, and this should be taken account of in monitoring activities, and in the management of potentially harmful activities.

Samenvatting

Zoals in vorige jaren werd de temporele en spatiale verspreiding van zeezoogdieren onderzocht in het kader van de inschatting van de mogelijke effecten van de constructie en expoitatie van offshore windparken. Gezien de bruinvis *Phocoena phocoena* het enige zeezoogdier is dat algemeen voorkomt in het Belgische deel van de Noordzee, ligt de focus van het onderzoek bij deze soort. Er werd een combinatie van methoden gebruikt om informatie te verzamelen. Luchtsurveys laten toe om *ad hoc* informatie te bekomen over de verspreiding en dichtheid van zeezoogdieren, relatief tot de windparkgebieden en geplande activiteiten. Passieve akoestische monitoring (PAM) laat toe plaatselijke veranderingen, veroorzaakt door menselijke activiteiten of natuurlijke fenomenen, aan te tonen in de aanwezigheid van bruinvissen op middellange tot lange termijn. Tenslotte kan een analyse van strandingsgegevens jaarlijkse en seizoenale trends aantonen in het voorkomen van de bruinvis in Belgische wateren. Gezien vrijwel geen palen geheid werden in 2010 – een activiteit waarvoor in het bijzonder bezorgdheid bestaat voor wat betreft de mogelijke effecten op zeezoogdieren – spitste het onderzoek zich in 2010 toe op het onderkennen van ecologische parameters, en het aantonen van seizoenale en spatiale variaties in de verspreiding van bruinvissen, in het bijzonder in het kader van toekomstige hei-activiteiten en de locatie van de huidige windparkprojecten.

De resultaten van de monitoring in 2010 bevestigen dat de bruinvis algemeen voorkomt in Belgische wateren tijdens de late winter en de vroege lente, zowel dicht bij de kust als verder offshore. Er werden echter tijdens de vroege zomer relatief veel bruinvissen waargenomen buiten de territoriale wateren. Strandingen waren meer gelijkmatig verspreid doorheen het jaar dan tijdens de eerste jaren van de 21^{e} eeuw. Pieken in strandingen traden op tijdens de lente en de late zomer - vroege herfst. Lage aantallen gestrande dieren werden geteld in juni en juli, en tussen november en februari.

De resultaten van de monitoring tonen aan dat het moeilijk blijft voorspellingen te maken over het voorkomen van de bruinvis in Belgische wateren, buiten de periode van de late winter tot vroege

lente, wanneer hun voorkomen tamelijk stabiel bleef gedurende het voorbije decennium. Erratische invasies van een relatief groot aantal dieren in Belgische wateren zijn mogelijk. Hiermee moet rekening gehouden worden bij monitoring, en bij het beheer van potentieel schadelijke activiteiten.

10.1. Introduction

Concerns exist about the possible consequences of the construction and operation of offshore wind farms on marine mammals. The scale and number of projects, especially in the southern part of the North Sea, is impressive. As the most common marine mammal in Belgian waters is – by far – the harbour porpoise *Phocoena phocoena*, and as it is very sensitive to disturbance, monitoring focuses on this species. It is well known that pile driving can disturb harbour porpoises up to distances of tens of km (Brandt *et al.*, 2009; 2011; Tougaard *et al.*, 2009a), and that acute physiological effects are possible in individual animals. The population effects of the disturbance of a relatively large number of individuals remain largely unknown. Also, possible chronic effects on marine mammals during the operational phases of the projects can be considered as a gap in our knowledge.

Given that virtually no pile driving was undertaken in 2010, the only effects – if any - could be expected in the form of a different distribution in and outside operational wind farms. As the underwater noise levels during the operational phase of offshore wind farms are much lower than during the construction phase (Norro *et al.*, 2010; 2011), effects are expected to be more localized (Madsen *et al.*, 2006; Tougaard *et al.*, 2009b; Scheidat *et al.*, 2011). It is even possible that positive effects occur, with porpoises preferring wind farm areas due to a diminished disturbance from shipping, and an increased availability of prey due to the fact that no fishing takes place within the wind farm and artificial substrates exist, attracting and increasing potential prey (Reubens *et al.*, 2010). However, within the current monitoring programme, small-scale effects of operational wind turbines on the presence of marine mammals are hard to detect, certainly for a shy and inconspicuous species such as the harbour porpoise. As such, the results of the monitoring during 2010 focused on spatial-temporal aspects of the harbour porpoise in Belgian waters, and on the possible consequences for future offshore wind farm planning. It remains challenging to discern natural changes in the distribution and seasonal occurrence of this highly mobile marine mammal from changes induced through anthropogenic activities.

10.2. Material and Methods

10.2.1. Aerial surveys

In 2010, a Norman Britten Islander aircraft, property of the RBINS, was used for aerial surveys of marine mammals. This aircraft is equipped with two bubble windows, and its GPS position is recorded every two seconds. The methodology that was used is line transect sampling (Buckland *et al.*, 2001). The track lines of the surveys were parallel, and perpendicular to the coastline, and had an interspacing of 5 km. For practical reasons, tracks started at 5 km from the coast (Haelters, 2009), and included a small part of the adjacent French waters. The flight altitude was 600 ft, and the speed was kept constant at around 100 kts. The length of the tracks ranged from 9 to 34 nm.

Two observers on board continuously observed the water surface for the presence of marine mammals. For every sighting they recorded the species, number, activity and the angle of the observed animals perpendicular to the aircraft. In total, four complete surveys were performed in nine flights during 2010, totalling a survey length of 1405 nautical miles and 15 hours 9 minutes on task (Table 1). Large deviations in wind speed and direction (Table 2) during one day were partly due to the different airfields where take-off and landing took place (Ostend or Antwerp). Some flights were interrupted for documenting oil slicks; other flights (not presented in Table 1) or one or more tracks during a survey were discontinued due to the onset of adverse observing conditions (wind, fog, glare). Due to the temporary unavailability of the aircraft and adverse meteorological conditions, no flights could be carried out between late summer and winter.

Table 1.
Overview of the dates, timing, number of tracks and observation conditions of the aerial survey flights carried out during 2010. The time on task includes the short time between the end of one track and the start of the next.

Date	Flight time	On task	Off task	Time on task	Number of tracks	Observation conditions	Remarks
07 Jan 10	2:28	8:53	10:43	1:50	8	Good to poor	
07 Jan 10	2:00	12:41	13:55	1:13	6	Good to poor	
17 Feb 10	2:00	10:24	12:14	1:49	6	Good to moderate	
02 Mrt 10	3:45	9:40	12:05	2:24	7	Good to moderate	
23 Mrt 10	2:35	12:43	14:44	2:00	6	Good to poor	
24 Mrt 10	2:19	10:31	10:58	0:26	4	Good to poor	Flight interrupted
30 Mrt 10	3:15	7:44	9:10	1:26	3	Good to poor	
08 Jul 10	2:35	8:38	10:39	2:01	6	Good to moderate	
08 Jul 10	3:01	12:37	14:39	2:02	7	Good to moderate	

Table 2.
Overview of the meteorological conditions (wind, seastate) during the successful surveys in 2010 (a and b indicate the first and second flight of the day respectively).

Date	Wind take-off		Wind landing		Seastate
	Dir (°)	Speed (kts)	Dir (°)	Speed (kts)	
07 Jan 10a	190	3	180	8	2-3
07 Jan 10b	180	9	120	3	2-3
17 Feb 10	100	4	80	2	1-2
02 Mrt 10	280	4	310	12	1-2
23 Mrt 10	220	3	180	2	0-2
24 Mrt 10	150	12	150	8	2
30 Mrt 10	150	9	180	12	1-4
08 Jul 10a	210	5	320	7	1-2
08 Jul 10b	350	6	230	10	1-2

The software programme Distance (version 6.0., release 2) was used for the analysis of the observations of harbour porpoises. The best model for the detection function was chosen on the basis of the Akaike Information Criterion (AIC) (Buckland *et al.*, 2001). Given that all observations of harbour porpoises are useful for establishing a detection probability model, also the 2008 and 2009 data were used in the analysis of data collected during 2010. The model, a hazard rate function with cosine adjustment, is now based on 223 observations instead of 89 as in Haelters *et al.* (2010). A consequence of the use of this new model, and its application to the 2008 and 2009 data, is that the values of density and abundance obtained for the 2008 and 2009 surveys, as reported here, deviate slightly from those reported previously (Haelters, 2009; Haelters *et al.*, 2010). The effective (half) strip width based on the new model was 144 m (128 m-162 m).

The following assumptions were made:

- The probability of detecting harbour porpoises does not depend on their group size.
- The detection probability remains constant over the area surveyed, season, time of day, density of animals, and between observers.
- A correction factor for the probability of observing a harbour porpoise at distance 0 m (g(0), which in theory would be 1) needs to be applied, given that not all animals are visible or observed. It was not possible to try and estimate the g(0), such as through mark-recapture (racetrack or circle-back) or double platform (ship-plane or plane-plane) methods (Hiby & Lovell, 1998; Borchers, 2005; Palka, 2005; Scheidat *et al.*, 2005) given technical and practical limitations. Instead, g(0) was set at 0.45, as estimated by Hiby (2008) for similar surveys during good observation conditions – this is useful for comparing similar surveys performed in waters of other countries bordering the North Sea. As no confidence interval (CI) was applied to g(0), the CI of the results obtained should be considered with caution. Given that the value of g(0) that was applied is the one for good observer conditions, the densities estimated for the surveys on 7 January and 23-24-30 March 2010 need to be considered as minimal values.

Given the sometimes adverse meteorological conditions, complete surveys, covering 13 to 14 tracks, could be performed in one day only on 7 January and 8 July. Other surveys could only cover part of the tracks, and surveys covering complementary tracks were subsequently treated as one survey. This was done if the interval between them was shorter than two weeks, assuming that density and distribution of harbour porpoises had remained constant over that period. As such, the survey flights on 17 February and 2 March were pooled and treated as one complete survey, as were the flights on 23, 24 and 30 March.

10.2.2. Passive acoustic monitoring

The devices used in passive acoustic monitoring (PAM) were Porpoise Detectors (C-PoDs). C-PoDs (see www.chelonia.co.uk) are devices that are moored from weeks to months, and record *ad hoc* sound event characteristics, such as frequency, duration, time of occurrence and amplitude. These sound event characteristics are later analyzed with dedicated software (CPoD.exe) to detect, within a certain probability, the sounds originating from small cetaceans. Sounds originating from harbour porpoises and dolphins can be distinguished. By using C-PoDs, continuous information can be provided on the presence or absence of small cetaceans at a preselected location over a short- to medium-term period, independent of weather conditions. C-PoDs only provide for a relative index of abundance of small cetaceans, as uncertainties exist in the probability to detect animals at different distances from the device, and in the group size of the animals detected.

In 2010 C-PoDs were moored at three locations, two of which within an offshore wind farm area, for a total duration of 485 days (Table 3). The C-PoDs were moored vertically, with their central position at 1 to 1.5 m above the seafloor. MOW1 is located off Blankenberge, 4.5 km offshore at a depth of 6.5 m below mean low low water spring (MLLWS). The Bligh Bank mooring was situated 46 km offshore, at a depth of 25 m (MLLWS), and the Thorntonbank mooring was located 28 km offshore at the C-Power offshore wind farm, at a distance of 150 m from windmill foundation D5 and at a depth of 15 m (MLLWS). The MOW1 and Bligh Bank C-PoDs were attached to a tripod (Haelters *et al.*, 2010), while the Thorntonbank C-PoD was attached to a lighter mooring system, and was combined with sensors to study the attraction of fish around wind turbine foundations (Reubens *et al.*, this volume). A C-PoD was present at the MOW1 location for 310 days, at the Bligh Bank for 27 days, and at the Thorntonbank for 148 days.

