Offshore wind farms in the Belgian part of the North Sea

Early environmental impact assessment and spatio-temporal variability

Edited by
Steven Degraer
Robin Brabant
Bob Rumes

2010

Royal Belgian Institute of Natural Sciences
Management Unit of the North Sea Mathematical Models
Marine Ecosystem Management Section

in collaboration with

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Research Institute for Nature and Forest

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The first phase of the C-Power wind farm on the Thorntonbank (photo Jan Haelters/RBINS)

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Dedicated to Thierry Jacques,
founder of the environmental monitoring of Belgian offshore wind farms
and retired in September 2010

Chapter 1. Executive summary

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Photo RBINS / MUMM

1.1. Introduction

The European directive 2001/77/EG imposes upon each member state a target contribution figure for the production of electricity from renewable energy sources that should be achieved in 2010. For Belgium, this target figure is 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. 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: 60 turbines, 330 MW), Belwind (Blighbank: 110 turbines, 330 MW) and Eldepasco ("Bank zonder Naam": 36 turbines, 180-252 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 still have to apply for an environmental permit.

Both C-Power and Belwind already started the installation of an offshore wind farm. C-Power put in place six gravity based foundation (GBF) windmills on the Thorntonbank in 2008, which were the first windmills in Belgian waters. In 2009 no major construction activities took place at the C-Power concession area. Yet, all six gravity based foundation windmills became fully operational on May 10th, 2009. At the Belwind concession area, construction activities started on September 8th, 2009, when the first of 56 monopiles was driven into the seabed. The piling activities of the first Belwind phase were finished on February 5th, 2010. A transition piece was installed on every monopile and in the first months of 2010 several wind turbines were already installed. It is expected that the first Belwind phase will be operational by the end of 2010.

To allow for a proper evaluation and auditing of the environmental impacts of offshore wind farms, the obliged environmental permit includes a 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[1]. 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 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).

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 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.

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-economical (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 2009, MUMM further collaborated with different institutes to complete the necessary expertise in the following domains: seabirds (Research Institute for Nature

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[1] While Degraer & Brabant (2009) and this report mainly deal with the results of the baseline monitoring aspect, it is anticipated that targeted or process monitoring issues will become more pronounced in the future scientific reports.

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.

and Forest, INBO), soft substratum epibenthos and fish (Institute for Agricultural and Fisheries Research, ILVO-Fisheries), and soft substratum macrobenthos and hard substratum fish (Marine Biology Section of Ghent University). For details on the specific research strategies followed and methodologies used, one is referred to the individual chapters.

1.2. This report's focus

Although an exhaustive and thorough evaluation of possible impacts of marine wind farms in the BPNS will only be possible after the first six years of monitoring, 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 group of scientific reports presented data on the baseline situation at future impact and reference sites[2]. The following compiled scientific report (Degraer & Brabant, 2009) 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). This year's report on data collected in 2009 mainly targets 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).

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, each having a selected focus. For a detailed description of all monitoring activities in 2009, one is referred to the monitoring activity report 2009, which is expected to be available late 2010.

1.2.1. Early impact assessments

While most impacts – both positive and negative – will only become established and detectable when more wind turbines will be installed (i.e. local cumulative effects) and or after a certain period of time (i.e. time lag) (Degraer & Brabant, 2009), some localized impacts can be expected to be expressed from the early stages of the wind farm development onwards. The latter cover either local alterations in geophysics as a direct or indirect consequence of the construction activities, or immediate alterations of the local biota as a consequence of the introduction of hard substratum, a new habitat type in a naturally soft sediment environment. As such, in this report early impacts were detected for (1) the geophysical environment of both the GBF windmills at the Thorntonbank and the monopile windmills at the Blighbank, (2) the establishment of hard substratum biota on and nearby the GBF windmills at the Thorntonbank and (3) the social attitude towards offshore renewables.

1.2.2. Natural spatio-temporal variability

The marine environment can and should not be considered to be stable. Cyclic phenomena, such as tides or seasonality, and (more) erratic phenomena, such as storms or cold winters, are important structuring features of the marine environment, especially in a temperate environment such as the North Sea. Each ecosystem descriptor (e.g. species richness, abundance, but also sediment transport and bathymetry) hence shows a certain natural dynamism. However, although each ecosystem shows at least some variability, this variability is to be found within specific limits, which is described by the ecosystem's dynamic equilibrium. This natural variability should be taken into account when aiming

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[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. 136 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.

at the quantification or even detection and evaluation of anthropogenic impacts onto the marine ecosystem. In fact, anthropogenic impacts are only visible and should only be considered relevant when they are pushing one or more ecosystem descriptors outside the dynamic equilibrium limits. This issue becomes particularly important when using a Before-After Control-Impact (BACI) design, in which the changes within the concession areas during construction and exploitation of the wind farms are not only compared with the state of highly similar, though non-impacted reference sites, but also with the state before the construction started (i.e. reference condition). A proper knowledge of the (natural) spatio-temporal dynamics of the reference conditions hence is a major advantage not only for a future quantification of the anticipated impacts, but also for the evaluation of the relevance of these impacts.

Given the fact (1) that only six windmills were in place during the major part of the monitoring year 2009 and (2) that the impact of these six windmills at a larger scale (e.g. marine renewable energy zone) is considered to be negligible, the combined 2008 and 2009 measurements thus allow for a description of (part of) the dynamic equilibrium of those ecosystem components for which no small scale data are available (yet). As such, this report focuses on the natural spatio-temporal variability within the soft substratum macrobenthos, soft substratum epibenthos, soft substratum fish and marine mammals.

1.2.3. Issues regarding future monitoring

Taking into account the lessons learnt from the 2009 monitoring activities, several issues regarding the future monitoring were raised. These issues covered aspects of fine-tuning the monitoring design (e.g. reference site evaluation), as well as the resource allocation and focus for integrating the baseline and targeted or process monitoring. While these considerations do not drastically change the monitoring design and hence do not hamper the continuity of the monitoring program, they will be a major help for future monitoring improvement.

1.3. Early impact assessment

1.3.1. Hydro-geomorphology

1. Comparison of the turbidity at the Thorntonbank and the Goote Bank, which was selected as reference site, showed suspended particulate matter (SPM) to be generally low (1-9 mg/l) and did not show any significant increase due to the construction works of the six GBFs.
2. As foreseen as a first step within the dynamic erosion protection at the Belwind site, erosion pits were observed nearby the monopiles at the Blighbank. The depth of the erosion pits varied between 2 and 6.5 m, depending on the prevailing sediments, geological substratum and hydrodynamics. No secondary erosion was detected around the C-Power GBFs at Thorntonbank, where the erosion protection layer is in place.
3. As a consequence of losses during dredging (10% loss rate), disposal works (20-25% loss rate) and natural erosion (8% loss rate), 280000 m^3 of sediment was lost during the backfill and infill operations of the installation of the GBFs, which lead to the creation of sand pits. These pits tend to be relatively stable, since no natural filling occurred so far.
4. Over the entire length of the C-Power cable trajectory, a depth of burial of around 2 m was reached. Except in certain areas with clay layers, only 1 m depth of burial was obtained. Given the specific hydrodynamic circumstances at the BPNS, with e.g. relatively high sand wave migration rates, regular verification of cable burial is advised.

1.3.2. Underwater noise

1. Maximum peak sound pressure levels (SPL) of 196 dB re 1µPa were recorded at 520 m from the place of piling at the Blighbank. Although the use of a transition loss model should be interpreted

with care for the near field (< 100 m) environment, the SPL at the apparent source was estimated at 270.7 dB re 1µPa (95% CI: 260.4 – 281.1 dB re 1µPa). This level is a concern for a.o. marine mammals in an area of at least tens of kilometer around the piling site.

1.3.3. Hard substratum macrofauna

1. In 2008 and 2009, a total of 75 taxa (mostly species), of which 42 taxa had not previously been recorded at the site under investigation, were encountered at the GBFs of the Thorntonbank. Most species (62) were found in the subtidal part of the GBFs, while another 13 taxa inhabited only the intertidal zone.
2. The three zones pattern observed in 2008, with an intertidal – splash zone, a transitional barnacle-*Jassa* zone and an extensive subtidal zone, became more diversified from summer 2009 onwards, with a conspicuous mussel belt establishing in the transitional barnacle-*Jassa* zone and an intertidal barnacle *Semibalanus balanoides* belt in the splash zone.
3. Both species richness and density showed a marked spatio-temporal pattern, with an increasing species richness and decreasing macrofaunal density with increasing depth and an increase in both species richness and density from winter to summer. Maximum species richness and density were respectively 27 spp./0.625 m² and some 20000 ind./m², respectively.
4. The observed temporal variability (at the species-level) should be interpreted as a combination of a medium-term seasonal cycle, overlaying a longer-term successional trajectory.
5. Three of the four non-indigenous species encountered in 2008, were found again in 2009: the slipper limpet *Crepidula fornicata*, the New Zealand barnacle *Elminius modestus* and the giant midge *Telmatogeton japonicus*.

1.3.4. Hard substratum fish

1. Being the commonest of seven fish species encountered at the GBFs on the Thorntonbank (line fishing, gillnet fishing and visual scuba diving surveys), pouting *Trisopterus luscus* reached a density of 7-74 ind./m² on the erosion protection layer. In other words, a single GBF hosted an estimated 29000 individuals or 3.500 kg wet weight of pouting. Pouting length ranged from 13 to 34 cm.
2. From the 46 prey types collected from the guts and stomachs of line fished pouting, the amphipod *Jassa herdmani* and its tube mats, crabs, such as *Pisidia longicornis* and detritus were most frequently (11-67 %) encountered. Especially *J. herdmani* (84 % of numerical prey abundance) and *P. longicornis* (10 %), two of the most common hard substratum macrofaunal species, tended to dominate the food composition of pouting at the Thorntonbank GBFs.

1.3.5. Soft substratum epibenthos, bentho-pelagic and demersal fish

1. Higher epibenthos, demersal fish and – to a lesser extent – bentho-pelagic fish densities (and biomass) were found within the reference and fringe areas compared to the impact site at the Thorntonbank. The opposite was true for the Bligh bank. These differences are a result of natural variation and as such, no changes related to the installation of the windmills were (yet) detected in the community structure of the epibenthos, bentho-pelagic and demersal fish.
2. However, some differences were observed within the impact area at the Thorntonbank, including a lower sole *Solea solea* density in spring 2009 and an increased density of horse mackerel *Trachurus trachurus* in autumn 2009 compared to the Thorntonbank reference area. These changes could possibly be attributed to altered food resources and or an altered competition as a consequence of the attraction to the GBFs (i.e. artificial reef function).

1.3.6. Socio-economic aspects

1. Compared to 2002, the population with a positive attitude towards offshore wind farms increased with 10% by 2009.

2. Still, people highly value the wideness and openness of the sea view, the naturalness and the tranquility of the marine environment, which consequently influences the perception of wind farm impact. Next to ecological and economic considerations, especially distance from the coast, orientation and number of visible windmills are hence considered important determinants of the public perception of offshore wind farms.

1.4. Natural spatio-temporal variability

1.4.1. Soft substratum macrobenthos

1. From a sedimentary perspective, the monitoring areas at the Bligh Bank and Thorntonbank (i.e. impact areas) and the Goote Bank (i.e. reference area) are highly similar, with a domination of medium sand (median grain size: 250-500 µm) in absence or with a very low mud content (max. 1 %) and a low organic matter content (0.3-1.8%). This pattern showed no significant difference over time (2005-2009).
2. The macrobenthic community structure showed quite some natural spatio-temporal variability, with macrobenthic densities, ranging from 10 – 1930 ind./m², being significantly lower in 2009 compared to 2008 at the Blighbank and to 2005 at the western part of the concession area at the Thorntonbank. Species richness (N0), ranging from 1 to 24 spp./0.1 m², was however comparable to 2005 and 2008, as well as biomass, ranging from < 0.001 to 37 g/m². As previously found, dominant species were *Nephtys cirrosa*, *Bathyporeia guilliamsoniana* and *Spiophanes bombyx*, although local variation exists.

1.4.2. Soft substratum epibenthos, bentho-pelagic and demersal fish

1. The variability of these three ecosystem components is mainly determined by geographic and seasonal patterns, of which seasonality is the most important structuring factor for both bentho-pelagic and demersal fish, while geographic patterns tend to determine the epibenthos.
2. Differences between sandbank tops and gullies were observed in all three ecosystem components, but were not consistent over the years, seasons and sandbank systems.

1.4.3. Seabirds

1. Through a refinement of the statistical set up, the observed seabird densities were modeled through a quasi-likelihood estimation, which will now allow for an improved testing of the difference in seabird occurrence and density between control and impact sites. This modeling process will also allow for a power analysis, as an estimation of the probability of being able to statistically detect changes.

1.4.4. Marine mammals

1. Since aerial surveys yielded actual population size estimates of up to 4000 individuals (i.e. 1.6 % of the total North Sea population), the harbour porpoise *Phocoena phocoena* should be considered a significant top of the food chain constituent at the BPNS.
2. A long-term pattern of elevated harbour porpoise occurrence at the BPNS is demonstrated by the tenfold increase of strandings between 1970 and 2009 (1970-1997: max. 6 ind./y versus 2005-2007: > 85 ind./y), which can be interpreted a southward shift in the spatial distribution of the southern North Sea harbour porpoises.
3. Combined data from aerial surveys, porpoise detector (PoD) recordings and strandings monitoring revealed a clear seasonal pattern, with harbour porpoises being typically abundant in late winter and early spring (min. 0.68 ind./km²), while in late spring to autumn lower numbers (max. 0.31 ind./km²) tend to stay in more offshore and northerly waters.

4. Erratic events of increased or decreased invasion of harbour porpoises in the BPNS might however blur the seasonal spatio-temporal pattern, which complicates our understanding of its spatial distribution and migration behaviour.

1.5. Issues regarding future monitoring

1.5.1. Hydro-geomorphology

1. Despite similar geographic, sedimentary and hydrodynamic conditions, the turbidity data suggest that the Goote Bank might be unsuitable as a reference site for the Blighbank and Thorntonbank regarding the monitoring of turbidity.

1.5.2. Underwater noise

1. To fine tune our estimates of noise propagation in the bathymetrically complex BPNS, further attention will be paid to the attenuation characteristics of underwater noise.

1.5.3. Soft substratum macrobenthos

1. Future baseline monitoring will target the only dominant macrobenthic community, prevailing in sediments with a median grain size of 350-400 µm. As such, the number of sampling locations can now be reduced in favour of replication (five replicates per sampling locations), allowing for an enhanced statistical reliability of the impact evaluation.
2. Future targeted monitoring will focus on the localized impacts of organic matter enrichment as a consequence of the biofouling drop offs from the windmills.