Table 3.
Overview of the moorings of C-PoDs during 2010.

Name	Pos N	Pos E	Date mooring	Date retrieval	Days in 2010
MOW1	51°21'N	003°07'E	11 Dec 2009	25 Jan 2010	25
MOW1	51°21'N	003°07'E	25 Jan 2010	25 Mar 2010	59
MOW1	51°21'N	003°07'E	25 Mar 2010	20 May 2010	56
MOW1	51°21'N	003°07'E	31 May 2010	23 Jul 2010	53
MOW1	51°21'N	003°07'E	6 Sep 2010	18 Oct 2010	42
MOW1	51°21'N	003°07'E	18 Oct 2010	17 Nov 2010	30
MOW1	51°21'N	003°07'E	17 Nov 2010	15 Dec 2010	28
MOW1	51°21'N	003°07'E	15 Dec 2010	2011	17
Bligh Bank	51°42.18'N	002°48.82'E	5 May 2010	1 Jun 2010	27
Thorntonbank	51°32.96'N	002°55.79'E	6 Aug 2010	1 Nov 2010	87
Thorntonbank	51°32.97'N	002°55.78'E	1 Nov 2010	2011	61

The data were analyzed using CPOD.exe software Version 2.009. All data were visually inspected for eliminating false positive detections, or restoring false negatives. It cannot be ruled out however that a low percentage of false detections was not recognized as such, and remained in the data. Only high and moderate train quality data (high and moderate detection probability) were retained, and the species filter was set to harbour porpoises.

The quantitative measure used to present harbour porpoise presence was detection positive 10 minutes per day (dp10m/day), which is the number of 10 minute blocks per day in which the presence of harbour porpoises was detected. Other methods of presenting data are possible, such as the number of detection positive minutes per day or per hour, but dp10m/d was preferred as the number of detections was usually low, and this measure minimizes potential differences in sensitivity between C-PoDs (www.chelonia.co.uk). The data collected on the days of the mooring and the recuperation of the C-PoDs was not used, as the presence of the tripod mooring and retrieving platform (RV BELGICA) in the vicinity of MOW1 and the Bligh Bank site, often for hours, potentially kept porpoises at a distance.

10.2.3. Strandings data analysis

The yearly and seasonal trend in the number of harbour porpoises that wash ashore, could be used as a measure for the trend in the abundance at sea. However, caution should be made, as this number is biased due to meteorological conditions, which can greatly influence the chances of a carcass to wash ashore, and due to a varying natural and bycatch-induced mortality throughout the year. It is also influenced by the distribution pattern of harbour porpoises, such as seasonal differences in the onshore-offshore density gradient: we expect that porpoises that have died close to the coast have a higher chance of washing ashore than porpoises that have died further out. Next to this, there are different speeds at which decomposition takes place, due to variations in water temperature. During decomposition, several stages of floating and sinking exist (e.g. Anderson & Hobischak, 2004), which undoubtedly has an influence on the chances of a carcass to wash ashore during different periods of the year.

MUMM manages a database on strandings of marine mammals, which is partly available online (www.mumm.ac.be). Most of the marine mammals washed ashore in Belgium are being reported and collected. Only basic strandings data are reported here: yearly and seasonal numbers of washed ashore animals. The numbers include washed ashore animals of which bycatch was identified as the cause of death. They also include a very small number of bycaught animals delivered by fishermen and animals found dead at sea in Belgian waters or ports.

10.3. Results

10.3.1. Results of the aerial surveys

Four species of marine mammal were observed during the aerial surveys: harbour porpoise, white-beaked dolphin *Lagenorhynchus albirostris*, grey seal *Halichoerus grypus* and common seal *Phoca vitulina* (Table 4). Some seals could not be identified to the species level (seal sp.).

Table 4.
Overview of the number of sightings of groups of marine mammals during the 2010 surveys, with between brackets the total number of animals sighted. Also observations made off task (eg. between the end of one track and the beginning of the next), inside Belgian waters, are included – they are however not used in the analysis.

Date	Harbour porpoise	White beaked dolphin	Grey seal	Common seal	Seal sp.
07 Jan 10	10 (10)	3 (6)	1 (1)		
17 Feb – 2 Mar 10	44 (56)				2 (2)
23 – 24 - 30 Mar 10	39 (41)				
08 Jul 10	30 (38)			1 (1)	1 (1)

A low average density of harbour porpoises was detected in early January 2010, and higher densities between mid-February and the end of March 2010, and in early July 2010 (Figure 1). The extrapolated number of harbour porpoises in an area equivalent to 3.600 km² (approximately the surface of the marine area under Belgian jurisdiction) was estimated at ca. 550 in January 2010, ca. 2.000 in February and March and ca. 1.500 in July 2010. The maximum numbers estimated in 2010 were lower than the highest estimate made since the beginning of the aerial surveys, which was more than 3,500 animals in April 2008. The average number of animals in the groups observed during 2010 was 1.00 in the survey in January, 1.30 in the survey of 17 February-2 March, 1.04 in the survey of 23-24-30 March, and 1.28 in the July survey. In international fora, a number of 1% of a population is often used as a basis for assessment; Figure 1 indicates an average density of harbour porpoises in Belgian waters which would, in absolute numbers, amount to 1% of the population of harbour porpoises in the greater North Sea, as estimated during a summer survey in 2005 (SCANS II, 2008).

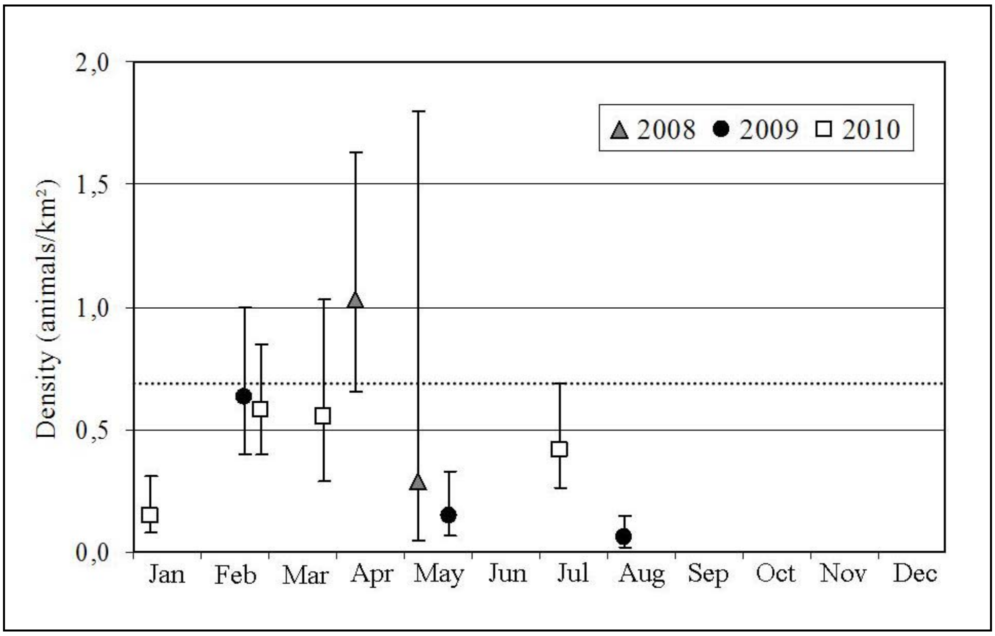

Figure 1. Density (animals/km²) of harbour porpoises, including 95% CI, as estimated on the basis of observations during aerial surveys between 2008 and 2010. The dotted line represents an average density of 0.69 animals/km², which, extrapolated to the surface of Belgian waters, indicates an absolute number of porpoises amounting to 1% of the number of harbour porpoises in the greater North Sea.

Figures 2 to 5, with all marine mammal observations presented on a map, give a visual indication of their distribution over Belgian waters, and more in particular in and around wind farm areas. They include a very small number of observations made off task that were not used in the density estimations. Porpoises occurred closer inshore during February and March than during July, when they were virtually restricted to waters outside the 12 mile zone. Observations of harbour porpoises were made in the immediate vicinity of the Thorntonbank and Bligh Bank wind farm areas.

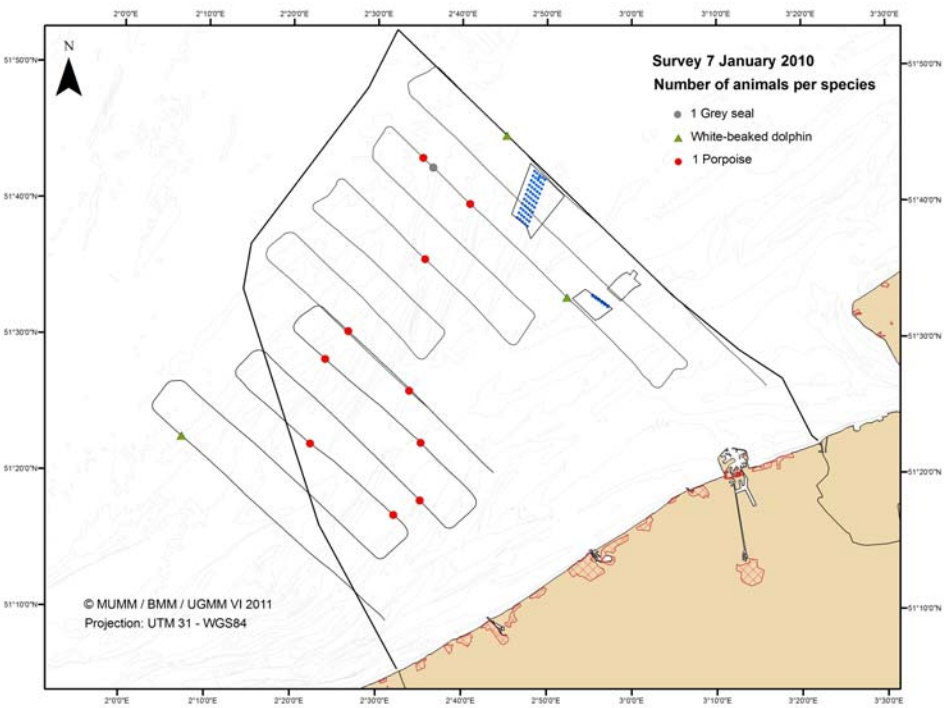

Figure 2. Observations of marine mammals during the surveys of 7 January 2010 (harbour porpoise: red circle; white-beaked dolphins: green triangle; grey seal: grey circle; flight track: grey line).

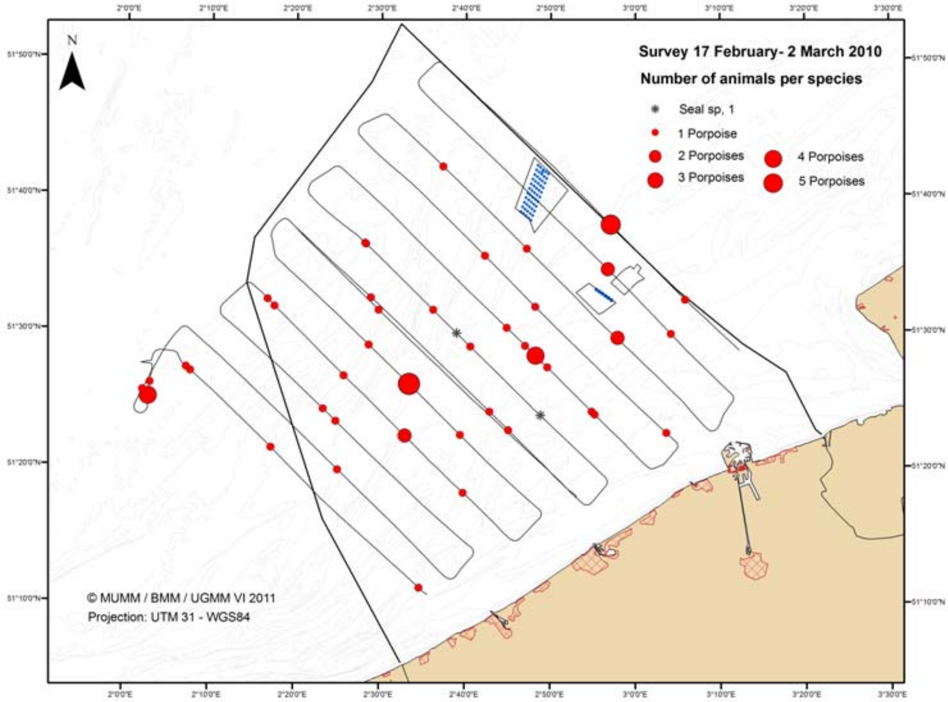

Figure 3. Observations of marine mammals during the surveys of 17 February–2 March 2010 (harbour porpoises: red circle; seal sp.: black star; flight track: grey line).

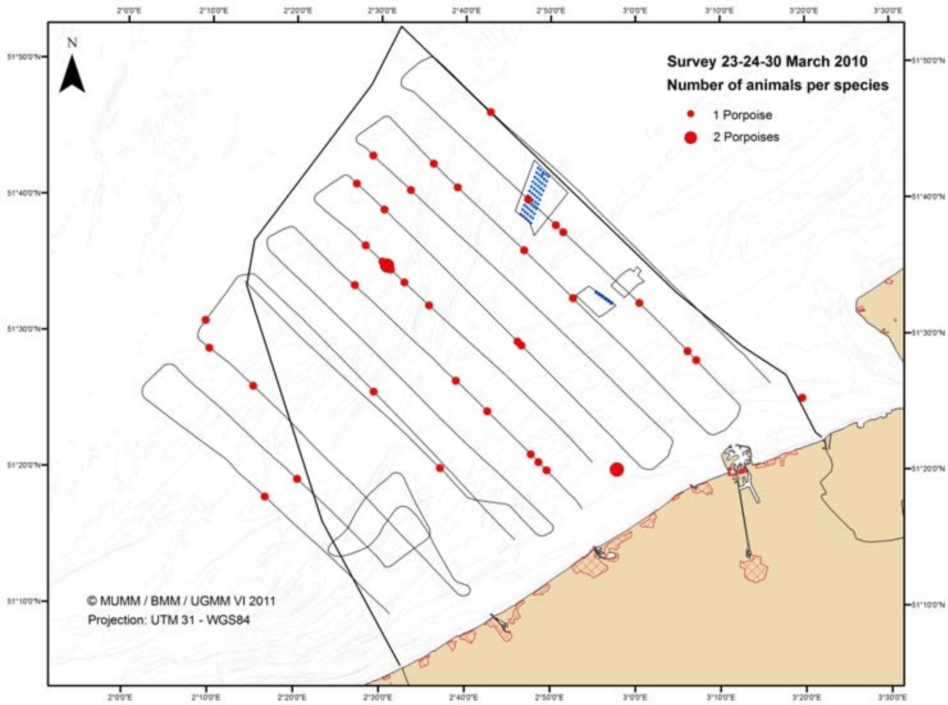

Figure 4. Observations of marine mammals during the surveys of 23-24-30 March 2010 (harbour porpoises: red circle; flight track: grey line).

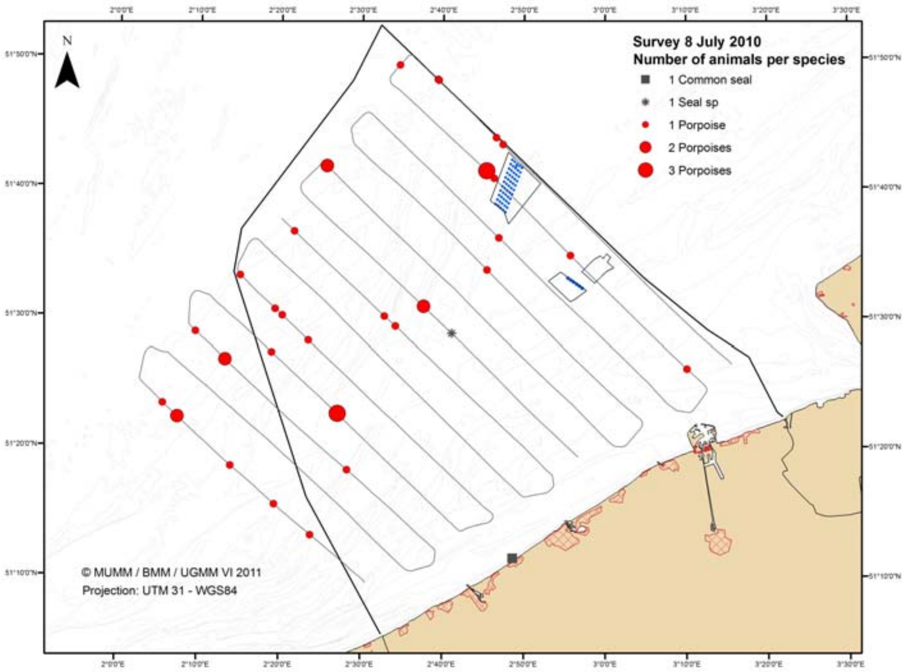

Figure 5. Observations of marine mammals during the surveys of 8 July 2010 (harbour porpoises: red circle; common seal: black square; seal sp.: black star; flight track: grey line).

An interesting observation in the results of the surveys in 2010 and previous ones (Haelters *et al.*, 2010), is the change of the average group size estimate during the period with the highest densities (late winter to early spring): while during the surveys between February and early March (18-19 February 2009 and 17 February–2 March 2010) often small groups of 2 to 5 animals were observed, it was rare to observe other than single harbour porpoises during the late March and early April surveys (23-24-30 March 2010 and 8-9 April 2008). The average group size estimate during the July survey was again higher.

10.3.2. Results of the PAM

All the moorings of C-PoDs at MOW1 during 2010, with the exception of one, were successful in providing data. No data could be obtained from the PoD at MOW1 from 6 September to 18 October 2010 due to the fact that the tripod had tipped over. PoDs have a built-in angle sensor that shuts them down at a horizontal or reverse position. No tripod was anchored at MOW1 during August.

The mooring at the Thorntonbank from 6 August 2010 to spring 2011 was located close to a pinger attached to another device, used to study the attraction of fish around turbine foundations. The presence of this pinger, emitting an almost continuous signal of of 147 dB (re 1µPa@1m) at a frequency of 69 kHz, can explain why the number of detections on this PoD was particularly low, and as such not useful for analysis. Some noise characteristics of this pinger are very similar to pingers used to warn porpoises about the presence of fishing gear to avoid them being bycaught (eg. a pinger manufactured by Fumunda: 145 dB re 1µPa@1m, frequency of 70 kHz).

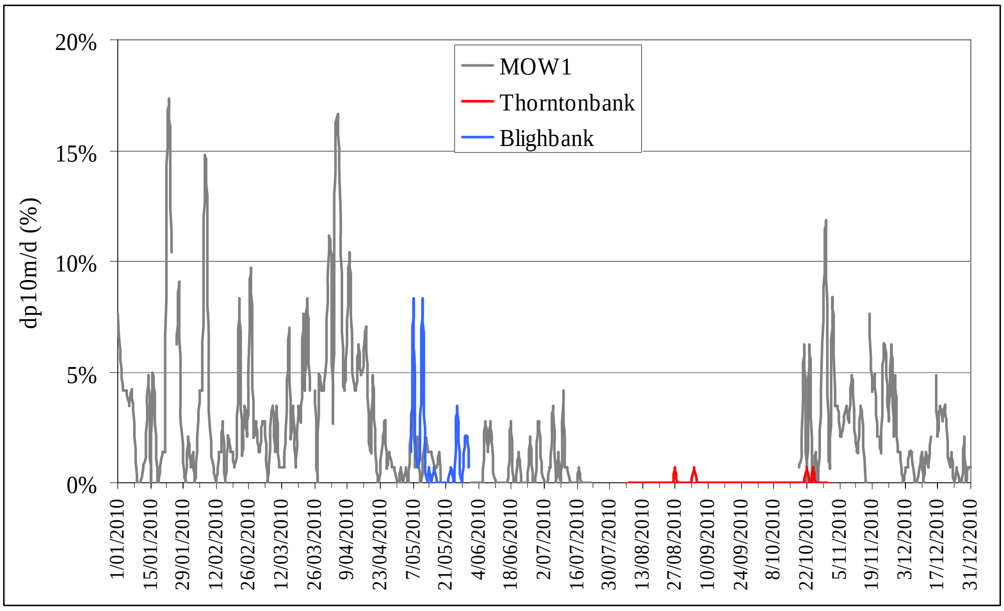

Figure 6. Number of dp10m/d, expressed as percentage of the 144 blocks of 10 minutes per day, in 2010 at the MOW1, Bligh Bank and Thorntonbank C-PoD moorings.

The detection rate at MOW1 (Figure 6) was very irregular, but higher between January and the end of April (on average 5.5 dp10m/d) than between May and July (on average 1.1 dp10m/d). A general increase in the detection rate was found between January and April, followed by a steep decline towards the end of April. The detection rate during November was higher (on average 4.8 dp10m/d) than between May and July, while it dropped again in December (on average 1.7 dp10m/d). The period during which a C-PoD was moored at the Bligh Bank was too short to draw conclusions; given that the mooring took place during a period with generally low densities of harbour porpoises, as indicated through previous aerial surveys, a low number of detections was expected and recorded (on average 1.9 dp10m/d). There were virtually no detections of harbour porpoises by the Thorntonbank C-PoD – probably as a consequence of the nearby pinger.

10.3.3. Results of the strandings data analysis

In 2010 lower numbers of stranded harbour porpoises (48 animals; Figure 7) were counted than during the five previous years (62 to 94 animals).

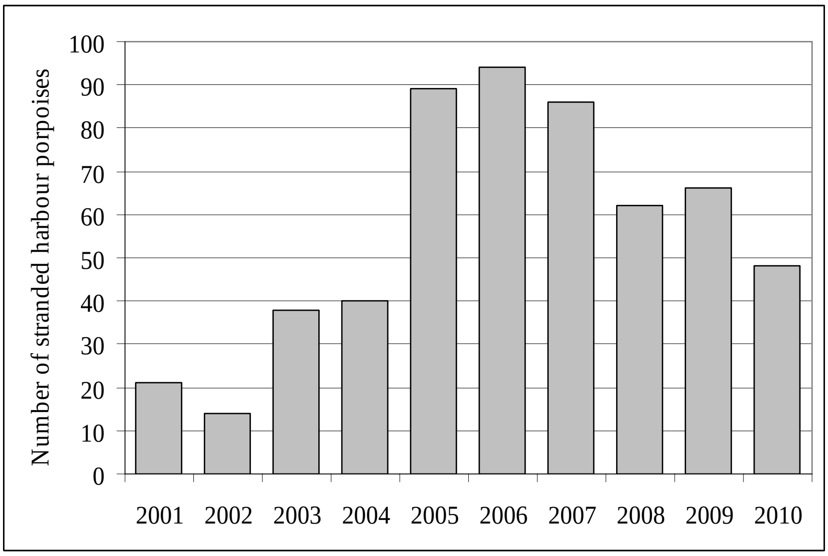

Figure 7. Number of stranded harbour porpoises per year between 2001 and 2010 in Belgium.