1.5.4. Soft substratum epibenthos, bentho-pelagic and demersal fish

1. To enlarge the spatial, as well as temporal scope, one ILVO long-term monitoring station, situated south of the Goote Bank, was found to fulfill all preset requirements and will hence be continued to be used as a reference station for the Thorntonbank gullies.
2. The application of short tracks (i.e. average: ~1800 m instead of ~3500 m) is considered acceptable for monitoring the effects of windmills on epibenthos, bentho-pelagic and demersal fish and will hence be implemented in the 2010 monitoring activities. This change in sampling methodology will facilitate the collection of beam trawl samples in the immediate vicinity of windmills and will increase the chance of detecting local changes.

1.5.5. Seabirds

1. The improved statistically approach proved northern gannet *Morus bassanus*, sandwich tern *Sterna sandvincensis*, black-legged kittiwake *Rissa tridactyla*, common guillemot *Uria aalge* and razorbill *Alca torda* to be suitable for the future impact evaluation at either the Thorntonbank and or the Blighbank.

1.5.6. Marine mammals

1. Aerial surveys will be performed on a more regular basis, with special emphasis on (a) an equal distribution of the counts over the year and (b) direct observations of the immediate impact of piling activities.
2. Given the continuity of data retrieved by PoDs, allowing for the detection of short- to medium-term impacts, it is advised to further elaborate the monitoring through PoDs.

1.5.7. Socio-economic aspects

1. Given the considerations on distance from the coast, orientation and number of visible windmills regarding the public's acceptance of offshore wind farms, a follow-up inquiry on the attitude towards a further infilling of the wind farm area is proposed.

Chapter 2. Introduction: offshore wind energy development in the Belgian part of the North Sea & anticipated impacts

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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 be achieved in 2010. For Belgium, this target figure is 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 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, MUMM 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 report 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 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 certain expertise of the marine environment. The costs of the monitoring program are paid by the permit holders.

At this time, three companies have been granted environmental permits to build and exploit an offshore wind farm: C-Power in 2004, Belwind in 2008 and Eldepasco in 2009. C-Power had its permit revised in 2006 and 2008, and the monitoring programme was adapted accordingly (Table 1). Eldepasco will be located on the ‘Bank zonder Naam’. This is a sandbank located at mid-distance between the C-Power concession on the Thorntonbank and the Belwind concession on the Bligh Bank (Figure 1). Whilst C-Power and Belwind have already started their construction activities, Eldepasco’s construction activities will not start before 2011. More information on those projects can be found on following websites: www.c-power.be, http://meewind.nl/belwind/ & www.eldepasco.be

In 2009 two new projects were granted a domain concession. The Norther project is located in the southern part of the wind energy zone, the other one, Rentel, obtained a concession in between C-Power and Eldepasco (Figure 1). A third project, Seastar, was granted a concession in March 2010. As to now, neither of these projects have applied for an environmental permit yet (Table 1).

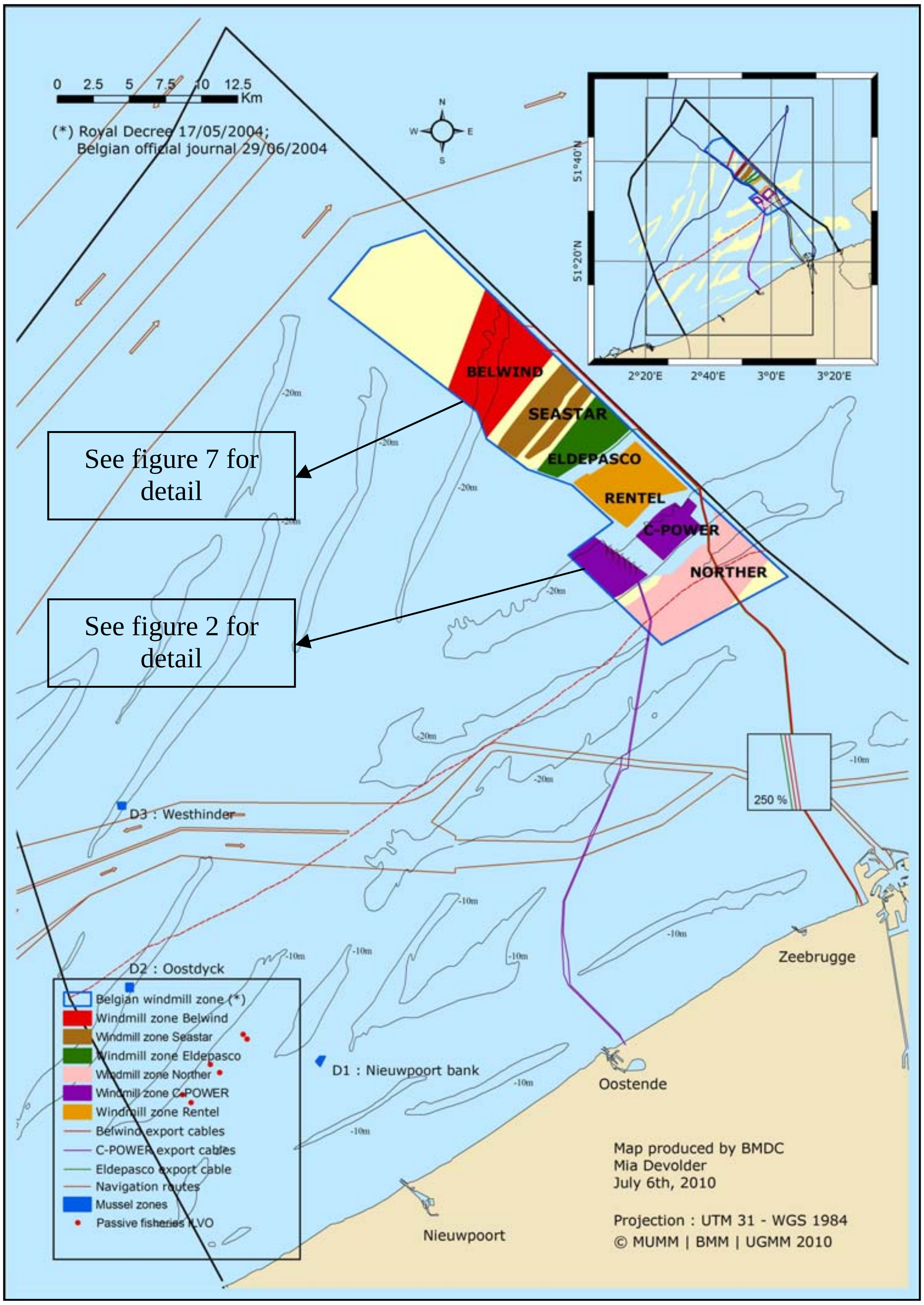

Figure 1. Zone reserved for the production of electricity by the Royal Decree of 17 May 2004.

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	No application yet	
Rentel	4/6/2009	No application yet	
Seastar	24/3/2010	No application yet	

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 56 turbines will be installed. During phase I, six turbines were installed on row D of sub-area A (Figure 2).

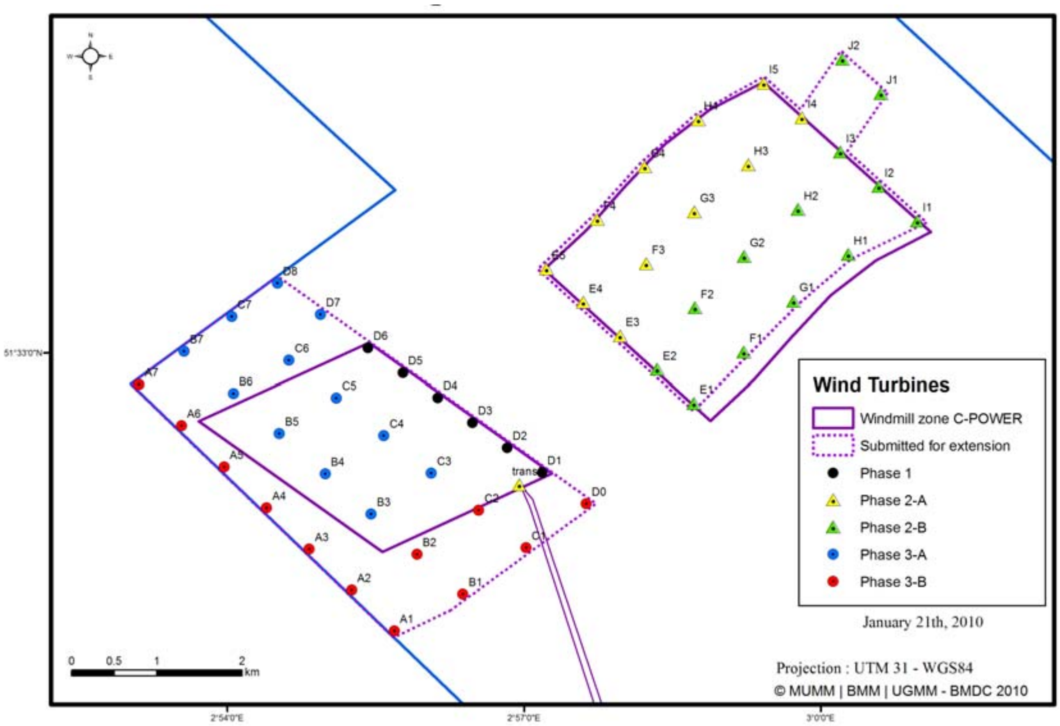

Figure 2. Layout of the C-Power project.

Because pile driving at first seemed to be difficult on the Thorntonbank, C-Power decided to build gravity based foundations (GBF) for their phase I. These GBFs are hollow, concrete structures that are filled with sand, once they sit on the seabed. Due to its weight, the GBF remains stable. The GBFs were constructed in the port of Ostend and then shipped to the Thorntonbank (Figure 3).

Because the Thorntonbank is a sandbank characterised by large dynamic dunes, there is a necessity to level the seabed at the wind turbine location before the GBF can be placed. A foundation pit was dredged to remove the loose sand and to create a flat surface on dense seabed. This sand was dumped at three temporary disposal areas, within the concession area, situated in the gullies between the large dunes of the Thorntonbank. A foundation bed of about 1 m thick and about 30 m diameter was laid in the foundation pit before the GBF was lowered. That foundation bed consists of a filter layer and a gravel layer. Crushed gravel is used for both layers. The diameter of the gravel used for the gravel layer (10 to 80 mm) is slightly bigger than what is used for the filter layer (0 to 63 mm).

The six GBF were set in place in 2008. The temporarily stored sand was re-used as (1) backfill material to increase the stability of the structures, (2) backfill of the temporary trench that was dredged for the cable-crossing of the sea-lane and (3) infill of the foundations.

Finally, a scour protection was laid around each GBF. This is a layer of gravel and rocks that should prevent the erosion of the backfill sediment by water currents accelerating around the structures (Figure 4). This scour protection consists of a filter and an armour layer. The crest diameter of those layers is different for every GBF. The filter layer crest diameter varies between 48.5 m and

62.5 m. The armour layer goes on top of the filter layer and the crest diameter varies between 44 m and 58 m. The filter layer is minimum 0.60 m thick and consists of crushed gravel with a diameter of 10 to 80 mm. The armour is 0.70 m thick and consists of quarried rock. The weight of those rocks ranges from 10 to 200 kg (Peire *et al.*, 2009).

Figure 3. Transport of a GBF from the port of Ostend to the Thorntonbank (Peire *et al.*, 2009)

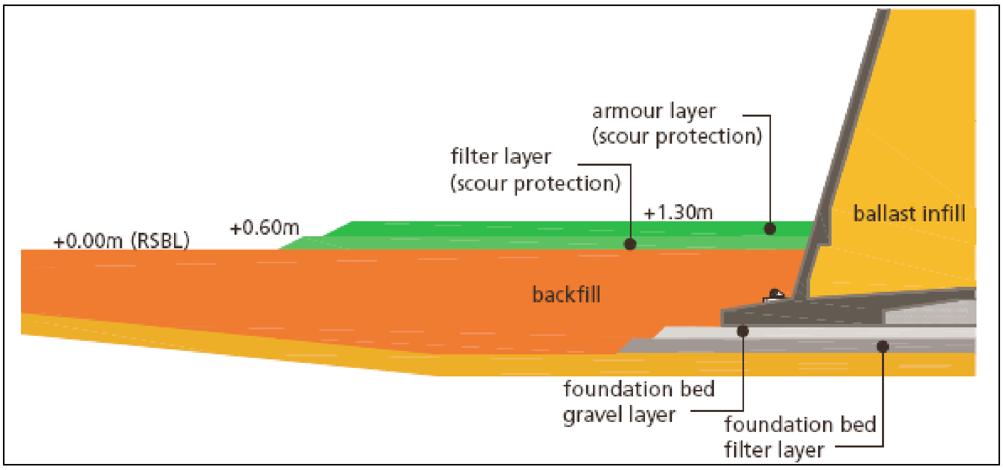

Figure 4. Lay-out of the GBF installation (Peire *et al.*, 2009).

C-Power installed the first six turbines (Repower, 5MW), i.e. phase I of the project, in summer of 2008 (Figure 5). In the first months of 2009, C-Power commissioned and started the phase I of the project. All six turbines were producing electricity on the 10th of May 2009 (Figure 6).

In 2010 bottom surveys are conducted in preparation of construction phase II, which is scheduled for 2011. C-Power will possibly use another type of foundation for the construction of phase II, but a final decision has yet to be taken.

Figure 5. Installation of a turbine on the Thorntonbank (Photo RBINS).

Figure 6. C-Power phase-I on the Thorntonbank produces electricity since May 2009 (Photo RBINS).

2.2.2. Belwind

The Belwind project is situated on the Bligh Bank at about 40 km of the Belgian coast (Figure 7). Water depth in the concession area varies between 15 and 40 m. The sub sea cable comes ashore at Zeebrugge.

Belwind will operate 110 Vestas V90-3MW turbines with a total capacity of 330 MW. Construction of the park is divided in two phases. Belwind started with the construction of phase I, 55 turbines and 1 offshore high voltage station (OHVS), in September 2009.

Instead of gravity based foundations (GBF) Belwind will use monopiles (MPs). The MPs are driven into the seabed with a hammer (Figure 8).