In comparison to the years 2005 to 2007, the monthly variation in strandings between 2008 and 2010 was more uniform, with relatively more strandings between August and October (Figure 8). Although the peak in strandings between March and May still existed, it was much less pronounced (half of all strandings in 2005-2007, vs. only one third of the strandings in 2008-2010), and similar to the one during summer months. There was a consistently low stranding rate between November and February (in total 11% of all strandings, both in the period 2005-2007 as in 2008-2010), and during June and July (in total 10% of all stranded animals in the period 2005-2007; 15% of all stranded animals in 2008-2010).

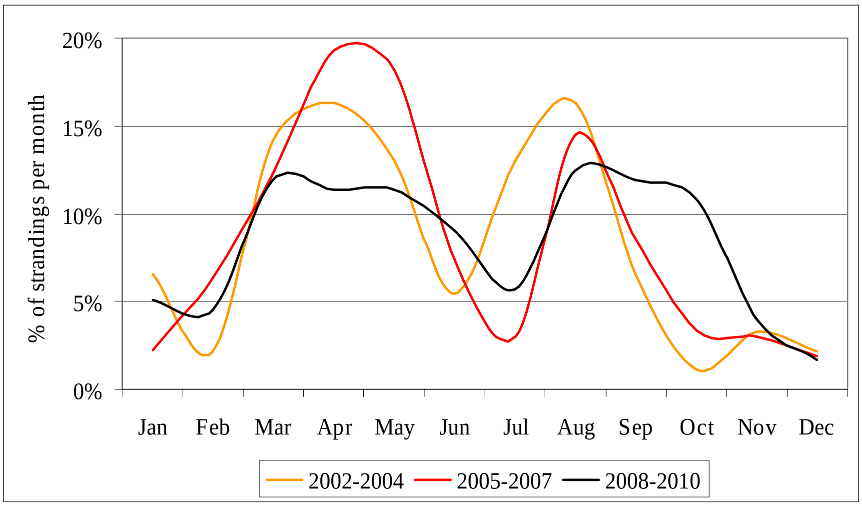

Figure 8. Percentage of the stranded harbour porpoises per month in the triennia 2002-2004, 2005-2007 and 2008-2010.

10.4. Discussion

10.4.1. Seasonal occurrence of harbour porpoises

The aerial survey data for 2010 presented in Figure 1 partly confirm the previous assessments of seasonal occurrence of harbour porpoises in Belgian waters, with higher numbers in late winter and early spring than during the rest of the year (Haelters, 2009; Haelters *et al.*, 2010; Haelters & Camphuysen, 2009). However, since aerial surveys have until now not been performed during autumn or early winter, the importance of Belgian waters to harbour porpoises during these seasons is yet to be assessed. The estimates of density during February-March 2010 were similar to the estimates during February 2009, but lower than those of April 2008. It is obvious however that large confidence intervals in the estimates exist.

The relatively high density of porpoises estimated on the basis of the observations during the July 2010 survey is remarkable. During these surveys a very high density of compass jellyfish *Chrysaora hysoscella* was observed near the sea surface over large parts of Belgian waters – a phenomenon which was visible due to the very low seastate. Furthermore, associated blooms of phytoplankton, possibly of *Noctiluca scintillans*, were observed from the aircraft. The relatively high density of harbour porpoises during that period might have been a consequence of a suitable prey species being present in high densities. This might further be elucidated through stomach content analyses. The relatively high density estimate during early July indicates that any predictions about the seasonal presence of harbour porpoises in Belgian waters should be made with caution: short and erratic intrusions of a relatively high number of harbour porpoises are possible. It is likely that nowadays higher densities of harbour porpoises occur in, and in the vicinity of Belgian waters during late spring and summer months than a decade ago, and that occasionally numbers of these highly mobile animals can venture into Belgian waters in search of food during this period. This phenomenon may be due to a continuation of the spatial shift of the bulk of the North Sea harbour porpoises towards the south:

the SCANS II survey, performed during the summer of 2005, indicated that the summer distribution of harbour porpoises had shifted south since 1994 (SCANS II, 2008).

10.4.2. Seasonal distribution of harbour porpoises

The C-PoDs moored at MOW1 provided useful information about the presence or absence of harbour porpoises close inshore throughout the year, but given the differential geographical distribution pattern of porpoises, with at least an onshore-offshore gradient, it is of limited value as a reference C-PoD in the framework of the assessment of impacts of the construction and operation of offshore wind farms. All C-PoD data showed a high variability in detections from day to day. As a consequence, extrapolating a small number of data of C-PoDs, as available in this study, to absolute densities on the basis of observations during aerial surveys, is very difficult. However, the C-PoD at MOW1 showed an increasing detection rate from January to April, and a very low detection rate from May to July, and thus confirmed partly the general trends in the seasonal distribution of harbour porpoises in the nearshore area. It provided some data on the presence of porpoises in the nearshore area during autumn and early winter, a period in which no aerial surveys were undertaken.

The differential geographical distribution of harbour porpoises in Belgian waters throughout the year, as suggested through aerial surveys, is important. A low number of stranded animals, and very few anecdotal observations, mostly originating from people navigating close inshore, should not be extrapolated to a low density of harbour porpoises in Belgian waters in general, including the wind farm areas. As such, impact monitoring should be in place for activities potentially harming or disturbing marine mammals, and relevant mitigation measures should be considered during the periods and in areas in which we do not expect high densities.

The very low detection rate at the Thorntonbank PoD from August 2010 onwards can be attributed to the nearby presence of a pinger, keeping porpoises at a distance beyond the detection range of the C-PoD. Thus, caution is needed in interpreting the results of PoD data when these were obtained in an area where simultaneous fish studies using acoustic tags were undertaken, or where pingers were deployed with other objectives. Another explanation of a low detection rate would be that the porpoises were kept at a distance due to the noise of the operational wind turbine at 150 m from the C-PoD; however, this would mean that at least during weather conditions with virtually no wind, porpoises would be expected to occasionally venture close to the mooring, which was not the case.

10.4.3. Group size of harbour porpoises

The slightly higher average group size estimate in February and early March vs. late March and April could be partly due to the weaning of calves: most calves are born between May and August, with a peak in June and July (Addink *et al.*, 1995), after a gestation period of 10 to 11 months. It cannot be excluded however that the period when birth take place varies due to changing sea temperatures. The lactation period lasts six to eight months (Gaskin *et al.*, 1984; Lockyer, 2003), which would mean that they are weaned between the beginning of December and the end of March – a decreasing average group size in Belgian waters during this period could well partly illustrate this phenomenon. The average group size estimate during the July survey was again slightly higher than between the end of March and April, with the more frequent observation of small groups. This might indicate further more social stages in the life cycle of harbour porpoises: the mating season (June-August; Lockyer, 2003) and the period when young are born (Figure 9).

Another possible reason for this phenomenon could be a seasonal variation in prey, with during the periods with a higher group size more prey that occurs in schools than during periods with smaller group sizes. This could be further investigated through stomach content analyses of stranded harbour porpoises.

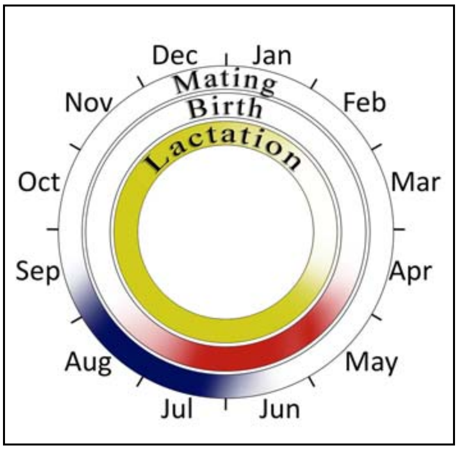

Figure 9. Distinct periods of mating, breeding and lactation (highlighted areas) of harbour porpoises in the southern North Sea.

10.4.4. Other marine mammals

Although fairly large numbers of common and grey seals occur in colonies around Belgian waters (a.o. Delta area (NL), Goodwin Sands and Wash Estuary (UK), Somme Bay (F)), and a varying but small number of common seals occupies a haul-out site at Koksijde, Belgium, observations of seals during the surveys were rare. Groups of white-beaked dolphins regularly occur, but not close to shore, during winter and early spring; however, their numbers remain low compared to the number of harbour porpoises during the same period.

10.5. General conclusions and outlook

The aerial surveys confirm that the harbour porpoise remains the only (seasonally) abundant marine mammal in Belgian waters, and that monitoring should continue to focus on this species. However, such surveys should be more regularly conducted throughout the year, as information for autumn is currently lacking.

The results of aerial surveys in 2010 confirmed previous observations about the seasonal presence of harbour porpoises in Belgian waters: the highest densities occur during late winter and early spring. Noteworthy however was the relatively high density estimate of July 2010, illustrating that erratic intrusions of numbers of harbour porpoises into Belgian waters can occur and that it is difficult to predict the seasonal presence of this highly mobile species in Belgian waters. The relatively high number of stranded animals during the summer months of 2010 (and previous years) confirms the current occurrence of a higher number of harbour porpoises in, or close to Belgian waters during this period vs. the beginning of the 21st century.

The analysis of PoD data at MOW1 indicated a consistent very low presence of harbour porpoises from May to mid-July at this location, and as such confirms previous results of aerial surveys during these months in the nearshore area in general. Also the mapping of observations made during aerial surveys indicates that the distribution of the animals varies seasonally: while relatively high densities of harbour porpoises occur throughout Belgian waters, including in territorial waters, during late winter and early spring, their distribution during the other periods of the year lies on average further offshore, but not further than the offshore wind farm location at the Thorntonbank. Harbour porpoises were observed in, or in the vicinity of the Bligh Bank and Thorntonbank wind farm areas during all aerial surveys.

Mooring PoDs cost-efficiently is not an easy task, but in order to be able to discern natural variation in the presence and distribution of harbour porpoises from the effects of human activities, every effort should be made to increase the number of C-PoDs deployed in or at wind farm areas and at reference areas. Especially for detecting possible effects with a chronic nature that occur over relatively small areas, such as due to the operation of wind turbines, the use of passive acoustic monitoring devices should be amplified. Passive acoustic monitoring has some advantages over aerial surveys in its possibilities to detect small-scale, long-term changes in the presence of harbour porpoises: data are not affected by short-term changes in harbour porpoise distribution, they are more consistent than data collected by human observers, are less affected by meteorological conditions, and are not restricted to daylight hours.

10.6. Acknowledgements

We would like to acknowledge the patience and endurance of pilots and observers during aerial surveys, the assistance of personnel of Meetdienst Oostende and of the crew of the RV BELGICA for mooring and retrieving PoDs, and the cooperation of the companies currently constructing and operating offshore wind farms, i.e. C-Power and Belwind. We would also like to mention the continued assistance of Nick Tregenza (Chelonia Ltd.) in interpreting data and in advising on technical aspects of PoDs and mooring systems. Strandings were dealt with in the strandings network MARIN.

10.7. References

Addink, M.J., Sorensen, T.B. & Garcia Hartmann, M., (1995). Aspects of reproduction and seasonality in the harbour porpoise from Dutch waters. *In:* Blix, A.S., Walloe, L. & Ulltang, O., (eds.). Whales, seals, fish and man. Proceedings of the International Symposium on the Biology of Marine Mammals in the North East Atlantic. Tromsø, Norway, 29 November - 1 December 1994. Elsevier, Amsterdam: 459-464.

Anderson, G.S. & Hobischak, N.R., (2004). Decomposition of carrion in the marine environment in British Columbia, Canada. Int. J. Legal Med. 118: 206–209; DOI 10.1007/s00414-004-0447-2.

Borchers, D.L., (2005). Estimating detection probability from line-transect cetacean surveys when detection on the line is not certain: an overview. *In:* Thomsen, F., Ugarte, F. and Evans, P.G.H. Estimation of g(0) in line–transect surveys of cetaceans. ECS Newsletter 44, Special Issue, 4-11.

Brandt, M.J., Diederichs, A. & Nehls, G., (2009). Harbour porpoise responses to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Final report to DONG Energy. Husum, Germany, BioConsult SH.

Brandt, M.J., Diederichs, A., Betke, K. & Nehls, G., (2011). Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Marine Ecology Progress Series 421: 205–216; doi: 10.3354/meps08888.

Gaskin, D.E., Smith, G.J.D., Watson, A.P., Yasui, W.Y. & Yurick, D.B., (1984). Reproduction in the porpoises (Phocoenidae): implications for management. Rep. Int. Whaling Comm. Spec. Issue No. 6. pp. 135-148.

Haelters, J., (2009). Monitoring of marine mammals in the framework of the construction and exploitation of offshore wind farms in Belgian marine waters. *In:* Degraer, S. & Brabant, R. (Eds.). Offshore wind farms in the Belgian part of the North Sea: State of the art after two years of environmental monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine ecosystem management unit. Chapter 10: 237-266.

Haelters, J. & Camphuysen, K., (2009). The harbour porpoise in the southern North Sea: abundance, threats and research- & management proposals. Royal Belgian Institute of Natural Sciences (RBINS/MUMM) and the Royal Netherlands Institute for Sea Research (NIOZ); report commissioned by the International Fund for Animal Welfare (IFAW); 56 pp.

Haelters, J., Kerckhof, F., Jacques, T.G. & Degraer, S., (2010). Spatio-temporal patterns of the harbour porpoise Phocoena phocoena in the Belgian part of the North Sea. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.). Offshore wind farms in the Belgian part of the North Sea: early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine ecosystem management unit. Chapter 10: 153-163.

Hiby, L. & Lovell, P., (1998). Using aircraft in tandem formation to estimate abundance of harbour porpoise. Biometrics 54: 1280-1289.

Lockyer, C., (2003). Harbour porpoises (Phocoena phocoena) in the North Atlantic: Biological parameters. NAMMCO Scientific Publications volume 5: 71-89.

Madsen, P.T., Wahlberg, M., Tougaard, J., Lucke, K. & Tyack, P.L., (2006). Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Mar. Ecol. Prog. Ser. 309: 279-295.

Norro, A., Haelters, J., Rumes, B. & Degraer, S., (2010). Underwater noise produced by the piling activities during the construction of the Belwind offshore wind farm (Bligh Bank, Belgian marine waters). *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.). Offshore wind farms in the Belgian part of the North Sea: early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine ecosystem management unit. Chapter 4: 37-51.

Norro, A., Rumes, B. & Degraer, S., (2011). Characterisation of the operational noise, generated by offshore wind farms in the Belgian part of the North Sea.. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2011). Offshore wind farms in the Belgian part of the North Sea: Selected findings from the baseline and targeted monitoring. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 3: pp. 17-26.

Palka, D., (2005). Aerial surveys in the northwest Atlantic: estimation of g(0). *In:* Thomsen, F., Ugarte, F & Evans, P.G.H. Estimation of g(0) in line–transect surveys of cetaceans. ECS Newsletter 44, Special Issue, 12-17.

Reubens, J., Degraer, S. & Vincx, M., (2010). The importance of marine wind farms, as artificial hard substrata, for the ecology of the ichthyofauna. *In:* Degraer, S., Brabant, R. & Rumes, B., (Eds.). Offshore wind farms in the Belgian part of the North Sea: early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute of Natural Sciences, Management Unit of the North Sea Mathematical Models, Marine ecosystem management unit. Chapter 6: 69-82.

SCANS II, (2008). Small Cetaceans in the European Atlantic and North Sea (SCANS II). Final Report to the European Commission under project LIFE04NAT/GB/000245. Available from SMRU, Gatty Marine Laboratory, University of St Andrews, St Andrews, Fife, KY16 8LB, UK.

Scheidat, M., Gilles, A. & Siebert, U., (2005). Applying the circle-back method to estimate g(0) – experiences and results from aerial surveys in German waters. *In:* Thomsen, F., Ugarte, F. & Evans, P.G.H. Estimation of g(0) in line–transect surveys of cetaceans. ECS Newsletter 44, Special Issue, pp. 18-24.

Scheidat, M., Tougaard, J., Brasseur, S., Carstensen, J., van Polanen Petel, T., Teilmann, J. & Reijnders, P., (2011). Harbour porpoises (*Phocoena phocoena*) and wind farms: a case study in the Dutch North Sea. Environ. Res. Lett. 6, 025102 (10p.) doi:10.1088/1748-9326/6/2/025102.

Tougaard, J., Carstensen, J., Teilmann, J., Skov, H. & Rasmussen, P., (2009a). Pile driving zone of responsiveness extends beyond 20 km for harbour porpoises (*Phocoena phocoena*, (L.)). J. Acoust. Soc. Am. 126: 11-14.

Tougaard, J., Henriksen, O.D. & Miller, L.A., (2009b). Underwater noise from three offshore wind turbines: estimation of impact zones for harbor porpoises and harbor seals. J. Acoust. Soc. Am. 125: 3766-3773.

Chapter 11. The use of the Benthic Ecosystem Quality Index (BEQI) for the evaluation of the impact of the Thorntonbank wind farm on the soft-bottom macrobenthos

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Phase I of the C-Power wind farm on the Thorntonbank Photo A. Braarup Cuykens / INBO

Abstract

The use of benthic indicators, more specifically level 3 of the Benthic Ecosystem Quality Index (BEQI), was tested to evaluate possible changes in the benthic community characteristics because of the windmill construction activities in the Thorntonbank concession area. In this area, benthic data were gathered before (2005), during (2008) and after (2009) these construction activities in a BACI design approach, which is an appropriate data structure for calculating the BEQI. This index evaluates the deviation in the parameters density, number of species, species composition and biomass between the benthic data collected in the impact area and the control area for each period.

The index and its parameters showed that the benthic characteristics in the different sub-areas of the Thorntonbank concession area corresponded with those observed in the control areas (Thorntonbank and Goote Bank), except in sub-area A (the impact area) in 2008, which is the moment of the construction of the six windmills. At that moment the species richness was lower in sub-area A compared to the control.

This test shows that the use of a benthic indicator BEQI to evaluate the changes in a soft-bottom benthic community following wind farm construction is a very valuable tool to summarize the observed patterns.

Samenvatting

Het gebruik van benthische indicatoren, meer specifiek level 3 van de Benthische Ecosysteem Kwaliteits Index (BEQI), werd getest om mogelijke veranderingen in de karakteristieken van de benthische gemeenschap, ten gevolge van de constructie van windmolens in de Thorntonbank concessie, te evalueren. Er werden benthische gegevens verzameld voor (2005), tijdens (2007) en na (2009) de constructie activiteiten volgens een BACI benadering. Dit is een geschikt concept om de BEQI te berekenen. Deze index evalueert de verandering in de parameters densiteit, aantal soorten, soortensamenstelling en biomassa in de gegevens van het impactgebied en het controlegebied voor elke periode.

De index en de parameters toonden aan dat de benthische karakteristieken uit de verschillende deelgebieden van de Thorntonbank concessie overeenkwamen met de geobserveerde karakteristieken in de controlegebieden (Thorntonbank en Goote Bank), behalve voor deelgebied A (het impact gebied) in 2008, dit was de constructieperiode van de zes windmolens. Op dat moment was het aantal soorten in deelgebied A lager, in vergelijking met de controlegebieden.

Deze test toont aan dat het gebruik van een benthische indicator BEQI om de veranderingen in een benthische gemeenschap in een zandige omgeving ten gevolge van de constructie van windmolens teevalueren een zeer waardevol hulpmiddel is om de waargenomen patronen samen te vatten.

11.1. Introduction

In 2004 an environmental permit was granted to C-power for the construction of 54 windmills at the Thorntonbank in the Belgian Part of the North Sea. Six windmills, with concrete gravity based foundations were installed in the summer of 2008 in the eastern subarea (zone A). The macro-invertebrate fauna in the soft-sediments of the concession areas and control areas were sampled before (2005), during (2008) and after (2009) this construction activity. A detailed reporting on the characteristics of the soft-bottom benthic community in these periods is available (De Maersschalck *et al.*, 2006; Reubens *et al.*, 2009; Coates & Vincx, 2010). These areas were and are still characterised by medium sand and by the species *Nephtys cirrosa* and *Spiophanes bombyx*.

This data was gathered in a design (BACI-design) that allowed to test the applicability of benthic indicators. Benthic indicators are considered to be appropriate tools to quantify the impact degree of anthropogenic activities (Van Hoey *et al.*, 2010). In this case, the impact was evaluated by the use of level 3 of the BEQI index (Benthic Ecosystem Quality Index) (Van Hoey *et al.*, 2007). This index evaluates the deviation in the parameters density, number of species, species composition and biomass between the benthic data collected in the impact area and the control area for each period.

11.2. Material and Methods

11.2.1. Sampling design

The strategy consisted of taking a certain number of grab samples (Van Veen, 0.1m²) (Table 1) in the following subareas:

- TI-A: the eastern part of the Thorntonbank concession area (subarea A) in which the first six windmills were constructed
- TI-B: The subarea B, i.e. the western part of the Thorntonbank concession area (no windmills present)
- TE: The edge around the Thorntonbank concession area
- TC: The control area on the Thornton bank
- TCG: The control area on the Goote Bank

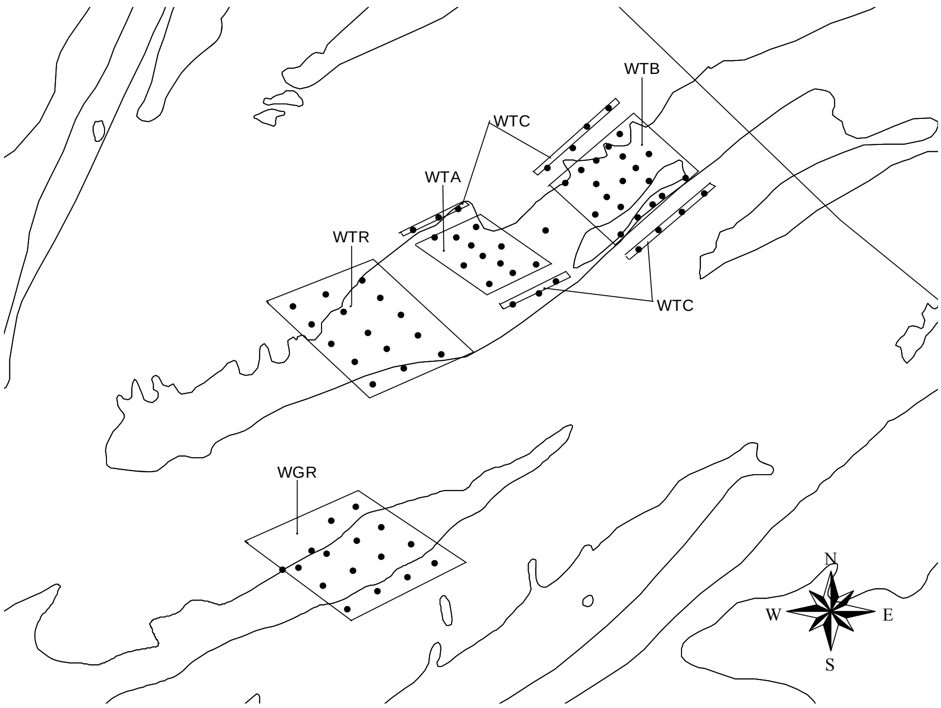

Figure 1. Position of the sub-areas on the Thorntonbank (WTA = TI-A; WTB = TI-B; WTC=TE; WTR=TC; WGR=TCG)

This design enables to evaluate, with the BEQI, the deviation in the benthic characteristics between TI-A, TI-B and TE compared to respectively TC and TCG. Samples were taken in all 5 areas for the years 2005 (spring[s] and autumn[a]), 2008 and 2009 (autumn) (Table 1). Only in autumn 2008, less samples in TI-A could be taken, due to sampling problems (positioning of the ship nearby the windmill constructions).