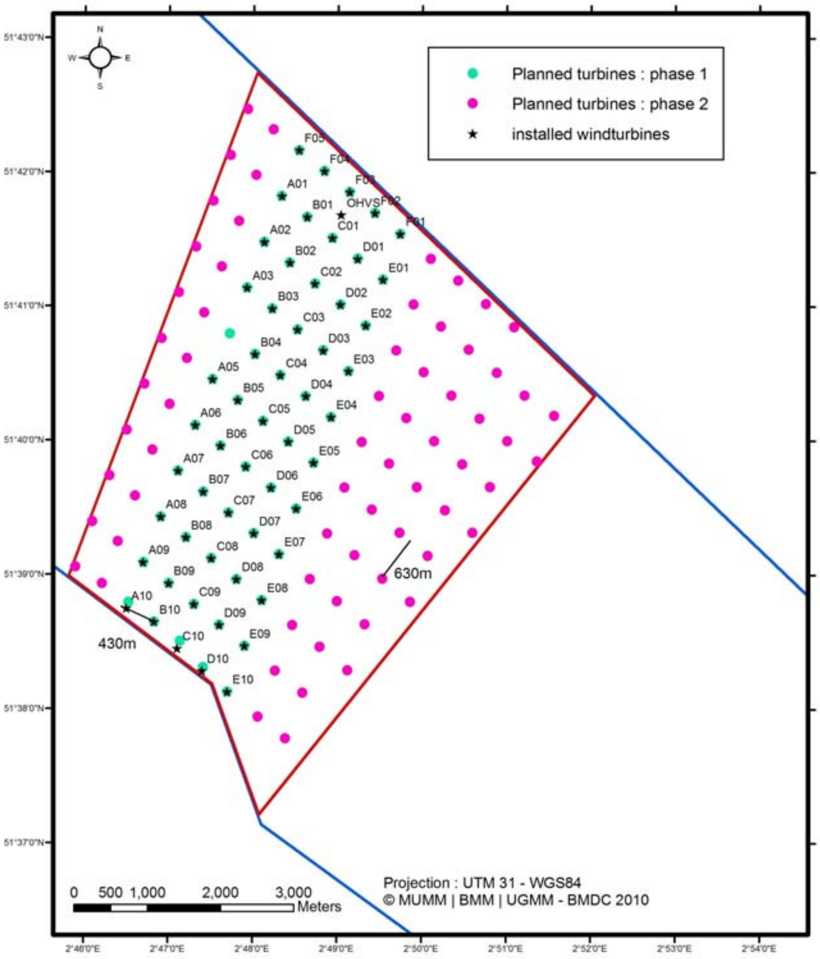

Figure 7. Lay out of the Belwind project (situation 1/2/2010).

Figure 8. The piling vessel Svanen, with a monopile ready to be lifted and piled and the red and white hammer central in the image (Photo RBINS).

In total 56 MPs needed to be installed. The first one was driven into the seabed on September 8th 2009. The 56th, and last, monopile was installed on February 5th 2010.

The MPs were towed out the port of Zeebrugge, one by one, with a tug vessel. The ends of the monopiles were closed with plugs. During the transport to the Bligh Bank, two of the 56 monopiles sank due to damaged hydraulics in the plugs (Figure 9) and had to be recovered. The incidents occurred on October 24th and November 7th. After the second incident the local port authorities suspended the transport permits until an investigation into the causes was done. This resulted in a re-design of the plugs. Furthermore, additional safety measures were implemented, for instance the sea state for which the transport of MPs was allowed, was reduced from 1.5m significant wave height to 1m significant wave height. After the investigation and the re-design the transport of MPs started again on 12 December. The above mentioned incidents together with bad weather conditions during the end of November and beginning of December, explain why only one MP was installed in November (Figure 10).

Figure 9. Two monopiles sank during the transport from the port of Zeebrugge to the Bligh Bank. MP C05, which was lost on October 24th, remained partially above the water surface (Photo Belwind).

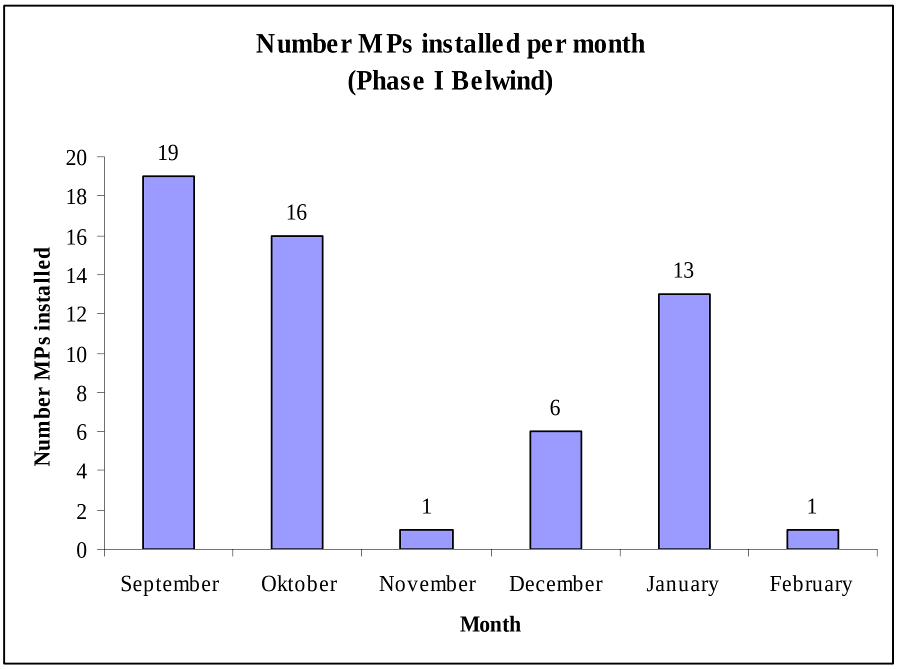

Figure 10. Number of MPs installed per month for the phase I of the Belwind project (2009-2010).

On every monopile a transition piece (TP) was installed. The TP makes the connection between the MP and the wind turbine (Figure 11). In 2010, Belwind will install 55 wind turbines and one offshore high voltage station. In the first months of 2010, several wind turbines were already installed (Figure 12). After the infield cables and the land cable are laid, the phase I of the project should be operational by the end of 2010.

Figure 11. Installed MPs with transition pieces (yellow) on the Bligh Bank (Photo RBINS).

Figure 12. Wind turbines on the Bligh Bank, installed in the first months of 2010 (Photo RBINS).

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 achieving 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 positive and/or negative for the marine ecosystem.

The environmental impact assessments (MUMM, 2004 & 2007) revealed a variety of possible impacts, e.g.:

- Erosion around wind turbine foundations by accelerating currents next to the foundations;
- Increased turbidity during the construction of the wind farms;
- Underwater noise generated during construction and exploitation phase and the associated impact on marine mammals and fish;
- Colonisation of the introduced hard substrata (i.e. foundations) by epifauna and the possible stepping-stone effect for 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 soft substrata by the hard substratum epifauna;
- Impact of wind farms on the distribution, densities and migration routes of seabirds and marine mammals;
- Public perception of offshore wind farms.

With the monitoring programme, MUMM and its partners will assess the extent of the anticipated impacts on the different aspects of the marine ecosystem and will try to reveal the processes behind the impacts. In 2009, we reported on the lessons learnt and recommendations from the first two years of environmental monitoring (Degraer & Brabant, 2009). This year's report targets the first scientific results on the natural spatio-temporal variability and the evaluation of the early and localized environmental impacts at the C-Power and Belwind sites.

2.4. Acknowledgement

The authors wish to thank Steven Degraer for reviewing this paper and the critical remarks he made.

2.5. References

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Chapter 3. Monitoring of hydrodynamic and morphological changes at the C-Power and the Belwind offshore wind farm sites – A synthesis

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Photo RBINS / MUMM

Abstract

In 2008 the first six wind mills of the C-Power farm were installed on the Thornton Bank using gravity based foundations (GBF). The use of GBFs implies important dredging works to prepare the sea bed, whereby sand piles were stored in the concession area. The construction of 110 turbines on monopiles at the Bligh Bank for the Belwind farm started in 2009. Dynamic erosion protection was chosen around the monopiles, allowing the development of an erosion pit around the monopiles; later this pit is refilled with material ensuring protection against erosion. The effects of the installation of the wind turbines, especially of the GBFs and of the dynamic erosion protection, on the turbidity and the morphodynamics of the sand banks is not well known; therefore assessment of possible impacts is necessary, based on a sound monitoring programme.

The monitoring includes: (1) measurements of currents, waves and turbidity, near the wind mill parks and at a reference site, before the works, during the works and after the works; (2) the control of the possible erosion and generation of erosion pits around the foundations of the turbines; (3) monitoring of the coverage of the cables from the farms to the shore; and (4) monitoring of the movement and evolution of the sand piles or pits, which were generated, during the construction of the GBFs.

Measurements of the turbidity, currents and waves were executed on the Thornton Bank before the works, during the works and after the works by International Marine and Dredging Consultants (IMDC) and at a reference site, located at the Goote Bank. Although biofouling of the OBS sensors disturbed some of the measurements, the analysis of the results showed that no significant increase in turbidity could be demonstrated. Measurements on the Bligh Bank were executed before the works by MUMM. The measurements during and after the works are foreseen in 2010 and 2011.

The sea bed around the GBFs was intensively monitored. In the final survey, the scour protection is clearly visible. No indication of secondary scour is apparent. The monitoring of the dynamic erosion protection at the Bligh Bank was executed around six monopiles. In the north of the farm, an erosion pit of 6.5 m was developed.

The depth of burial of the cable of the C-Power farm to the shore was monitored during the jetting and the ploughing of the cable. The cable lies most of the time 2 m below the sea bed, although at some sections with clay layers, only 1 m was obtained.

Finally, the monitoring showed that, during the installation of the GBFs, an important amount of sand was dredged at the concession area for the backfill of the foundation pits and the fair channel, and that some sand pits were created. It appeared that more material was dredged and used than was expected. During backfill, most of the sediment was lost during disposal. Monitoring of these sand pits, during several months, showed that the sand pits are relatively stable and that no natural filling of the sand pits occurs.

Samenvatting

In 2008 werden de eerste zes windturbines voor het C-Power windpark gebouwd op de Thorntonbank, gebruik makend van gravitaire funderingen. Het gebruik van deze gravitaire funderingen impliceerde belangrijke baggerwerken om de zeebodem voor te bereiden, waarbij zandhopen gecreeërd werden in het concessiegebied. Voor het Belwind park startte de constructie van 110 turbines op monopile funderingen in 2009. Rond de monopiles werd gekozen voor een dynamische erosiebescherming, waarbij de ontwikkeling van een erosieput wordt toegelaten, alvorens deze put te vullen met materiaal, die de bescherming tegen erosie moet garanderen. Het effect van deze windmolens, vooral door het gebruik van gravitaire funderingen en van dynamische erosiebescherming, op de turbiditeit en de morfodynamica van de zandbanken is nog niet voldoende gekend, zodat een monitoring werd opgelegd, om de impacten in te schatten.

Deze monitoring omvat: (1) metingen van stromingen, golven en turbiditeit ter hoogte van het windmolenpark, en op een referentiesite, voor de werken, tijdens de werken en na de werken; (2) de controle van het ontstaan van erosieputten rond de funderingen van de turbines; (3) de controle van de bedekking van de kabels van de parken naar de kust; en (4) de monitoring van de bewegingen en de

evolutie van de zandhopen of -putten, die werden gegenereerd als gevolg van de gravitaire funderingen.

Metingen van de turbiditeit werden uitgevoerd op de Thorntonbank voor, tijdens en na de werken door International Marine and Dredging Consultants (IMDC), evenals op een referentiesite op de Gootebank. Ondanks het feit dat begroeiing van de OBS sensoren de metingen verstoorden, kon de analyse van de resultaten geen significante verhoging van de turbiditeit, als gevolg van het windmolenpark aantonen. Voor de Blighbank, werden metingen van de turbiditeit voor de werken uitgevoerd door BMM. De metingen tijdens en na de werken zijn voorzien in 2010 en 2011.

De zeebodem rond de gravitaire funderingen werd intensief opgemeten. In de finale meetcampagne is de erosiebescherming rond de funderingen duidelijk zichtbaar. Er was geen aanduiding van de aanwezigheid van secundaire erosieputten. De monitoring van de dynamische erosiebescherming werd uitgevoerd rond zes monopiles. In het noorden van het park werden erosieputten tot 6,5 m opgemeten.

De diepte van de kabel onder de zeebodem van het C-Power park, naar de kust, werd opgemeten tijdens de installatie van de kabel. De kabel ligt over het gehele traject op een diepte van ongeveer 2 m, uitgezonderd in enkele secties met harde kleilagen, waar slechts een diepte van 1 m werd bereikt.

Gedurende de installatie van de gravitaire funderingen werd een belangrijke hoeveelheid zand gebaggerd en vervolgens gestockeerd als zandhopen voor het heropvullen van de funderingsputten en de vaargeul. Op deze locaties toonde de monitoring echter depressies aan en bleek veel meer materiaal weggebaggerd, dan oorspronkelijk begroot. Dit is wellicht te wijten aan verliezen tijdens de bagger- en stortwerken, alsook aan natuurlijke erosie. Monitoring van de zandputten, over verschillende maanden, toonden aan dat de putten relatief stabiel zijn, en dat er weinig natuurlijke opvulling van de putten optreedt.

3.1. Introduction

3.1.1. Context

A worldwide climate strategy was agreed upon in the framework of the 1992 United Nations Climate Change Convention and its 1997 Kyoto Protocol. One of the essential components to renewable energy is the use of offshore windmills. Permits were given to the consortia C-Power NV, Belwind NV and Eldepasco NV to build and exploit offshore wind farms. The C-Power farm comprises 60 windmills and is constructed 27 km from Zeebrugge on the Thornton Bank. The water depth varies between 12 and 27 m MLLWS (mean lowest low water during spring tide). The wind farm will have a total power of 300 MW. In 2008 the first six windmills were installed on the Thornton Bank. The Belwind wind farm lies 42 km offshore on the Bligh Bank and is, today, the world’s most offshore wind farm. Water depth varies between 20 and 35 m MLLWS. The farm will have a total power of 330 MW. The construction of 110 turbines started in 2009. The start of the construction of the Eldepasco wind farm on the Bank Zonder Naam is foreseen in 2011.

In the Environmental Impact Report (Ecolas, 2003; 2005; 2007) and the Environmental Impact Assessment (EIA) (MUMM, 2004; 2006; 2007a; 2007b), the possible effects of the construction and the exploitation of the wind farm on the marine environment are discussed. For the hydrodynamic and morphological aspects, main effects to be expected are: (1) increase in turbidity; (2) formation of erosion pits around the foundations; and (3) erosion around the cables. Specifications of this monitoring, methodological approach and first results are presented in the next sections.

Due to the water depth and geology of the Thornton Bank, gravity based foundations (GBF) were used. Because of the large sand dunes on the Thornton Bank, a seabed levelling was required before the GBFs could be placed. A foundation pit was dredged removing the loose sand and creating a flat surface on dense sand. Part of the sand could be re-used to infill the GBF itself, as back-fill of the construction pit or for the backfill of the temporary trench that was dredged for the cable-crossing of the sea-lane. It was expected that, finally, a net amount of 385,000 m³ of sand had to be disposed within the concession area, situated in the troughs between the large dunes.

To ensure that the height of the sand piles was restricted to the height of the sand dunes (*i.e.* about 5 m), three disposal sites were defined. These sites had to be located in the concession zone where the sand transport would redistribute the sand towards the possible erosion pits around the GBFs. To define the best possible position for these disposal sites, information from MUMM (2006) was used, giving a general overview of the estimated sediment transport, based on numerical modelling and bedform asymmetries. The latter were derived from multibeam bathymetry maps (Roche and Degrendele, Federal Public Service Economy, SME's and Energy, unpublished). From the bedform asymmetries, sand transport direction to the northeast was derived for the southern part of the Thornton Bank. Model results (Van den Eynde, 2005) did confirm a dominance of the northeast sand transport; as such, it was decided to define three sand disposal sites southwest of the constructed wind turbines. Monitoring is required to follow-up of the evolution of these sand piles.

For the Belwind wind farm, dynamic erosion protection was chosen around the monopiles. This means that an erosion pit around the monopiles was allowed to develop. This pit then was refilled with erosion protection. The fact that the formation of erosion pits was accepted, could have important implications on the increase in turbidity in the area.

Overall, it was considered that important uncertainties still exist on the possible effects on the hydrodynamics and morphodynamics in the area, especially considering the fact that GBF and dynamic erosion protection were used, and therefore an appropriate monitoring campaign was set up.

3.1.2. Environmental setting

The Thornton and Goote Bank, as also the Bank Zonder Naam, are quasi coast parallel sandbanks, belonging to the Zeeland Ridges, whilst the Bligh Bank is one of the Hinder Banks, lying more obliquely to the coastline (see Figure 1). Minimum water depths are close to -6 m MLLWS for the Zeeland Ridges and -9 m for the Bligh Bank. In the swales, -28 m up to -36 m is reached, respectively. Sandbank length is about 15 km for the Goote Bank, 30 km for the Thornton Bank and 24 km for the Bligh Bank. Widths vary from 1 km for the Bligh Bank, up to more than 4 km for the Zeeland Ridges. Sandbanks are covered with large to very-large dunes (*senso* Ashley, 1990) with a wavelength of several hundreds of meters, a crest length of several tens of metres and heights varying from 2 m to 6 m. Their asymmetry varies according to preceding hydro-meteorological conditions (Lanckneus et al., 2001). The cross-section of the sandbanks is clearly asymmetrical, with the steeper side (slope ~3 %) facing south-east for the Zeeland Ridges and Bligh Bank. The gentle slopes of the banks are less than 1%. The topography of the Goote Bank is the least pronounced. Medium sands characterise the sandbanks with a median grain size between 300 µm and 350 µm. The geological substratum consists of alternating sand and clay layers of the Tertiary.

Semi-diurnal tides of macrotidal range (4-5 m at spring tide) characterise the hydrodynamics. Average tidal movement corresponds to an elongated current ellipse, with a southwest-northeast axis. Flood and ebb peak currents are oriented towards the northeast and the southwest, respectively. Tidal currents are rotating counter clockwise around the Zeeland Ridges; clockwise around the Bligh Bank. Surface peak currents reach up to 1 m/s; flood and ebb currents are competitive in strength, thought the ebb period lasts longer. Sand transport directions are linked to the tidal currents. Flood currents are strongest along the southern slope of the Zeeland Ridges, whilst the ebb is strongest along the steep side of the Bligh Bank (Van Lancker et al., 2007). Mostly, an ebb oriented sand transport is observed along the gentle slope of the Zeeland Ridges, though dependent on preceding hydro-meteorological conditions.

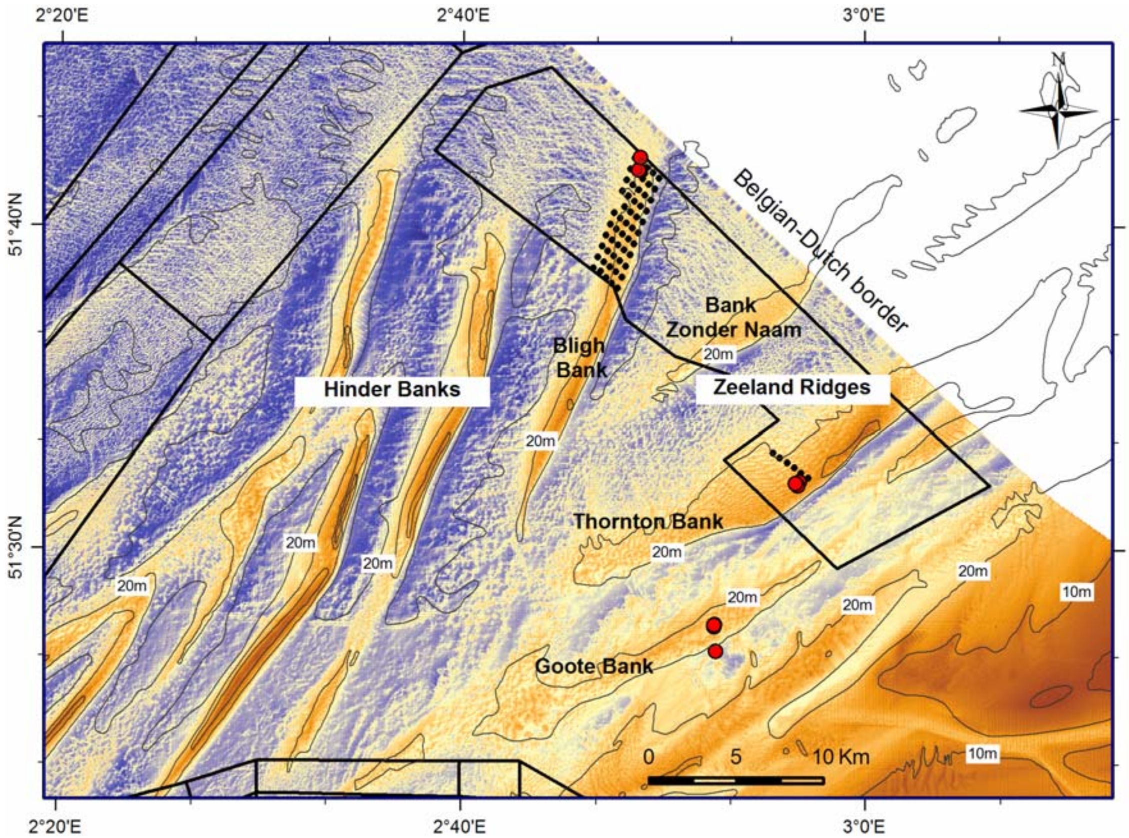


Figure 1: Bathymetry of the Thornton Bank, Bank Zonder Naam, Bligh Bank and Goote Bank. The black dots indicate the position of the windmills, the red dots indicate the position of the turbidity and current measurements.

3.2. Material and methods

3.2.1. Monitoring

The monitoring comprises four sections. First of all, measurements of currents, waves and turbidity were specified near the wind farms. To investigate the effects of the works and of the exploitation of the windmills, measuring campaigns were set up before, during and after the works. It was expected that meteorological effects could have significant effects on turbidity also; therefore simultaneous measurements were done near the windmills and at a nearby reference site. As reference site, the Goote Bank was chosen. The measuring campaigns had to be executed for a period of at least 15 days, to cover a spring-neap tidal cycle. International Marine and Dredging Consultants (IMDC) executed the monitoring for the C-Power wind farm; MUMM the one for Belwind.

A second part of the monitoring consists of bathymetrical surveys to identify erosion and formation of erosion pits around the foundations of the turbines. Based on numerical sediment transport studies (Van den Eynde, 2005; 2007), and on maps of median sand grain size of the Belgian part of the North Sea (BPNS) (Van Lancker et al., 2007), some specific sites were selected for the measurements, *e.g.* on the top of the sand bank. The bathymetrical surveys had to be carried out 1 month after the installation of the foundation, one month after the construction, after a severe storm in the area and one month after this storm during the first year. Additionally, a yearly control of the erosion pits had to be executed.

Further, the coverage of the cables in the wind farms and from the farms to the shore needs regular verification. To ensure a burial of 1 m, as requested by the environmental permit, the cable is buried, where possible, at two meter below the sea bottom. However, in some sections with clay layers, only 1 m is reached. Monitoring is important to assure that the cable will remain buried. These control measurements have to be executed after a severe storm in the area and one month after this storm. Additionally, a yearly control is needed.

Finally, an additional monitoring was defined in the case GBFs were used (C-Power wind farm). As indicated above, it was expected that an excess volume of 385,000 m³ sand had to be stored in the concession zone. In the EIA it was specified, that this storage of sand should occur in piles, with a maximum height of the same order of the sand dunes in the area, *i.e.* 5 m height, and preferably at such a place that the natural sand transport will use this sand to fill the construction pits. However, there are still large uncertainties on natural sand transport on these sand banks and on the behaviour of such sand piles. Therefore, it was specified that the movements of the stored sand had to be monitored with the same frequency, as the control of the erosion pits.

3.2.2. Measurements of the turbidity

Monitoring of currents, waves and turbidity were executed on the Thornton Bank and on the Goote Bank (reference site) (IMDC, 2008a; 2008b; 2008c; 2009a). For current profiles, water level and wave heights, an Acoustic Doppler Current Profiler (ADCP) from RD Instruments was used. An optical back scatter sensor OBS3A (Campbell Scientific) was mounted on the ADCP at about 0.7 m above the bottom (mab). Furthermore, an RCM9 current meter (Aanderaa) was used as backup for current, turbidity and water level. The RCM9 was deployed at 2 to 3.8 m above the bottom. A laboratory calibration, using fine material from the harbour of Oostende, was performed relating OBS readings in Nephelometric Turbidity Units (NTU) to the actual material in suspension in mg/l. Fine material was used for this calibration, since measurements with a Laser In-Situ Scattering and Transmissometry sensor (LISST) showed that on the Kwinte Bank, a sand bank 15 km offshore, the material in suspension consists of fine-grained cohesive material (Fettweis, 2008). To estimate the effect of the works on the suspended particulate matter (SPM), three measuring campaigns were executed: before (IMDC, 2008b), during (IMDC, 2008c) and after the works (IMDC, 2009a). In table 1 the period of the measurements and the position of the ADCP and OBS3A sensor are indicated.

Table 1
Location and period of deployments of the ADCP and OBS3A for C-Power monitoring.

Thornton Bank			
Before	51°32’08.4”	2°56’44.8”	18/02/2008 - 03/03/2008
During	51°32’00.8”	2°56’40.0”	17/06/2008 - 17/07/2008
After	51°32’05.1”	2°56’32.6”	05/06/2009 - 03/07/2009
Goote Bank			
Before	51°27’38.6”	2°52’30.7”	14/02/2008 - 03/03/2008
During	51°27’42.9”	2°52’32.3”	17/06/2008 - 24/07/2008
After	51°27’41.8”	2°52’30.5”	05/06/2009 - 14/07/2009

During the summer campaigns biofouling on the OBS sensors started after about 14 days of deployment on the OBS sensors and the Thornton Bank RCM9 and after 26 days on the Goote Bank RCM9. During the last campaign, the OBS sensor on the Goote Bank was lost.

MUMM monitored currents and turbidity on the Bligh Bank. Two tripod benthic bottom landers were deployed by the *RV Belgica* on the Bligh Bank and on the Goote Bank (reference site), respectively. The tripod measuring system was developed to monitor SPM and current velocity. Mounted instruments include a SonTek 3 MHz Acoustic Doppler Profiler (ADP), a SonTek 5 MHz Acoustic Doppler Velocimeter (ADV Ocean), a Sea-Bird SBE37 CT conductivity sensor system, two OBS sensors (one at about 0.2 m above the bottom, the other one at about 2 m above the bottom), and two SonTek Hydra systems for data storage and batteries. The ADV Ocean includes an altimeter, measuring the distance from the measuring point to the bottom. This can provide information on the movement of the bottom, and thus indirectly of sediment transport near the bed. On the tripod system, deployed on the Bligh Bank, also a LISST-100X, together with an additional OBS, were mounted. This LISST measures particle size of the material in suspension. Furthermore, an ADCP was deployed nearby the tripod, to measure current profiles.

To calibrate the OBS sensors, field calibration was executed at a location nearest to the tripod location using the *RV Belgica*. During a tidal cycle, a Niskin bottle was closed every 20 or 30 minutes, resulting in about 30 to 40 samples per tidal cycle. Three sub samples were filtered on board using pre-weighted filters (Whatman GF/C). After filtration, filters were rinsed with Milli-Q water to remove salt, and dried and weighted to obtain the SPM concentration. A linear correlation between OBS readings and SPM concentrations was established. Remark that measuring SPM concentration is associated with uncertainties. The uncertainties due to filtration and consequently also on SPM concentration derived from OBS, are relatively higher in clearer waters due to a relatively higher systematic error. Fettweis (2008) showed that tidal cycle measurements, taken in low turbide waters, include a systematic error of 4.5 mg/l.

The ADV data have been used to calculate the bottom shear stress, based on turbulent kinetic energy, which can be obtained for the variance of the velocity fluctuations (Fettweis et al., 2010). Since the measurements are executed in water depths of about 25 m, and waves were limited, no wave correction was applied in this case.

MUMM executed one measuring campaign before, during and after the works. In table 2, the location and period of the deployments are given. A joint measuring campaign with IMDC, for the Eldepasco monitoring, is being executed in May 2010, with tripods deployed simultaneously on the Bank Zonder Naam, Bligh Bank and Goote Bank.

Table 2
Location and period of deployments of the ADCPs and tripods for the Belwind monitoring.

Bligh Bank			
Before	51°41’47.5”	2°48’44.4”	24/06/2009 - 14/07/2009
During	51°42’10.4”	2°48’49.6”	21/10/2009 - 09/12/2009
Goote Bank			
Before	51°27’00.6”	2°52’40.2”	23/06/2009 - 13/07/2009
During	51°26’53.2”	2°52’35.2”	19/10/2009 - 09/12/2009

For the Bligh Bank campaign, before the works, the recordings with the LISST were limited to 2 days, and those of the ADP to 18 days. Due to technical problems the CTD, ADV and OBS did not work properly during the works on the Bligh Bank and only data from the ADP, LISST-100X and OBS are available. Therefore a second measuring campaign, during the works on the Bligh Bank, was set-up in May 2010. Biofouling started deteriorating the OBS data quality after about 9 days on the Goote Bank (before) and 14 days on the Bligh Bank and Goote Bank (during).