Details of the sampling, sample processing and data generation can be found in De Maersschalck *et al.* (2006), Reubens *et al.* (2009), Coates & Vincx (2010).

Table 1.
The total sample surface (SS) (m²) collected in each subarea.

SS (m²)	2005s	2005a	2008	2009
TI-A	1.1	1.1	0.6	1
TI-B	1.9	1.9	1.8	1.9
TE	1.5	1.5	1.2	1.3
TC	1.5	1.5	1.5	1.5
TCG	1.5	1.6	2.4	2.1

11.2.2. Benthic Ecosystem Quality Index (BEQI), level 3

The BEQI level 3 evaluates four biological parameters: number of species (N), total density (D, ind.m^{-2}), total biomass (B, g AFDW.m^{-2}), and species composition (S, Bray-Curtis similarity based on densities). In this study, biomass was not included in the results, because the variability within the biomass data was too high to get a confident assessment for this parameter. More samples are needed in each area to assess biomass. Each parameter gives different information about the structure and functioning of the benthic community (Van Hoey *et al.*, 2007). The BEQI evaluates the benthic community at the level of a habitat, rather than an evaluation of a single sample. By doing so, intrinsic natural variability (spatial and temporal) is incorporated. This requires a certain amount of reference (control) and assessment samples. A power analysis is used to evaluate the confidence related to the index value, which depends on the sampling effort.

Parameter results strongly depend on the sediment surface area sampled (Van Hoey *et al.*, 2007). Therefore, the expected reference values for the BEQI parameters were calculated from permutations executed over increased sampling surface areas. An algorithm is used that computes rarefaction curves using a random re-sampling procedure with replacement (i.e. bootstrapping, using 2000 random samples). For any given sampling surface, the obtained reference value can then be compared with the assessment value of a similar sampling surface used to evaluate the current ecological status. For N and S, a one-sided evaluation (only values lower than the reference are evaluated in a high-bad gradient) is used, whereas for D and B a two-sided evaluation (values lower or higher than the reference are evaluated in the high-bad gradient) is used. Additionally, the BEQI also produces a list of species that are responsible for observed deviations from the reference state for parameters (D, B, S), giving additional insight into how the current state has changed compared to the reference.

For each parameter, reference values were determined for each ecological status class boundary: high, > 0.8; good, 0.6-0.8; moderate, 0.4-0.6; poor, 0.2-0.4; bad, ≤ 0.2. The reference value of the good/moderate boundary is determined based on the 5th percentile (N, S) or on the 2.5th and 97.5th percentile (D, B) (respectively minimum and maximum reference value) out of the permutation distribution of each parameter (Van Hoey *et al.*, 2007). The moderate/poor and poor/bad reference values were determined by equal scaling (respectively 2/3 and 1/3 of the good/moderate reference value), whereas the median value (N, S) or the 25th and 75th percentile (D, B) out of the permutation distribution was used as the reference value of the high/good boundary. The reference value (EQR: 1) is defined as the maximum value out of the permutation distribution.

The BEQI score at level 3 is determined by the average of the EQR values of the parameters without weighting. It is advised, when using the BEQI, to analyze the separate EQR scores, because each parameter can have a different reaction on a disturbance event.

11.3. Results

11.3.1. Control area Thorntonbank

Values lower than 0.6 were not observed, except for spring 2005 at TI-B, which means that on average, the benthic characteristics observed in the sub-areas fell within those observed in the control area on the Thorntonbank (Figure 2). The benthic samples at the border of the concession showed the highest correspondence with the Thorntonbank reference. The BEQI average value was comparable for both concession areas on the Thorntonbank.

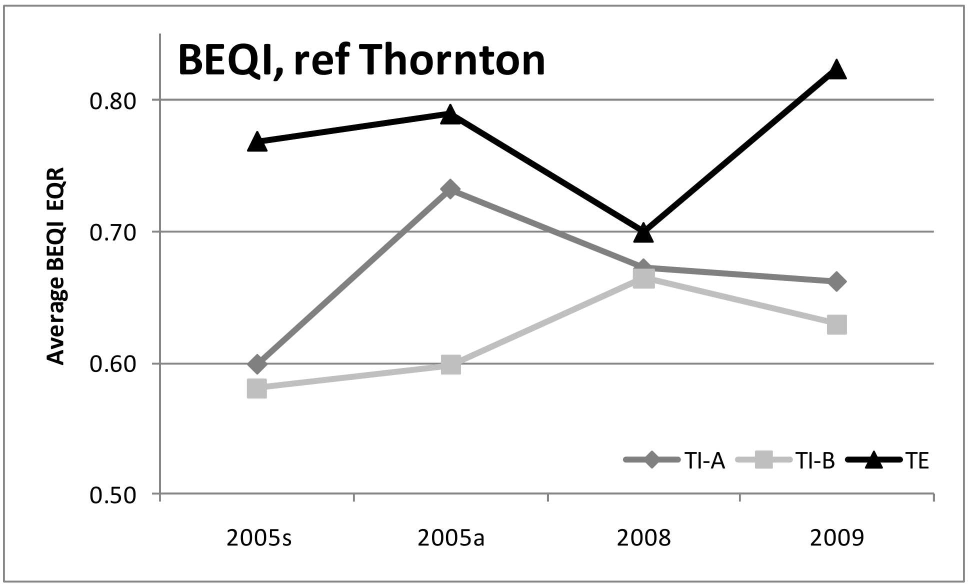

Figure 2. The average BEQI value, level 3 for each sample period for the three subareas.

The sub-metrics of the BEQI showed differences in their deviation from the control area over time (Figure 3; Table 2; Table 3). The parameter density showed the highest variability, with good to high correspondence with the reference area. The density in the subarea B deviated more and was lower than in the control area, except in autumn 2008. The number of species showed in most cases a high correspondence with the control, except in 2008 in subarea A. The parameter similarity showed a moderate correspondence for all areas, but with a stronger deviation for concession area B in the later years compared to the other areas. Biomass was not taken into account, because the confidence was classified as moderate or lower in all cases due the high variability in biomass values between the samples.

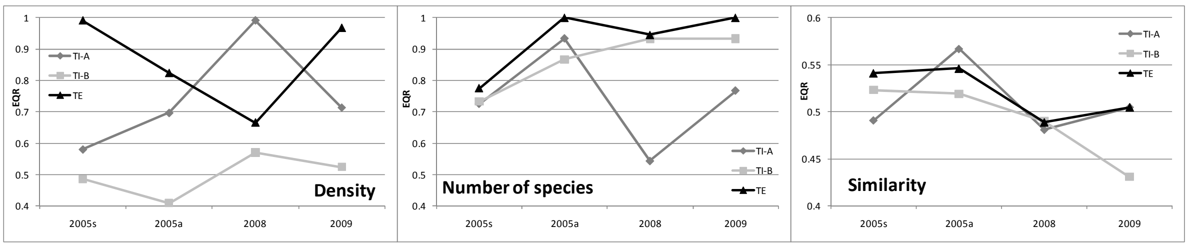

Figure 3. The sub-metrics of the BEQI, level 3 for each sample period for the three subareas.

Table 2.
Detail of the BEQI parameter calculations for the year 2005 (spring and autumn) with the Thorntonbank as control area. Density is expressed as ind./m²; Biomass is expressed as mg AFDW/m²

		parameter	Assessment		Reference boundary values									EQR		Confidence
			surface	value	Poor min	Mod min	Good min	High min	Reference	High max	Good max	Mod max	Poor max	score	status	Effect size class
2005 spring	TI-A	density	1.10	252	87	173	260	337	388	446	574	765	956	0.581	moderate	good
		biomass	1.10	3588	196	391	587	996	1420	1859	3041	4055	5068	0.492	moderate	moderate
		similarity	1.10	0.60	0.24	0.49	0.73	0.86						0.491	moderate	good
		species	1.10	24	6	13	19	27	36					0.725	good	good
		average of parameters												0.572	moderate	
	TI-B	density	1.90	235	97	194	291	353	391	433	527	703	879	0.486	moderate	good
		biomass	1.90	1923	227	455	682	1144	1457	1800	2579	3439	4299	0.768	good	moderate
		similarity	1.90	0.72	0.27	0.55	0.82	0.91						0.523	moderate	good
		species	1.90	29	8	17	25	31	36					0.733	good	good
		average of parameters												0.628	good	
	TE	density	1.50	391	93	186	279	348	393	441	545	727	909	0.991	high	good
		biomass	1.50	1956	219	439	658	1108	1426	1811	2689	3586	4482	0.767	good	moderate
		similarity	1.50	0.71	0.26	0.52	0.78	0.9						0.541	moderate	good
		species	1.50	29	7	15	22	30	36					0.775	good	good
		average of parameters												0.769	good	
2005 autumn	TI-A	density	1.10	382	109	219	328	439	497	563	686	915	1144	0.697	good	good
		biomass	1.10	3022	303	605	908	2471	4119	5717	9300	12400	15499	0.867	high	low
		similarity	1.10	0.77	0.27	0.54	0.81	0.89						0.567	moderate	good
		species	1.10	27	6	13	19	23	29					0.933	high	good
		average of parameters												0.766	good	
	TI-B	density	1.90	246	121	241	362	453	500	544	630	840	1050	0.409	moderate	good
		biomass	1.90	1798	508	1015	1522	3035	4142	5448	8144	10858	13573	0.636	good	moderate
		similarity	1.90	0.76	0.29	0.58	0.88	0.93						0.519	moderate	good
		species	1.90	27	7	15	22	26	29					0.867	high	good
		average of parameters												0.608	good	
	TE	density	1.50	453	116	232	347	447	497	546	647	862	1078	0.823	high	good
		biomass	1.50	2681	356	711	1067	2842	4153	5383	8439	11252	14065	0.782	good	moderate
		similarity	1.50	0.78	0.28	0.57	0.85	0.92						0.546	moderate	good
		species	1.50	33	7	14	21	25	29					1.000	high	good
		average of parameters												0.788	good	