3.2.3. Bathymetric measurements

Bathymetric measurements were performed using a Reson Seabat 8125 multibeam for the monitoring of erosion pits in the C-Power farm by Dredging International. GEOxyz executed the bathymetric measurements for the Belwind consortium, using a Simrad EM2003 multibeam.

During the construction of the GBFs, the morphological evolution of the construction site was intensively monitored (C-Power, 2009). For each of the 6 GBFs, five surveys were executed. A survey prior to the works was executed from February 28 to 29, 2008. A survey after the dredging of the foundation pits and one after installation of the gravel bed were executed in April 2008; a survey, prior to the installation of the filter layer in September 2008, and a final survey, after the completion of the works, in June 2009.

Three measuring campaigns at 6 monopiles have been executed by Dredging International: A10 in the southwest corner of the farm, C05 and D06 in the middle of the farm, and F03, F04 and F05 in the north of the farm. Surveys were executed on January 6, January 15 and February 8, 2010.

Differential bathymetry maps were produced with respect to reference bathymetry, obtained in August 2009 (Belwind, 2010).

For the 150 kV cable of the C-Power wind farm to the cable landing at Oostende, a monitoring has been executed during jetting and ploughing of the cable. The cable laying ended on September 29, 2009.

On February 27-28 2008, a reference survey of the bathymetry at the disposal sites in the concession area was executed. Further, five bathymetric surveys in 2008 and two in 2009 were carried out. A first campaign was executed on April 22, 2008, after the dredging of the foundation pits.

3.3. Results

3.3.1. Hydrodynamics and SPM concentration measurements

In figure 2 the measurements during the works on the Thornton Bank of currents, waves and SPM are presented as an example (from IMDC, 2009b). It can be observed that after about 14 days, OBS3 measurements halted, due to biofouling on the sensors.

Waves were higher during the campaign in February 2008, in the winter period, than during the campaigns in June-July 2008 and June-July 2009, occurring in summer time. Around March 1st, 2008, a storm passed by, with significant wave heights higher than 3.5 m at the Thornton Bank.

Statistical analyses of wave, current and SPM concentration data was performed (IMDC, 2009b). The analysis showed that SPM concentration was low, on the Thornton Bank and Goote Bank. During the winter period, the median SPM concentration was 9 mg/l on the Goote Bank and 4 mg/l on the Thornton Bank. The analyses showed that high turbidity was correlated with higher wave conditions. However, during periods of high waves, low concentrations occur as well, indicating that wave action is not the only driving factor. During the summer periods, the median concentration of SPM on the Thornton Bank and Goote Bank was very low (1 to 2 mg/l). The measurements showed a similar behaviour of SPM concentration on the Thornton Bank and Goote Bank.

In Figure 3, the measurements at the Bligh Bank, before the works, are presented. The SPM concentrations at the Bligh Bank during June-July 2009 show a clear correlation with spring-neap tidal cycle variation, and almost no influence of wave activity is visible. SPM concentrations are low (< 5 mg/l) at both locations, except during autumn 2009 when the SPM concentration was surprisingly high on the Goote Bank (see Table 3). The tidal cycle measurement, during the same period, indicated mean values of 32 mg/l and a maximum of 58 mg/l; data from the tripod confirmed these values during the first days of deployment. SPM concentration decreased again a few days later.

During the measurement periods, significant wave heights of up to 2.2 m were recorded. Median significant wave heights were lower during the measurements (62 cm: June-July 2009; 64 cm: October-November 2009) than during the corresponding season of 2009 (66 cm, 95 cm). Mean SPM concentration was only slightly higher during periods with significant waves higher than 1.5 m on the Goote Bank (0.2 mab: 5.5*/1.0; 2 mab: 5.4*/1.2) and on the Bligh Bank (2 mab: 3.2*/1.2; 2 mab: 3.2*/1.3), both for June-July measurements (compare with Table 3). During the October-November measurements, no correlation was found and highest SPM concentrations occurred during lower wave conditions.

Altimeter data combine information of bed level changes and vertical movements of the tripod itself, due to settling. During the deployment the bed level changed during spring tide, possibly due to moving ripples or erosion/deposition events. During neap tide, no sediment transport at the bottom is apparent and the bed level remained nearly constant for about 5 days.

Current profiles at the Bligh Bank, during the works, are shown over the first 13 m above the bottom in Figure 4. Since no ADCP was available for deployment during this first campaign at the Goote Bank, an ADCP was used from Afdeling Maritieme Dienstverlening en Kust, Afdeling Kust. Unfortunately, no ADCP data were available during the second campaign.

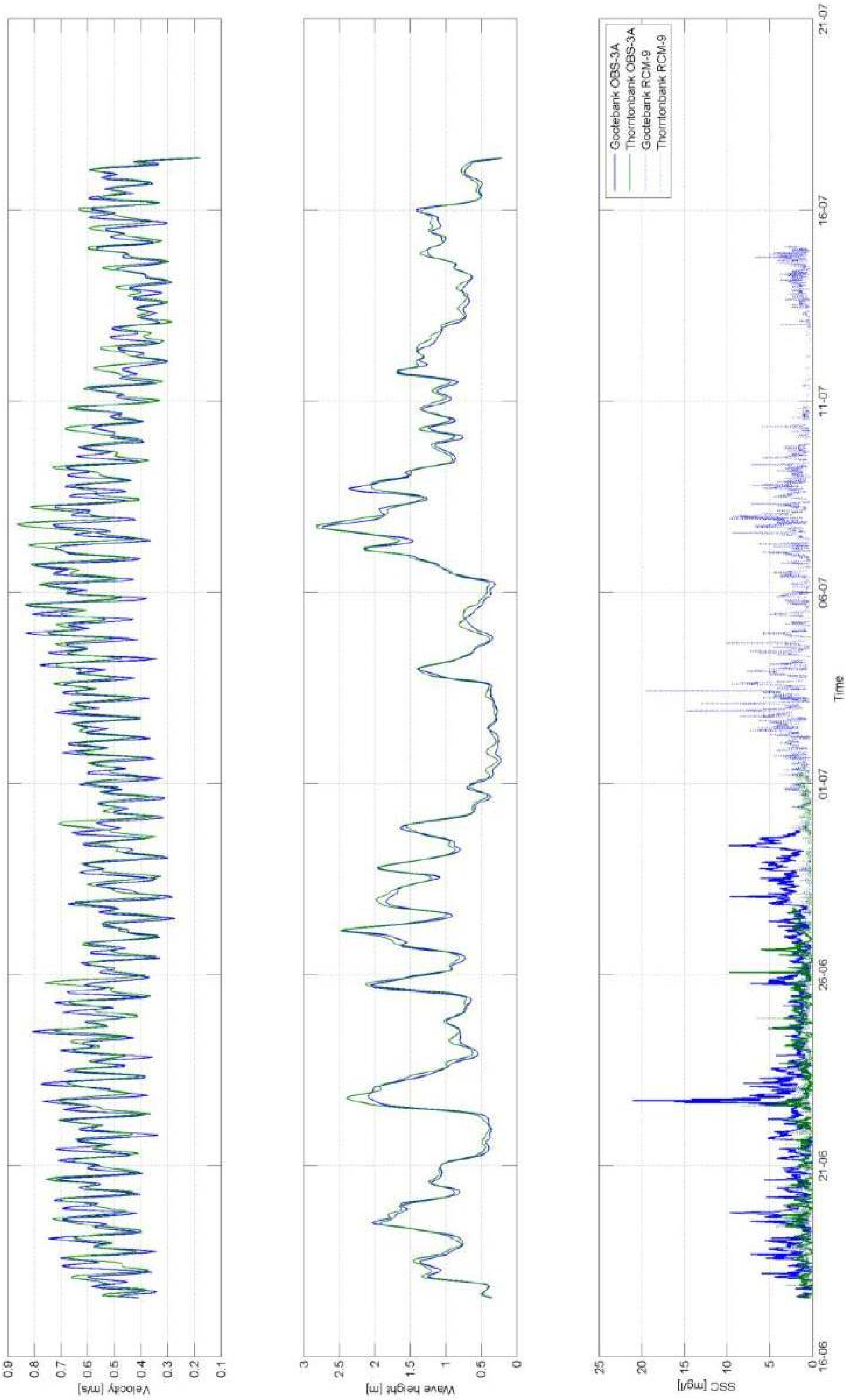


Figure 2: Measurements at the Thornton Bank and the Goote Bank in June-July 2009. Top: currents; middle: wave height; bottom: SPM measurements (from IMDC, 2009b).

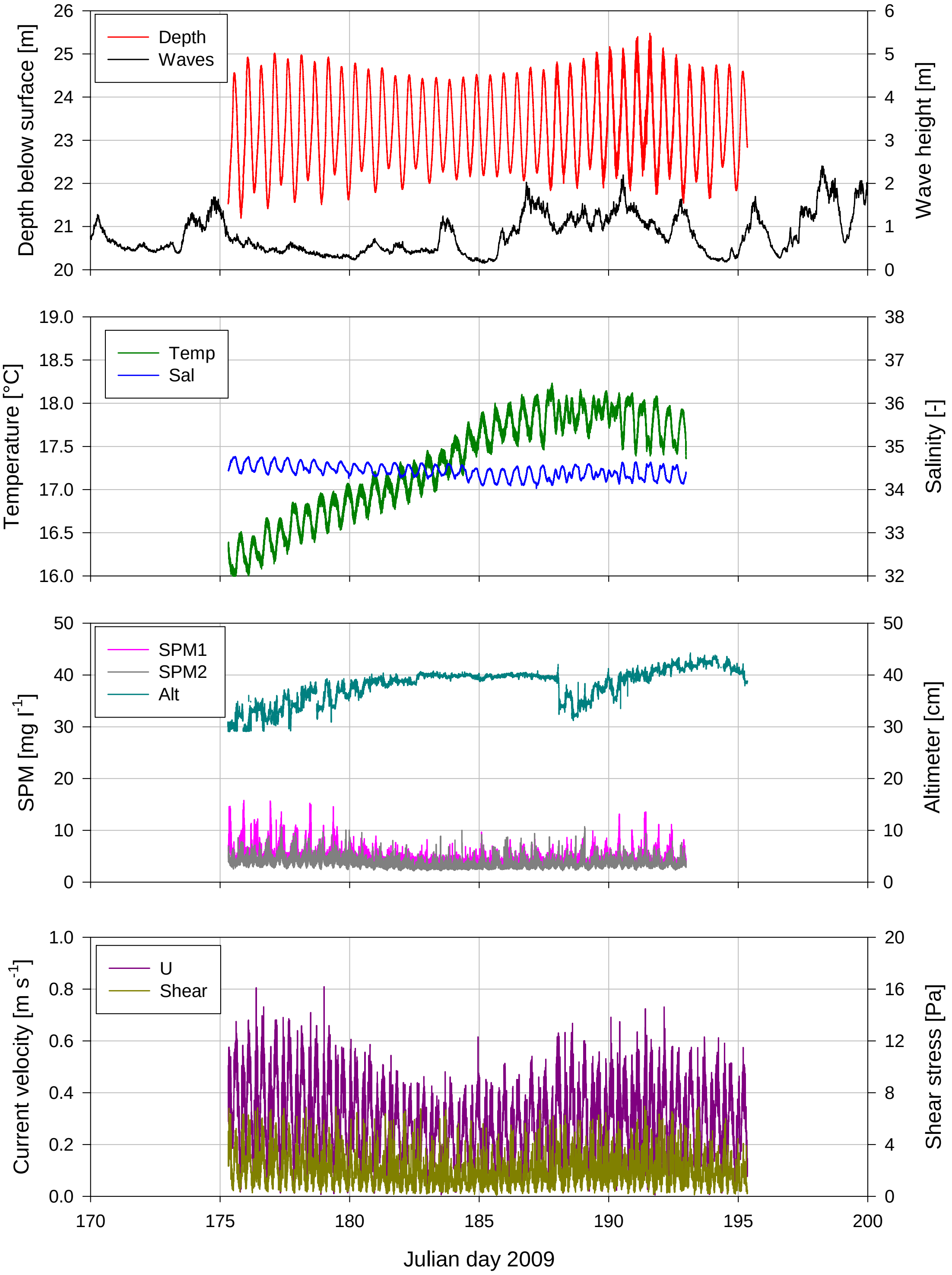


Figure 3: Measurements at the Bligh Bank (MUMM), during the Belwind monitoring campaign, before the works. Significant wave height data are from Akkaert Zuid (Meetnet Vlaamse Banken, Agentschap Maritieme Dienstverlening en Kust, Afdeling Kust); upper middle: temperature and salinity; lower middle:. SPM1: SPM concentration at 0.2 m above bottom, SPM2: SPM at 2.0 m above bottom, Alt: distance between ADV measuring volume and sea bottom; bottom: current velocity from the ADV and calculated bottom shear stress.

Table 3: Mean SPM concentration (mg/l) during tidal cycle and tripod measurements on Goote Bank and Bligh Bank. For the tidal cycle data the standard deviation, due to natural variability, is shown, whereas for the tripod data the multiplicative standard deviation is shown.

Location	Period	Type	Measuring height (m above bed)	SPM concentration (mg/l)
Goote Bank	25-26/06/2009	Tidal cycle	3.0	5.1±0.9
	23/06-3/07/2006	Tripod	0.2	5.2*/1.1
	23/06-3/07/2006	Tripod	2.0	5.1*/1.1
	19-20/10/2009	Tidal cycle	3.0	31.9±13.2
	19/10-6/11/2009	Tripod	0.2	14.4*/1.9
	19/10-6/11/2009	Tripod	2.0	11.2*/1.8
Bligh Bank	24/06/2009	Tidal cycle	3.0	4.0±0.7
	24/06-3/07/2009	Tripod	0.2	3.1*/1.3
	24/06-3/07/2009	Tripod	2.0	3.1*/1.2
	20-21/10/2009	Tidal cycle	3.0	4.5±0.8
	21/10-7/11/2009	Tripod	2.0	4.3*/2.2

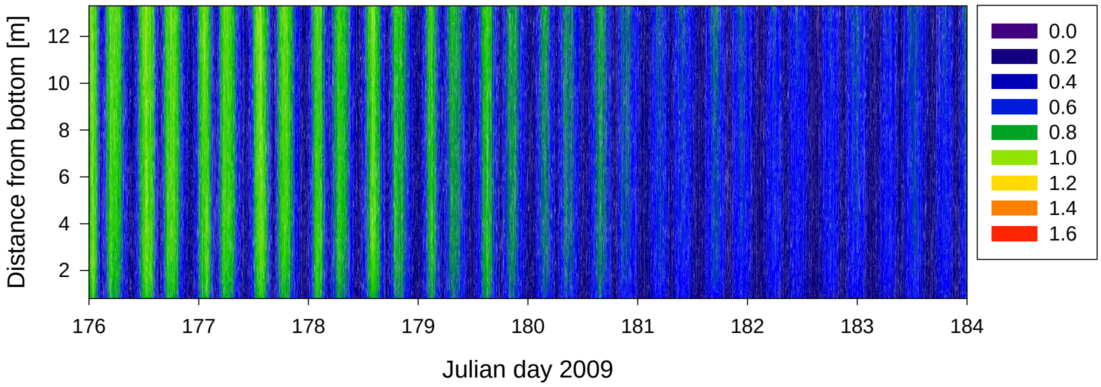


Figure 4: ADCP measurements at the Bligh Bank, during the Belwind monitoring campaign, before the works.

Finally, the average particle size, as measured by the LISST, are shown for the same campaign in Figure 5. The measurements, with a frequency of 1 Hz, show large variability. A 10 minutes running mean shows that the average flock size is around 250 μm during spring tide, decreasing to 200 μm during neap tide.

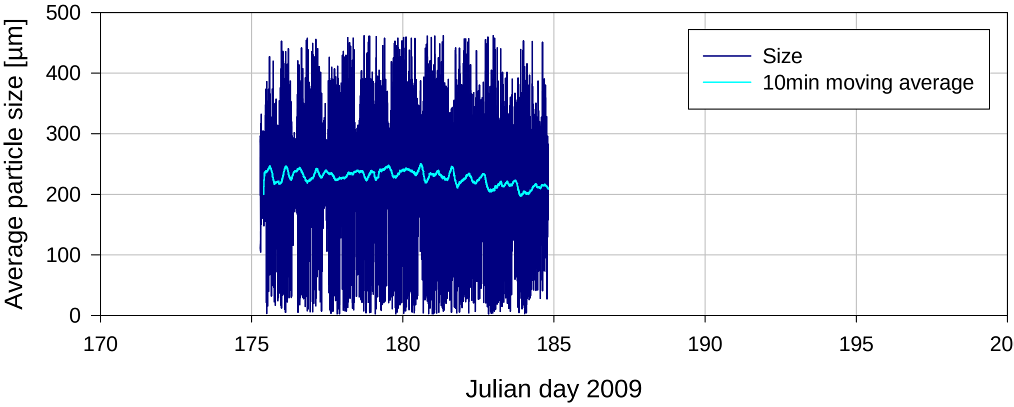


Figure 5: LISST measurements at the Bligh Bank, during the Belwind monitoring campaign, before the works, with a 10 minutes moving average.

3.3.2. Bathymetric measurements of erosion pits

In Figure 6, the results of four surveys around one of the GBFs, *i.e.* GBF2 at (51°32’24.63”N, 2°56’49.75”E), are presented. The bathymetry before the works, after the dredging of the foundation pit, prior to the installation of the filter layer and after the works, are shown. The foundation pit is clearly visible. However, after the installation of the erosion protection, no indication of secondary scour is found.

The erosion pits around the monopiles, during the dynamic erosion protection on February 8, 2010, were relatively limited and varying between 2 m (A10), 2.7 m (C05 and D06), 4-4.5 m (F04 and F05) and 6.5 m of depth (F03) (see Figure **7**).

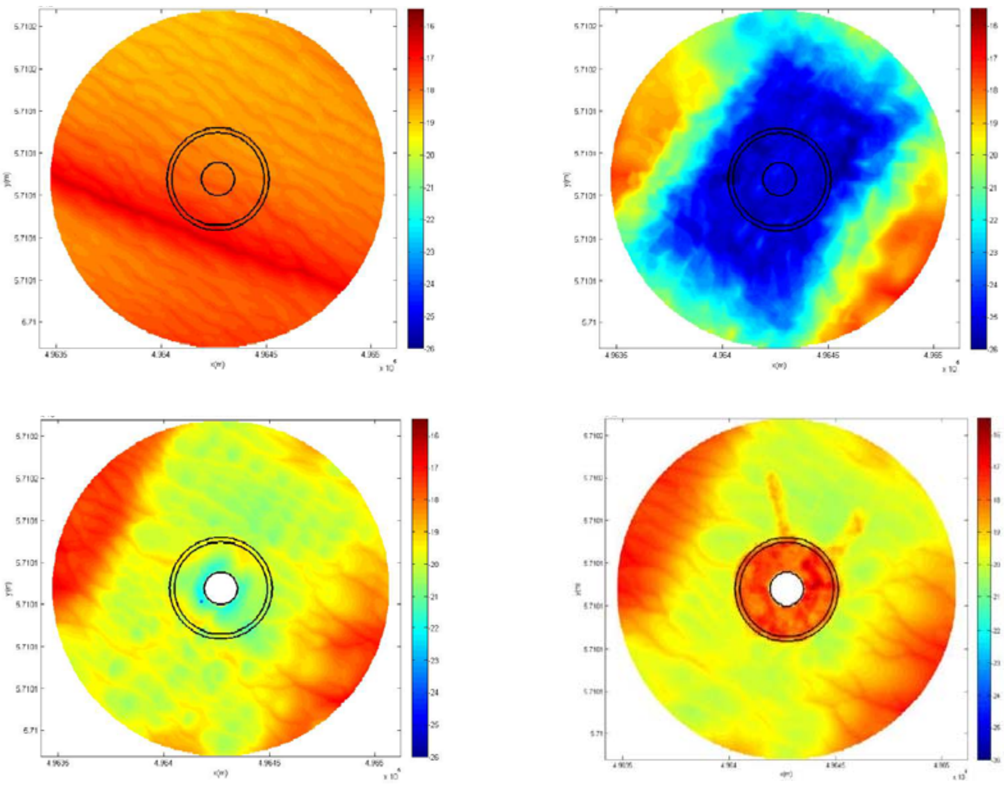
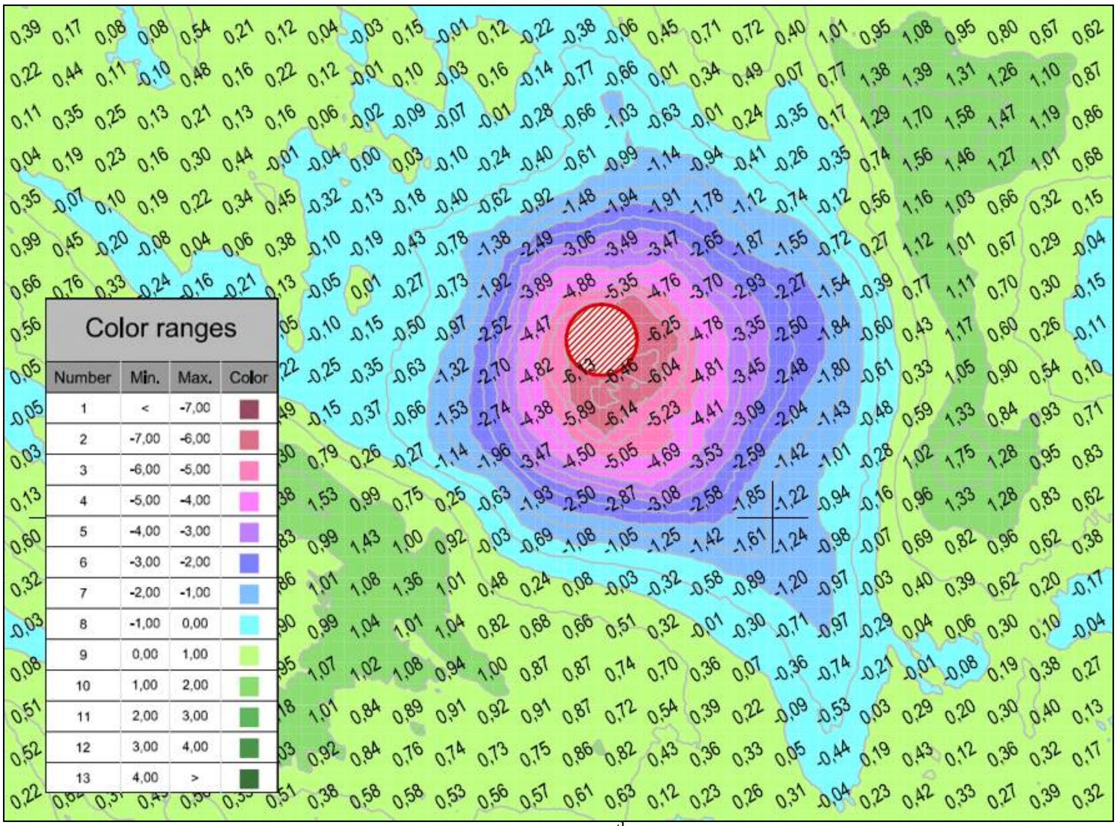


Figure 6: Depth variation near GBF2 (51°32’24.63”N, 2°56’49.75”E). Upper left: prior to the works; Upper right: after the dredging of the foundation pit; Lower left: prior to the installation of the filter layer; lower right: final survey after completion of the works (from: C-Power, 2009).



Color ranges

Number	Min.	Max.	Color
1	<	-7,00	🟥
2	-7,00	-6,00	🟥
3	-6,00	-5,00	🟪
4	-5,00	-4,00	🟪
5	-4,00	-3,00	🟪
6	-3,00	-2,00	🟦
7	-2,00	-1,00	🟦
8	-1,00	0,00	🟦
9	0,00	1,00	🟩
10	1,00	2,00	🟩
11	2,00	3,00	🟩
12	3,00	4,00	🟩
13	4,00	>	🟩

Figure 7: Differential bathymetry map between February 8th, 2010 and the reference situation, measured in August 2009. Monopile F03 in the Belwind wind farm (from: Belwind, 2010).

3.3.3. Bathymetric measurements of cable coverage

Over the entire length of the cable, a depth of burial of around 2 m was aimed for. In some cases, due to clay layers, only 1 m depth of burial was reached (Figure 8). Note that around km 14, a much deeper burial was observed, because of crossing of the navigation channel. This was required in the environmental permit for safety reasons. At km 24, a surface communication cable was crossed. At that place, gravel was disposed to protect the cable.

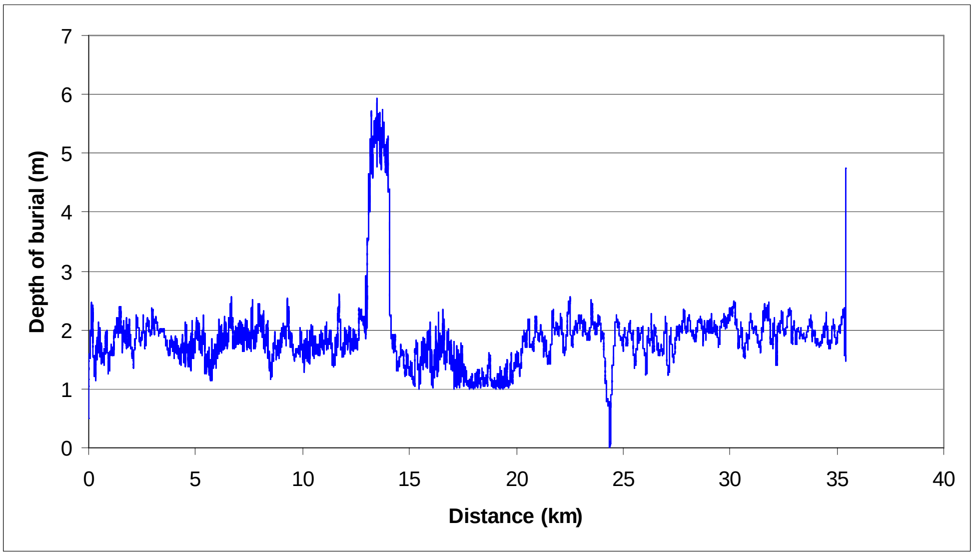


Figure 8: Depth of burial of the 150 kV cable from the C-Power wind farm from the most southern turbine (km 0) to the landing points at Oostende (km 36) (Figure prepared from data of C-Power, 2009b).

3.3.4. Bathymetric measurements of sand piles

Different surveys were executed on the disposal sites. They revealed that after the dredging of the foundation pits, only about 400,000 m³ was found on the disposal areas, although almost 579,000 m³ has been removed to construct the foundation pits.

In the following months, sand was used for backfill of the foundation pits, infill of the GBFs, correction disposals and backfilling of the fair channel. During the works, it appeared that more sand was necessary for the backfill of the foundation pits and the fair channel. After all the works, a total of 468,000 m³ sand was removed from the disposal site, causing three depressions (Figure 9). This means that a total of 868,000 m³, *i.e.* 400,000 m³ that was at the disposal sites and 468,000 m³ that was missing after the works, has been dredged; from this only 588,000 m³ were effectively found to be disposed for the backfill and infill operations.

In 2009, two additional surveys were executed to monitor the evolution of the depressions. Compared to October 2008, in June 14 2009, still 471,000 m³ was missing, indicating that over a period of 8 months only 9,000 m³ were naturally deposited in the depressions.

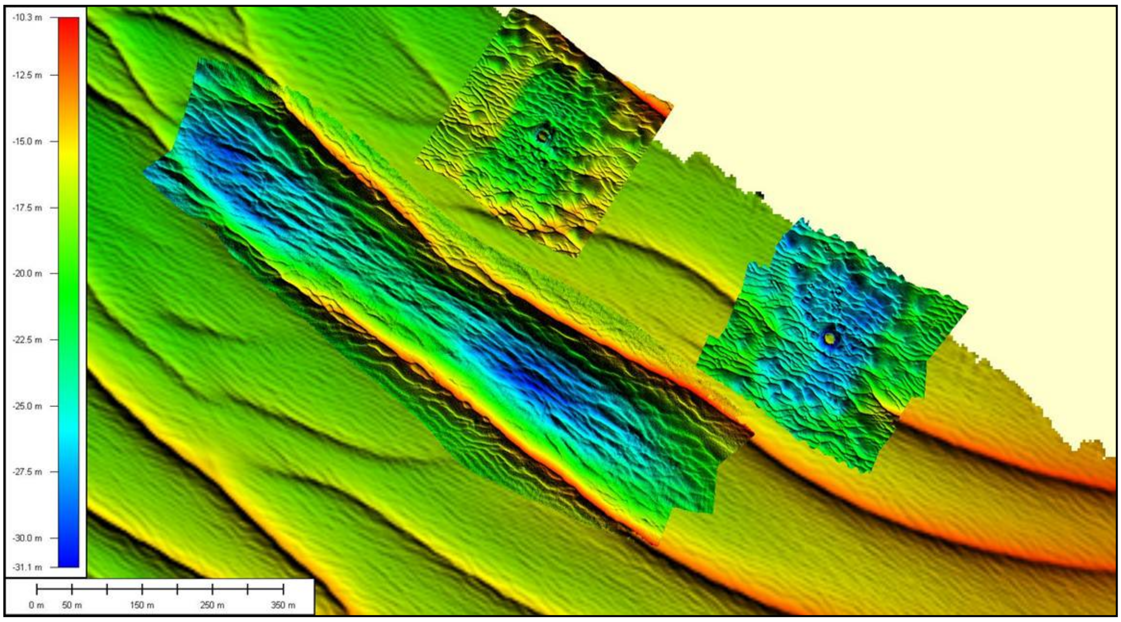


Figure 9: Example of 2 foundation pits with associated depression (2009 bathymetry). In the depression, sand from the GBF location was temporarily stored, though after infill of the GBFs and backfill of the cable, a sand deficit was encountered. This resulted in major depressions. (data: C-Power; visualization: M. Baeye UGent/MUMM). Background bathymetry is from 2006 (FPS Economy, SME's, Self-Employed and Energy).