Table 3.
Detail of the BEQI parameter calculations for the years 2008 and 2009 (autumn) with the Thorntonbank as control area. Density is expressed as ind./m²; Biomass is expressed as mg AFDW/m².

		parameter	Assessment		Reference boundary values									EQR		Confidence
			surface	value	Poor min	Mod min	Good min	High min	Reference	High max	Good max	Mod max	Poor max	score	status	Effect size class
2008 autumn	TI-A	density	0.60	457	86	171	257	363	452	565	807	1076	1344	0.991	high	moderate
		biomass	0.60	1618	207	413	620	880	1144	4124	7571	10094	12618	0.968	high	very poor
		similarity	0.60	0.49	0.20	0.40	0.61	0.75						0.481	moderate	good
		species	0.60	19	7	14	21	31	52					0.543	moderate	good
		average of parameters												0.746	good	
	TI-B	density	1.80	686	111	222	333	415	466	524	653	870	1088	0.570	moderate	good
		biomass	1.80	3891	273	546	819	1185	2106	3133	5287	7049	8811	0.730	good	moderate
		similarity	1.80	0.65	0.27	0.53	0.80	0.91						0.490	moderate	good
		species	1.80	50	12	24	36	46	52					0.933	high	good
		average of parameters												0.681	good	
	TE	density	1.20	631	100	200	299	401	463	534	678	903	1129	0.665	good	good
		biomass	1.20	10954	247	493	740	1014	2459	2803	5888	7851	9814	0.178	bad	moderate
		similarity	1.20	0.59	0.24	0.48	0.73	0.86						0.489	moderate	good
		species	1.20	49	10	20	30	41	52					0.945	high	good
		average of parameters												0.569	moderate	
2009 autumn	TI-A	density	1.00	397	104	209	313	461	565	673	894	1192	1490	0.714	good	moderate
		biomass	1.00	2966	422	844	1267	2196	3137	4176	6373	8498	10622	0.964	high	moderate
		similarity	1.00	0.63	0.25	0.50	0.75	0.84						0.505	moderate	good
		species	1.00	31	9	17	26	32	45					0.767	good	good
		average of parameters												0.738	good	
	TI-B	density	1.90	330	126	252	378	497	570	644	801	1067	1334	0.524	moderate	good
		biomass	1.90	1720	565	1130	1695	2625	3220	3959	5480	7307	9134	0.605	good	moderate
		similarity	1.90	0.61	0.28	0.57	0.85	0.91						0.431	moderate	good
		species	1.90	43	11.3	22.7	34	39	45					0.933	high	good
		average of parameters												0.623	good	
	TE	density	1.30	581	112	223	335	476	565	659	861	1148	1435	0.967	high	good
		biomass	1.30	2985	477	954	1431	2415	3213	4141	6144	8192	10239	0.943	high	moderate
		similarity	1.30	0.67	0.26	0.53	0.79	0.87						0.505	moderate	good
		species	1.30	51	10	19	29	35	45					1.000	high	good
		average of parameters												0.854	high	

11.3.2. Control area Goote Bank

It seems that, on average, the benthic characteristics in the subareas showed a lower correspondence with those in the Goote Bank control area. When the Goote Bank is used as control area, we see that the average BEQI value deviated from the values found in the two other subareas in 2008. In the other periods, there was a high correspondence with subarea E and B, except for 2005 for subarea B. The stronger deviation of subarea B from the control area Goote Bank is due to the lowest EQR values for density and similarity in 2005. In this case, it was also the diversity parameter that deviated most compared to the other periods and other subareas.

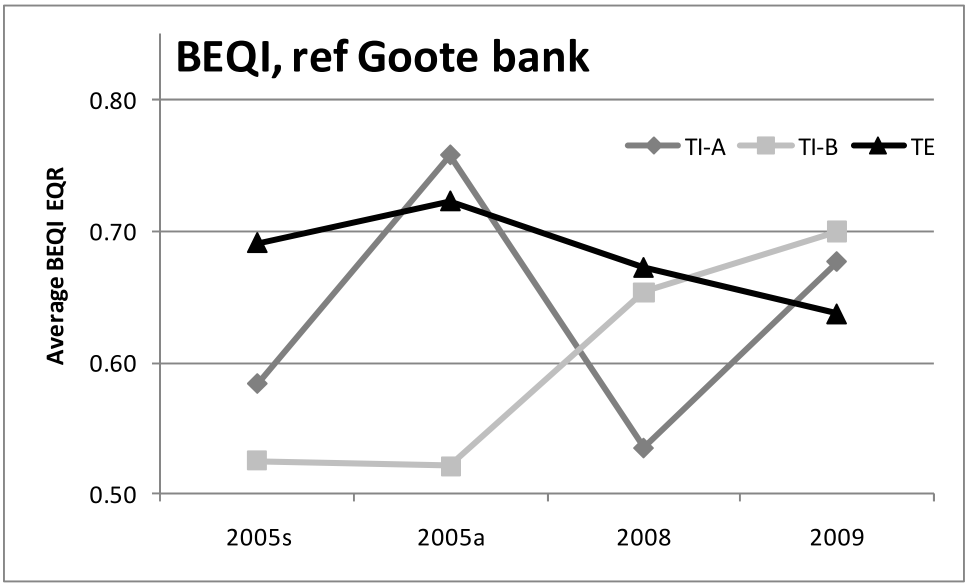

Figure 4. The average BEQI value, level 3 for each sample period for the three subareas

For the parameter density, deviations from the control were observed in 2005 for subarea B, where the density was lower than expected, and in 2009 for subarea E were the density was higher than expected. For the parameter number of species, one major deviation was for subarea A in 2008. The EQR values for the parameter similarity showed a consistent pattern over the sampling period for subareas B and E, but a variable pattern for subarea A with the lowest EQR value in 2008.

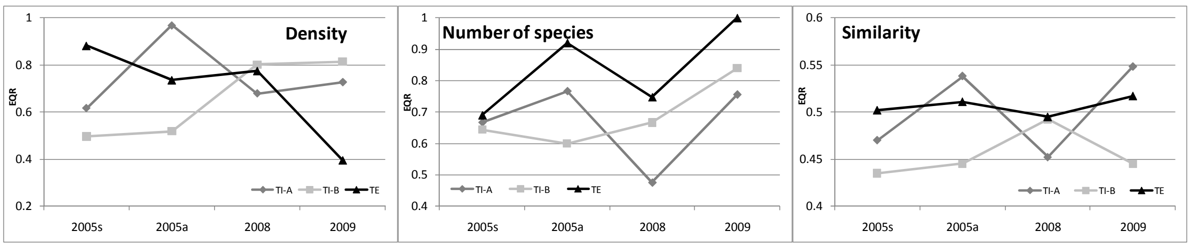

Figure 5. The submetrics of the BEQI, level 3 for each sample period for the three subareas.

Table 4.
Detail of the BEQI parameter calculations for the year 2005 (spring and autumn) with the Goote Bank as control area. Density is expressed as ind./m²; Biomass is expressed as mg AFDW/m².

		parameter	Assessment		Reference boundary values									EQR		Confidence
			surface	value	Poor min	Mod min	Good min	High min	Reference	High max	Good max	Mod max	Poor max	score	status	Effect size class
2005 spring	TI-A	density	1.10	252	81	162	243	354	421	491	638	851	1064	0.616	good	good
		biomass	1.10	3588	278	556	835	2577	3935	5534	9276	12367	15459	0.949	high	low
		similarity	1.10	0.55	0.24	0.47	0.71	0.85						0.470	moderate	good
		species	1.10	24	7	14	21	30	40					0.667	good	good
		average of parameters												0.676	good	
	TI-B	density	1.90	235	95	190	284	371	423	477	585	780	975	0.497	moderate	good
		biomass	1.90	1923	494	988	1481	3122	4138	5432	7990	10653	13316	0.654	good	moderate
		similarity	1.90	0.58	0.27	0.54	0.8	0.92						0.435	moderate	good
		species	1.90	29	9	18	27	36	40					0.644	good	good
		average of parameters												0.558	moderate	
	TE	density	1.50	391	90	180	269	366	427	483	617	823	1029	0.882	high	good
		biomass	1.50	1956	398	796	1194	2836	3985	5327	8368	11157	13946	0.693	good	moderate
		similarity	1.50	0.65	0.26	0.52	0.77	0.89						0.502	moderate	good
		species	1.50	29	8	17	25	34	40					0.689	good	good
		average of parameters												0.692	good	
2005 autumn	TI-A	density	1.10	382	88	175	263	343	389	436	528	704	880	0.969	high	good
		biomass	1.10	3022	421	841	1261	5086	8103	11423	19909	26545	33181	0.692	good	low
		similarity	1.10	0.69	0.26	0.51	0.77	0.87						0.538	moderate	good
		species	1.10	27	7	15	22	28	35					0.767	good	good
		average of parameters												0.758	good	
	TI-B	density	1.90	246	95	190	285	350	387	422	491	655	818	0.519	moderate	good
		biomass	1.90	1798	860	1719	2579	5752	8138	10721	16462	21950	27437	0.418	moderate	moderate
		similarity	1.90	0.63	0.28	0.56	0.85	0.92						0.445	moderate	good
		species	1.90	27	9	18	27	32	35					0.600	good	good
		average of parameters												0.496	moderate	
	TE	density	1.50	453	93	186	279	346	387	427	508	677	847	0.736	good	good
		biomass	1.50	2681	629	1257	1886	5352	8164	10954	17364	23153	28941	0.646	good	moderate
		similarity	1.50	0.70	0.27	0.55	0.82	0.91						0.511	moderate	good
		species	1.50	33	8	17	25	30	35					0.920	high	good
		average of parameters												0.703	good	

Table 5.
Detail of the BEQI parameter calculations for the years 2008 and 2009 (autumn) with the Goote Bank as control area. Density is expressed as ind./m²; Biomass is expressed as mg AFDW/m².

		parameter	Assessment		Reference boundary values									EQR		Confidence
			surface	value	Poor min	Mod min	Good min	High min	Reference	High max	Good max	Mod max	Poor max	score	status	Effect size class
2008 autumn	TI-A	density	0.60	457	121	242	364	598	762	953	1430	1907	2383	0.679	good	moderate
		biomass	0.60	1618	396	793	1189	2234	3667	5339	9032	12042	15053	0.682	good	moderate
		similarity	0.60	0.41	0.18	0.36	0.54	0.7						0.452	moderate	good
		species	0.60	19	8	16	24	39	77					0.475	moderate	good
		average of parameters												0.572	moderate	
	TI-B	density	1.80	685.6	173.3	346.7	520	682.2	788.9	911.1	1164.9	1553.2	1941.5	0.801	high	good
		biomass	1.80	3890.7	647.1	1294.2	1941.3	3089.7	3883	4745.1	6704.3	8939.1	11173.8	0.998	high	moderate
		similarity	1.80	0.62	0.25	0.5	0.76	0.86						0.492	moderate	good
		species	1.80	50	15	30	45	60	77					0.667	good	good
		average of parameters												0.740	good	
	TE	density	1.20	631	154	307	461	655	783	936	1281	1708	2135	0.775	good	moderate
		biomass	1.20	10954	536	1071	1607	3035	3931	4948	7479	9972	12465	0.321	poor	moderate
		similarity	1.20	0.57	0.23	0.46	0.69	0.81						0.495	moderate	good
		species	1.20	49	13	25	38	53	77					0.747	good	good
		average of parameters												0.585	moderate	
2009 autumn	TI-A	density	1.00	397	76	153	229	296	331	367	449	599	748	0.727	good	good
		biomass	1.00	2966	229	458	687	1259	1787	2390	3711	4948	6185	0.713	good	moderate
		similarity	1.00	0.61	0.22	0.45	0.67	0.79						0.548	moderate	good
		species	1.00	31	8	16	24	33	51					0.756	good	good
		average of parameters												0.686	good	
	TI-B	density	1.90	330	86	172	257	306	333	362	419	559	698	0.814	high	good
		biomass	1.90	1720	276	552	828	1417	1817	2278	3167	4222	5278	0.952	high	moderate
		similarity	1.90	0.58	0.26	0.52	0.79	0.87						0.445	moderate	good
		species	1.90	43	11	22	33	41	51					0.840	high	good
		average of parameters												0.763	good	
	TE	density	1.30	581	81	162	242	303	334	369	433	578	722	0.395	poor	good
		biomass	1.30	2985	250	501	751	1345	1805	2343	3626	4835	6043	0.700	good	moderate
		similarity	1.30	0.61	0.24	0.47	0.71	0.82						0.517	moderate	good
		species	1.30	51	9	18	27	36	51					1.000	high	good
		average of parameters												0.653	good	

11.4. Discussion

The year of the construction activities on the Thorntonbank, 2008, is the starting point of possible disturbance of the soft-bottom benthic community. The installment of the six turbines and the sand movements related with it have disrupted the soft bottom in subarea A, and have presumably lead to changes in the benthic community. This because benthic animals were sensitive to physical disturbance (sand removal, sedimentation and changes to the current), especially when they are chronic over a time period.