3.4. Discussion

3.4.1. Hydrodynamics and SPM concentration measurements

SPM concentration variation during the measurements was mainly controlled by currents (spring-neap cycle). Most of the time, high concentrations were related to high waves. However, during periods of high waves, low concentrations occur as well, indicating that wave action is not the only driving factor.

At the reference site, Goote Bank, high SPM concentration was correlated with low salinities (±33 psu). This was due to persistent easterly winds, generating offshore advection of SPM and fresh water from the coastal area. To our knowledge, it is the first time that such an increase in SPM concentration was observed on the Goote Bank. However, as no long term data series are available, it remains unclear, if such an event is exceptional or common. These findings indicate also that the

Goote Bank is possibly not a good reference station for the Bligh Bank and/or Thornton Bank, as SPM dynamics might differ for these locations under varying conditions or events.

For the assessment of construction induced turbidity changes, natural variability needs quantified first. Indeed, Orpin et al. (2004) argue that the natural variability of the system could be used to define the initial limits of acceptable turbidity levels. Such an approach assumes that a short-term increase (several hours) that falls within the range of natural variability will not have any significant ecological effect. For at least coral communities, very sensitive to turbidity, they showed that changes in species density or faunal community may be due to changes in sediment composition and increased SPM concentration.

Building further on this, a methodology has been developed comparing variations of statistical parameters during the data collected during the field experiments. It is assumed that SPM concentration is log-normally distributed (Fettweis & Nechad, 2010). By using frequency distributions of different data sets, calculations can show whether (or not) two distributions are drawn from the same distribution function, using standard statistic tests. If the data, collected during different sampling periods, have similar log-normal distributions, geometric means and standard deviations, it can be concluded that - within the range of natural variability and measuring uncertainties - similar sub-samples from the whole population are obtained and no changes have occurred due to external disturbances. At present, there are no indications of a construction induced increase of turbidity, during nor after the works.

3.4.2. Bathymetric measurements of erosion pits

Around the GBFs, erosion protection was installed and no secondary erosion was observed.

During the installation of the dynamic erosion protection, erosion pits were allowed to develop around the monopiles at the Bligh Bank. Depth measurements of these pits indicated a variation of 2 to 6.5 m. This range is still below the values reported in den Boon et al. (2004), where information is given on the expected dimension of erosion pits, based on physical models. Results indicate that monopiles, with a diameter of about 5 m, will generate an equilibrium erosion pit of about 8.75 m. Still, according to Sumer & Fredsøe (2001), the development of the erosion pit is a fast process, as such monitoring remains important.

The fact that the depth of the erosion pit varies between 2 m and 6.5 m, indicates that there can be a large variation in the depth of erosion pits, depending possibly on the seabed sediments, geological substratum and prevailing hydrodynamics. More research is needed to gain more insight in these differences. The observed variation does indicate that for some other turbines, the erosion pit could be even larger.

3.4.3. Bathymetric measurements of cable coverage

Morelissen et al. (2003) showed that pipelines in the North Sea could be uncovered by movements of sand dunes. In some cases even erosion underneath the pipelines occurred. Model results and measurements showed that in the North Sea, sand wave migration occurs of about 10 m per year (Van Dijck & Kleinhans, 2005). Using a migration velocity of only 1 to 3 m per year and a depth of burial of the cable of 1.8 m, Galagan et al. (2005) showed that cables could be uncovered after 6 to 18 years. For higher migration rates and smaller depths of burial, less time is expected. The cable from the C-Power wind farm to the shore is buried at a depth of about 2 m, and less (1m) in areas with clay layers. Therefore it is clear that the coverage of the cable has to be verified regularly, *i.e.* after a severe storm and one month after this storm, and from then, every year.

3.4.4. Bathymetric measurements of sand piles

From the measurements, it appeared that much more sand was dredged, than was effectively used for backfill or infill operation. From a detailed analysis of the results (IMDC, 2009b), it was concluded that losses were most probably due to dredging (10%), disposal works (20-25%) and natural erosion processes (8%). These estimates result in a closed sand balance and showed that a larger quantity of sediment was dredged than was originally disposed on the three temporary disposal sites; this would explain the three depressions, as found in the concession area.

The fact that over a period of 8 months only a very limited amount of material was filling up the sand pits, that were generated, agrees with other research, where the stability of sand pits, after severe aggregate extraction, was demonstrated (for an overview see Van Lancker et al., 2010). Specifically, for the Kwinte Bank, a sandbank 12 km offshore, a depression of 5 m in depth was created. Degrendele et al. (2010) showed that after cessation of marine aggregate extraction, this depression remained stable and no recovery of the depression occurred. Also in the SANDPIT project (Walstra et al. 2003), the stability of sand pits was demonstrated (MUMM, 2007).

3.5. Conclusions

The natural turbidity regime and a first assessment of the effects of the construction of windmills on sediment dynamics are presented. The results remain preliminary, since monitoring is still on-going and only short-term effects can be discussed. However, collected data allowed evaluating the monitoring procedure. Initially, it was designed that the monitoring should include *in situ* measurements before, during and after the construction and this during two simultaneous measurements, at two locations, for at least 14 days. One location was defined as reference station, not influenced by impacts of construction sites. However, data have shown that the natural variability at the Goote Bank and the Thornton Bank is rather high, whereas at the Bligh Bank no significant variations have been observed during the deployments.

Despite similar geographic, sedimentary and hydrodynamic conditions the turbidity data suggest that the Goote Bank is possibly not a good reference site for the Bligh Bank and the Thornton Bank for the monitoring of turbidity. This is due to the higher variability in SPM concentration observed at the Goote Bank and the fact that SPM dynamics might be different on the three sites. The data suggest that SPM concentration on Thornton Bank and Bligh Bank is mainly influenced by waves and current resuspension, whereas on the Goote Bank, situated closer to the shore, advection of coastal water masses with higher turbidity and lower salinity are also responsible for the observed SPM concentration variability (see Fettweis et al., 2010).

Data so far demonstrate that, due to spatial variations in turbidity, the use of a reference site is not advised. Therefore, it is recommended to limit the monitoring to the construction sites only, but to extend the duration of the measurements (a few months, distributed over different seasons) in order to have sufficient data for meaningful statistical analysis. Long time series at one location have the advantage that natural variability can be assessed and that impact of construction works can be identified with higher probability. Such an approach was successfully used for the assessment of turbidity changes due to disposal experiments of dredged material from Zeebrugge harbour (Lauwaert et al., 2009).

The sea bed around the GBFs was intensively monitored. In the final survey, the scour protection is clearly visible, but no indication of secondary scour has been observed. The monitoring of the dynamic erosion protection was executed around six monopiles. The depth of the erosion pits varied between 2.0 m and 6.5 m, in the north of the farm. This is in agreement with the expected maximum depths of 8.7 m. The variation however indicates that the erosion pit depth possibly depends on seabed sediments, geological substratum and prevailing hydrodynamics.

The depth of burial of the cable of the C-Power farm to the shore was monitored during the jetting and the ploughing of the cable. The cable lies most of the time 2 m below the sea bed, although, where clay layers occur, only 1 m was obtained. Due to movement of sand dunes, these cables could become unburied; a regular control of the coverage of the cables is therefore necessary.

Finally the monitoring showed that, during the installation of the GBFs, an important amount of sand was dredged at the concession area for the backfill of the foundation pits and the fair channel, which resulted in the creation of some sand pits. Calculation showed that 868,000 m^3 was dredged (IMDC), while only 588,000 m^3 were effectively found to be disposed for the backfill and used for the infill operations. These losses are due to dredging and disposal works and, to a lesser extent, to natural erosion processes. Monitoring of these sand pits during several months showed that the sand pits are relatively stable and that no natural filling of the sand pits occurs.

3.6. Acknowledgements

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Chapter 4. Underwater noise produced by the piling activities during the construction of the Belwind offshore wind farm (Bligh Bank, Belgian marine waters)

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Abstract

The piling of 56 foundations for 55 windmills and one offshore platform at the Blighbank (Belgian part of the North Sea, BPNS) has been surveyed for underwater noise. Maximum peak Sound Pressure Levels (SPL) up to 196 dB re 1µPa were recorded at 520 m from the piling location. The extrapolated apparent source SPL was estimated at 270.7 dB re 1µPa (95% CI: 260.4 – 281.1 dB re 1µPa), although such an extrapolation of the measured levels to the near field (< 100 m) environment should be interpreted with care.

It is confirmed that the underwater noise level is a reason for concern, at least for marine mammals such as porpoises, seasonally abundant around the construction area. It is however very difficult to quantify and qualify the effects of the increased underwater noise level on components of the ecosystem, and a continued effort to do so is needed. To fine tune our estimates of noise propagation in the bathymetrically complex BPNS, in future more attention will be paid to the attenuation characteristics of underwater noise.

Samenvatting

Tijdens het heien van 56 funderingen voor 55 windmolens en 1 offshore platform op de Bligh Bank (Belgisch deel van de Noordzee, BDNZ), werd het geproduceerde onderwatergeluid onderzocht. Maximale piek geluidsdrukniveaus (SPL) tot 196 dB re 1µPa werden gemeten op een afstand van 520 m van de heilocatie. Door extrapolatie werd het SPL ter hoogte van de bron geschat op 270.7 dB re 1µPa (% CI: 260.4 – 281.1 dB re 1µPa). Dergelijke extrapolaties van de gemeten niveaus naar de SPL in de nabijheid de bron (< 100 m) moeten echter met enige voorzichtigheid geïnterpreteerd worden.

Onderwatergeluid is een bezorgdheid wegens de mogelijks schadelijke impact op zeezoogdieren zoals de bruinvis, die seizoenaal abundant voorkomt in het constructiegebied. Het is echter bijzonder moeilijk om de effecten van het verhoogde onderwatergeluid op bepaalde componenten van het mariene ecosysteem te kwantificeren en te kwalificeren. Verdere inspanningen om dit te kunnen doen zijn nodig. Om de schattingen van de propagatie van onderwatergeluid in het bathymetrisch complex BDNZ te verbeteren, zal er in de toekomst meer aandacht worden besteed aan de attenuatie karakteristieken van onderwatergeluid.

4.1. Introduction

The main objective of the measurements of underwater noise in the construction and operational phases of offshore wind farms is to assess possible impacts on biota. Recent investigations have indicated that the environmental impact of anthropogenic underwater noise can be important in general (e.g. OSPAR 2009a, 2009b), while the activity of greatest concern is pile driving during the construction phase of the projects (Bailey *et al.*, 2010; Gordon *et al.*, 2009; OSPAR 2008, 2009a, 2009b). Indeed, this activity produces very intense underwater noise, with a level potentially directly affecting biota such as marine mammals, cephalopods and fish larvae (Finneran *et al.* 2005; Kastak *et al.* 2005; Lucke *et al.* 2009; Madsen *et al.*, 2006; Nachtigall *et al.*, 2003; Prins *et al.*, 2009; Richardson *et al.*, 1995; Thomsen *et al.*, 2006). Human generated noise is now considered an important form of pollution and marine managers and policy makers are aware of the environmental impact anthropogenic underwater noise may have. This is for instance demonstrated by its coverage by international agreements and conventions, such as in the framework of the European Union[1], the Convention on Migratory Species[2] and ASCOBANS[3]. As such, the underwater noise of offshore wind

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[1] Marine Strategy Framework Directive; Directive 2008/56/EC

[2] CMS Resolution 9.19 on adverse anthropogenic marine/ocean noise impacts on cetaceans and other biota, adopted by the 9th Meeting of the Conference of the Parties

[3] Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas: Resolution on adverse effects of underwater noise on marine mammals during offshore construction activities for renewable energy production, adopted at the Meeting of the Parties 6.

farm related activities remains an important issue of the wind farm monitoring programme in Belgian waters.

Considering the wind farm area in the Belgian part of the North Sea (BPNS), Haelters *et al.* (2009) quantified the mean background underwater sound pressure level (SPL) at the Belwind location, prior to the construction activities, and during weather conditions with wind force < 3 Bft and seastates < 3, at around 95 to 100 dB re 1µPa for frequencies ranging between 10 Hz and 2 kHz. Various wind farm related activities during the construction and operation phase add to the underwater noise. Especially piling activities are considered to be of concern in relation to the increases of the underwater noise levels. The effects on harbour porpoises of increases in underwater noise due to piling can be death or injury (permanent or temporary hearing threshold shift; respectively PTS and TTS) close to the sound source, and an avoidance reaction and masking of the porpoise sonar further away (Bailey *et al.*, 2010, Lucke, 2010; Southall *et al.*, 2007).

This paper aims at (1) the quantification of the SPL generated by piling activities at different distances from the piling location, (2) a spectral analysis of the noise and (3) an extrapolation of the measured SPL to the apparent source SPL and to the distance at which a background SPL is reached.

4.2. Material and methods

The measurement protocol, as used for previous underwater noise measurements (see Haelters *et al.*, 2009) was used for the present study; it is summarised below. It was however slightly adapted in view of the different characteristics of piling noise: shorter measurements (of around 2 minutes each) allowed for measurements of noise during piling activities over a large range of distances (400 m to 14 km from the piling location).

4.2.1. Measurement methodology

As a platform for the measurements we used the Tuimelaar, a rigid inflatable boat (RIB) owned by the RBINS-MUMM. All instruments possibly interfering with the noise measurements were turned off during recording. For each recording, the RIB was left adrift from a predefined position with the engines shut off. The position of the RIB was registered automatically every five seconds by a GARMIN GPSMAP 60 Cx. At the beginning and the end of each measurement a reference signal was recorded. The clock of the recorder was synchronised beforehand with the GPS-time (UTC).

A proper and (near) real time communication between the piling operator and the measuring team on when exactly the piling will take place, proved to be a very delicate aspect for the planning and implementation of the measurement campaigns. As such, many planned or ongoing campaigns were cancelled or interrupted due to changes in the piling procedure and timing. An overview of the successful campaigns is presented in Table 1.