This was not observed with the average BEQI score (Thorntonbank control area), because the scores for density and number of species compensated for each other. When the BEQI score was calculated with the Goote Bank as control area, a stronger deviation was observed in 2008. Based on the score for number of species, it can be concluded that the diversity of the benthic community was disrupted in 2008. A species, which is abundant in the impacted area is *Spiophanes bombyx* known as an opportunistic polychaete species with high recruitment rates. This was already mentioned in Reubens *et al.* (2009), in which a significant difference in diversity indices between subarea A and the other subareas was described. In 2009, the benthic community characteristics again showed a high correspondence with the characteristics observed in the control areas. This means that, after a single year, the benthic community in subarea A was recovered. This because the recruitment of the benthic species in 2009 was not disturbed in subarea A.

At subarea B, the BEQI average and sub-scores showed a trend of more correspondence between the benthic characteristics between subarea B and control. Only the parameter similarity shows a decreasing EQR trend when the Thorntonbank control area was used as reference. It is too early to make any conclusions, but it can be a signal that subarea B is gradually changing because of small changes in hydromorphology. The main current (Northeast) is affected locally by the presence of the six turbines, possibly leading to changes in sedimentology or food supply in the subarea B, compared to the western area of the Thornton bank.

This test shows that the benthic indicator BEQI is able to detect and summarize the observed changes (decrease in diversity in impact year, quick recovery) in the soft-bottom benthic community on the Thornton bank, due to the construction of six turbines.

11.5. References

Coates, D. & Vincx, M., (2010). Monitoring the effects of offshore wind farms on the soft substratum macrobenthos: Year-1 Bligh Bank and Year-2 Thorntonbank in Degraer, S., Brabant, R. & Rumes, B., (Eds.) (2010). Offshore wind farms in the Belgian part of the North Sea: Early environmental impact assessment and spatio-temporal variability. Royal Belgian Institute for Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 7: 83-103.

De Maersschalck, V., Hostens, K., Wittoeck, J., Cooreman, K., Vincx, M. & Degraer, S., (2006). Monitoring van de effecten van het Thornton windmolenpark op de benthische macro-invertebraten en de visfauna van zachte substraten. 88 pp.

Reubens, J., Vanden Eede, S. & Vincx, M., (2009). Monitoring of the effects of offshore wind farms on the endobenthos of soft substrates: Year-0 Bligh Bank and Year-1 Thorntonbank. *In:* Degraer, S. & Brabant, R., (Eds.) (2009). Offshore wind farms in the Belgian part of the North Sea: State of the art after two years of environmental monitoring. Royal Belgian Institute for Natural Sciences, Management Unit of the North Sea Mathematical Models. Marine ecosystem management unit. Chapter 6: 61-91.

Van Hoey, G., Drent, J., Ysebaert, T., & Herman, P., (2007). The Benthic Ecosystem Quality Index (BEQI), intercalibration and assessment of Dutch coastal and transitional waters for the Water Framework Directive. NIOO report 2007-02.

Van Hoey, G., Borja, A., Birchenough, S., Degraer, S., Fleischer, D., Kerckhof, F., Magni, P., Buhl-Mortensen, L., Muxika, I., Reiss, H., Schröder, A. & Zettler, M. (2010). The use of benthic indicators in Europe: from the Water Framework Directive to the Marine Strategy Framework Directive. Marine Pollution Bulletin 60: 2187-2196.

Annexes

Annex 1: Systematic species list of the soft substratum macrobenthos

Phylum	Class	Order	Family	Species
/	/	/	/	Egg/Larvae
Annelida	Clitellata	/	/	*Oligochaeta* sp.
	Polychaeta	Cirratulida	Paraonidae	*Aricidea minuta*
				Aricidea simonae
		Magelonida	Magelonidae	*Magelona mirabilis*
				Magelona sp.
		Opheliida	Opheliidae	*Ophelia limacina*
		Phyllodocida	Glyceridae	*Glycera lapidum*
				Hesionura elongata
			Hesionidae	*Microphthalmus* sp.
			Nephtyidae	*Nephtys caeca*
				Nephtys cirrosa
			Nereididae	*Nereidinae* sp.
			Phyllodocidae	*Eteone longa*
				Hydrozoa sp.
				Phyllodoce rosea
				Phyllodoce sp.
			Poecilochaetidae	*Poecilichaetus serpens*
			Polynoidae	*Malmgreniella glabra*
				Malmgreniella sp.
		Spionida	Spionidae	*Aonides oxycephala*
				Aonides paucibranchiata
				Scoloplos armiger
				Scolelepis bonnieri
				Spio filicornis
				Spio goniocephala
				Spio sp.
				Spiophanes bombyx
		Terebellida	Terebellidae	*Leptomysis gracilis*
			Pectinaridae	*Pectinaria korenii*
			Terebellidae	*Terebellida* sp.
Arthropoda	Maxillopoda	/	/	*Copepoda* sp.
	Malacostraca	Amphipoda	/	*Amphipode* sp.
			Atylidae	*Atylus falcatus*
				Atylus sp.
				Atylus swammerdami
			Calliopiidae	*Calliopius* sp.
			Caprellidae	*Pariambus typicus*
				Phtisica marina
			Corophiidae	*Corophium* sp.
				Monocorophium
				Monocorophium sextonae
			Eusiridae	*Eusirus longipes*
			Ischyroceridae	*Kurtiella bidentata*
			Leucothoidae	*Euspira pulchella*
				Leucothoe spinicarpa
			Melitidae	*Abludomelita obtusata*
				Maerella tenuimana
			Oedicerotidae	*Oedicerotidae sp.*
				Perioculodes longimanus
				Pontocrates altamarinus
				Pontocrates arenarius
			Pontoporeiidae	*Bathyporeia elegans*
				Bathyporeia
				Bathyporeia pelagica
				Bathyporeia sp.
			Sophrosynidae	*Sophrosyne robertsoni*
			Stegocephalidae	*Stegocephaloides sp.*

			Stenothoidae	*Stenothoe marina*
				Stenothoe sp.
			Urothoidae	*Urothoe brevicornis*
				Urothoe elegans
		Cumacea	Bodotriidae	*Bodotria arenosa*
				Bodotriidae sp.
				Diastylis rathkei
			Pseudocumatidae	*Pseudocuma gilsoni*
				Pseudocuma longicorne
		Decapoda	/	*Brachyura* juv.
			Crangonidae	*Crangon crangon*
				Crangon juv.
			Diogenidae	*Diogenes pugilator*
			Paguridae	*Paguridae* juv.
				Pagurus bernhardus
				Pagurus sp.
			Processidae	*Processa modica*
			Thiidae	*Thia scutellata*
		Mysida	Mysidae	*Glycera alba*
				Leucothoe incisa
				Neomysis integer
Chordata	Actinopterygii	/	/	*Callionymus* sp.
	Leptocardii	Perciformes	Branchiostomidae	*Branchiostoma*
Cnidaria	Anthozoa	Actiniaria	/	*Actiniaria* sp.
			Actiniidae	*Actiniidae* sp.
			Edwardsiidae	*Edwardsia* sp.
	Hydrozoa	/	/	*Jassa herdmani*
Echinodermata	Echinoidea	/	/	*Echinoidea* juv.
		Echinoida	Fibulariidae	*Echinocyamus pusillus*
			Spatangoidae	*Echinocardium cordatum*
	Ophiuroidea	/	/	*Ophiuroidea* juv.
		Asteroidea	Asteriidae	*Asterias rubens*
				Asteriidae juv.
		Ophiurida	Ophiuridae	*Ophiura ophiura*
				Ophiurae juv.
Mollusca	Bivalvia	/	/	*Bivalvia* juv.
		Pectinoida	Pectinidae	*Aequipecten opercularis*
		Veneroida	Tellinidae	*Tellina* juv.
			Semelidae	*Abra alba*
			Montacutidae	*Lanice conchilega*
			Mactridae	*Spisula elliptica*
			Tellinidae	*Tellina pygmaea*
				Tellina tenuis
	Gastropoda	Hypsogastropoda	Naticidae	*Gastrosaccus spinifer*
Nematoda	/	/	/	*Nematode* sp.
Nemertina	/	/	/	*Nemertina* sp.
Porifera	Demospongiae	/	/	*Demospongiae* sp.

Nematoda, Pisces and rare species (all species found in maximum three samples, with a maximum of two individuals per sample) were excluded from all analyses (species highlighted in grey).

The European directive 2001/77/EG imposes each member state a target figure for its contribution to the production of electricity from renewable energy sources. This figure was adjusted in the new European climate plan (January 2008) and is now, for Belgium, set at 13 % of the total energy consumption by 2020.

Since a Royal Decree assigned a zone for the production of electricity in the Belgian part of the North Sea, three companies, C-Power, Belwind and Northwind (formerly Eldepasco), were granted a permit to build and exploit an offshore wind farm on the Thorntonbank, Bligh Bank and Bank zonder Naam, respectively. The permits include an obligation to establish an environmental monitoring programme, focusing on e.g. hydrodynamics and seabed morphology, underwater noise, hard substratum epifouling and fish, soft substratum macrobenthos, epibenthos and fish, seabirds, marine mammals and seascape.

The Management Unit of the North Sea Mathematical Models (MUMM) of the Royal Belgian Institute of Natural Sciences (RBINS) coordinates the monitoring and specifically covers hydro-geomorphology, underwater noise, hard substratum epifauna, radar detection of seabirds, marine mammals and socio-economic aspects. In 2010, MUMM further collaborated with different institutions to complete its expertise in the following domains: seabirds (Research Institute for Nature and Forest, INBO), soft substratum epibenthos and fish (Institute for Agricultural and Fisheries Research, ILVO-Fisheries), atmospheric noise (INTEC of Ghent University), soft substratum macrobenthos and hard substratum fish (Marine Biology Research Group of Ghent University).

This year's report targets a selection of the major findings from the baseline and targeted monitoring on the evaluation of the environmental impacts at the C-Power and Belwind sites.

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