Table 1. Metadata of the underwater noise measurements at the Belwind site on the Blighbank: monopile A02 (September 26th, 2009) and monopile B10 (January 15th, 2010).

26th September 2009 (monopile A02)			
Position start recording		**Distance (m)**	**Energy/Blow (kJ)**
Latitude	**Longitude**		
51°40.39’	2°50.03’	~3000	~590
51°39.41’	2°50.64’	~4820	~760
51°38.25’	2°51.25’	~6990	~875
15th January 2010 (monopile B10)			
Position start recording		**Distance (m)**	**Energy/Blow (kJ)**
Latitude	**Longitude**		
51°34.59’	2°57.31’	~14150	~710
51°37.58’	2°52.89’	~7250	~940
51°38.61’	2°51.58’	~5500	~950
51°38.55’	2°50.29’	~4000	~960
51°38.45’	2°49.04’	~2580	~960
51°38.52’	2°48.16’	~1580	~970
51°38.60’	2°47.41’	~680	~970
51°38.56’	2°47.41’	~700	~980
51°38.50’	2°47.44’	~770	~970
51°38.55’	2°47.24’	~520	~990
51°38.52’	2°47.32’	~630	~970

4.2.2. Acoustic measurement equipment

At every occasion, one Brüel & Kjær hydrophone (type 8104) was deployed at a depth of 10 m. A Brüel & Kjær amplifier (Nexus type 2692-0S4) was placed between the hydrophone and the recorder in order to allow for an amplification of the signal. A reference signal is used to calibrate the signal. The signal is recorded using an audio MARANTZ Solid State Recorder (type PMD671). It was operated with the highest possible sampling rate of 44.100 Hz. The signal was recorded in WAVE format (.wav) on Compact Flash cards of 2 GB (Sandisk Ultra II). All equipment was powered by batteries.

Before the 2009 measurements started, the complete instrumentation chain, except the data recorder, was calibrated by the manufacturer Brüel & Kjær.

4.2.3. Analysis of the recordings

A spectral analysis of the signal in the form of the third octave band spectrum of the underwater Sound Pressure Level (SPL) is presented. The spectra were computed using a routine built on MATLAB and according to the norm IEC1260. The maximum peak SPL at the measuring stations, located at different distances from the piling site, are provided, together with a simple linear model allowing for an extrapolation of this SPL at distances, at which no measurements were available, including to the apparent source SPL (at 1 m). This extrapolation should be treated with care, taking into account the complex bathymetry of the BPNS (cf. far field extrapolation) and the complexity of the near field noise generation.

4.2.4. Piling activity details

For the piling of the 56 monopile foundations at the Blighbank (at a depth of 10 – 24 m MLLWS – Mean Low Low Water Spring), a hammer IHC hydrohammer S1200, operated from the support vessel Svanen, was used. The hammer features a maximum power of 1200 kJ. The average energy used for each stroke however was 705 kJ (range: 526-965 kJ) (Table 2). The length of the monopiles ranged from 47 m to 65 m, and the outer diameter was 4 m at the top and 5 m at the lower part. The number of hammer blows needed to drive each monopile 18 to 37 m into the seabed was 1841 to 4811 (average: 2981). It took 112 h of piling to put the 56 monopiles in place.

In this report, the piling of the monopiles A02 and B10 is described. For a similar penetration depth (29 and 28 m) and a mass above the average (400 and 452 t), the piling of A02 and B10 showed a very different piling duration: 64 minutes for A02 versus 162 minutes for B10. Also the total energy used during pile driving was different: it was close to the minimum value for A02 (1.4 GJ) and it was the highest value for B10 (3.2 GJ). As such, both monopiles are illustrative for the variation in monopile characteristics and piling activities of the Belwind project phase 1.

Table 2. Summary statistics of the piling activities of monopiles A02 and B10, targeted in this study, as well as the averages, minima and maxima encountered for the 56 monopiles of Belwind phase 1 (source: Belwind).

Piling activities during Belwind phase 1						
	Unit	**A02**	**B10**	**Average**	**Min**	**Max**
Pile length	m	54	63	54	40	65
Mass	t	400	452	375	254	509
Number of strokes required		2114	3848	2982	1814	4811
Average energy per stroke	kJ	641	837	705	526	965
Duration of piling	min	64	162	120	64	233
Penetration	m	29	28	27	18	37
Total energy	GJ	1.4	3.2	2.1	1.38	3.2

4.3. Results

The acoustic pressure measured at 4.8 km from the piling location of monopile A02 reaches a maximum amplitude of about 700 Pa (Figure 1). A 0.35 s zoom into one single stroke shows the noise generated by a single stroke to last for about 0.25 s (Figure 2).

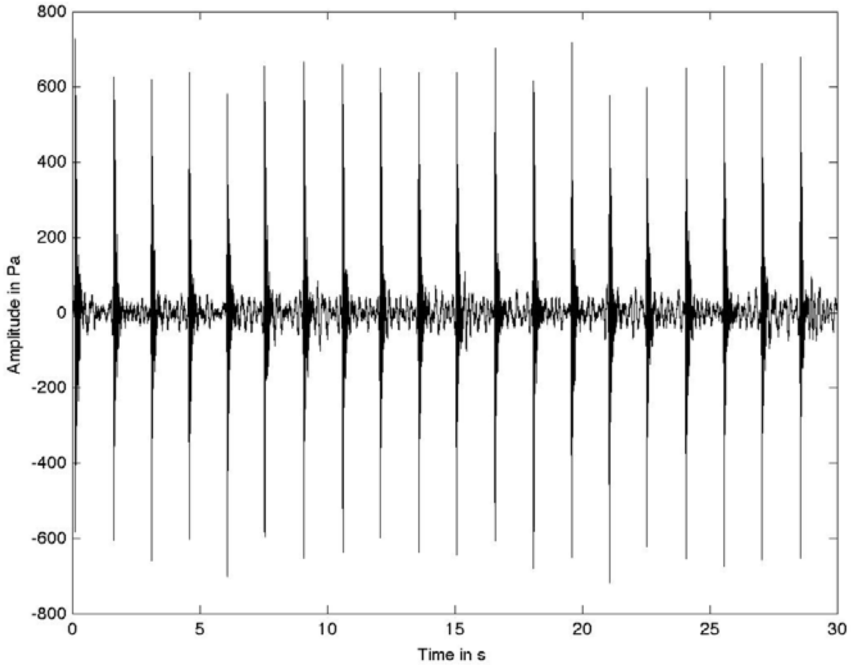

Figure 1. Amplitude of the acoustic pressure, produced by 20 piling strokes of 760 kJ and recorded at 4.8 km from the piling of the A02 monopile.

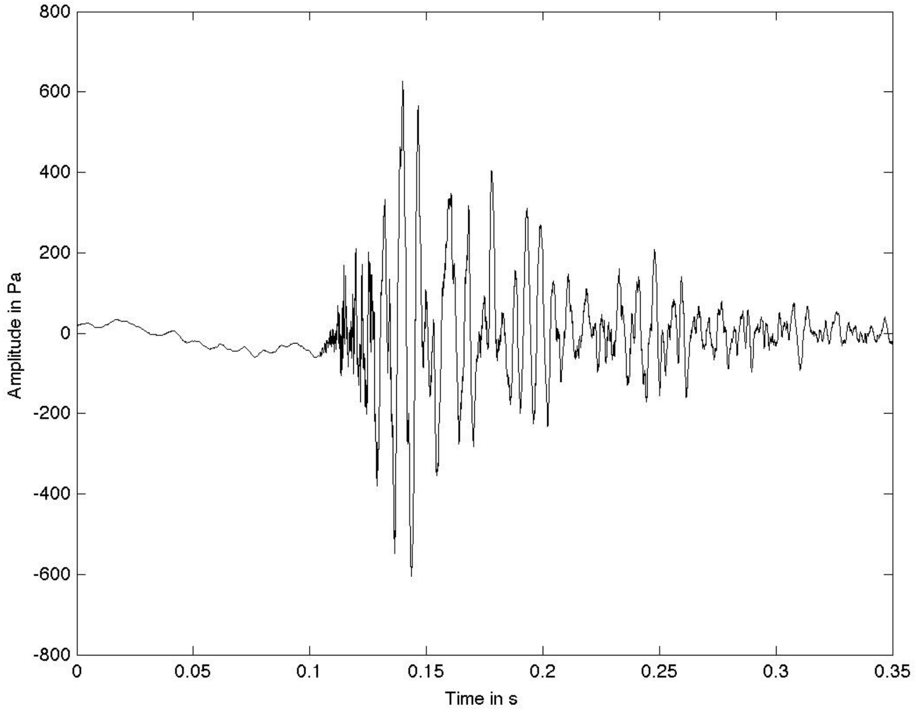

Figure 2. Acoustic pressure of a 0.35 s zoom into one stroke as taken from figure 1.

The spectral analysis of the underwater noise, produced by the piling of monopile A02 and recorded at 3 km from the source, shows a maximum amplitude of about 150 dB re 1 µPa between 100 Hz and 200 Hz, as well several secondary peaks (Figure 3). Most of the energy is found between 50 Hz and 1 kHz. The recording at 770 m from the monopile B10 (Figure 4) shows a similar pattern, with a maximum sound pressure level of about 160 dB re 1 µPa at a frequency of 150 Hz. In both examples presented, the SPL decreased with distance.

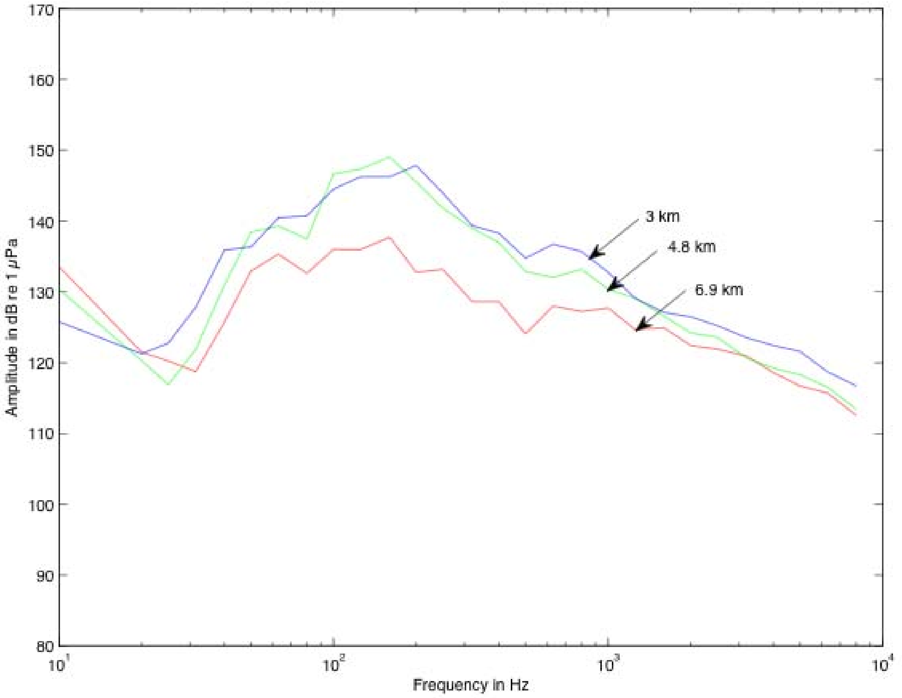

Figure 3. 1/3 octave spectrum of the underwater noise recorded during the piling of monopile A02 at three distances from the piling location.

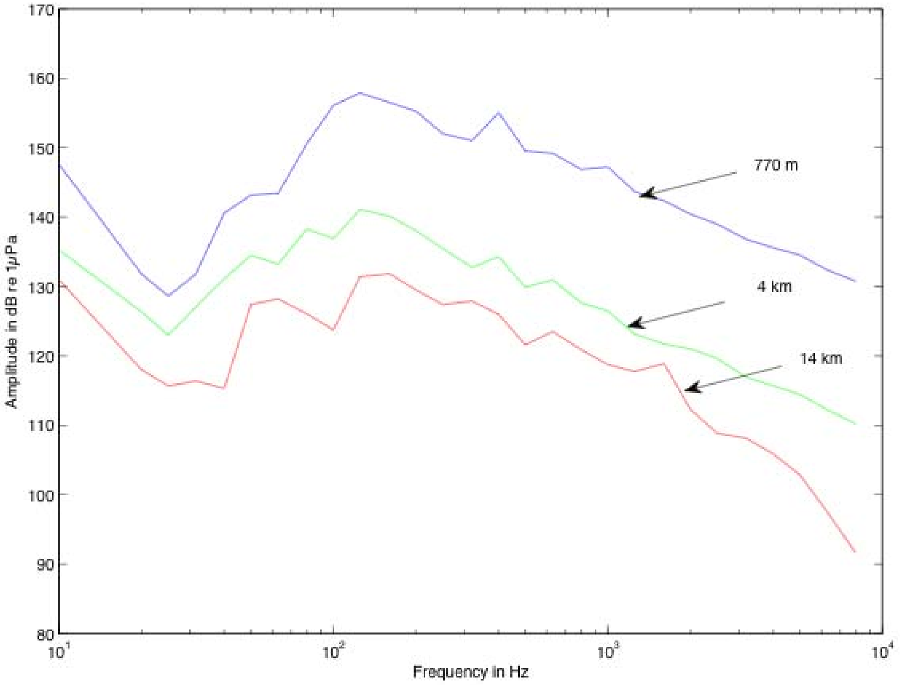

Figure 4. 1/3 octave spectrum of the underwater noise recorded during the piling of monopile B10 at three distances from the piling location.

The piling of monopile A02 showed a maximum peak SPL ranging from 166 dB re 1 µPa at 7 km to a maximum of 177 dB re 1 µPa at 3 km distance. Values measured for monopile B10 ranged from 160 dB re 1 µPa at 14 km from the pile to 196 dB re 1 µPa at 560 m.

Table 3 Maximum peak SPL and energy per blow during the measurements at different distances from the source (see Table 1).

Distance to A02 (m)	**Maximum peak sound pressure level amplitude (dB re 1 µPa)**	**Energy/Blow (kJ)**
~6990	166	~870
~4820	177	~760
~3000	177	~590
Distance to B10 (m)		**Energy/Blow (kJ)**
~14150	160	~710
~7250	165	~940
~5500	169	~940
~4000	168	~960
~2580	174	~960
~1580	185	~970
~770	193	~970
~700	193	~980
~680	192	~970
~630	195	~970
~520	196	~990

The energy used per blow showed a high variability for the piling of A02, while a more constant figure, except for the recording taken at 14 km, was observed for monopile B10 (Table 3). As such, an extrapolation of the relationship between SPL and distance could be attempted only for the piling of B10 (Figure 5).

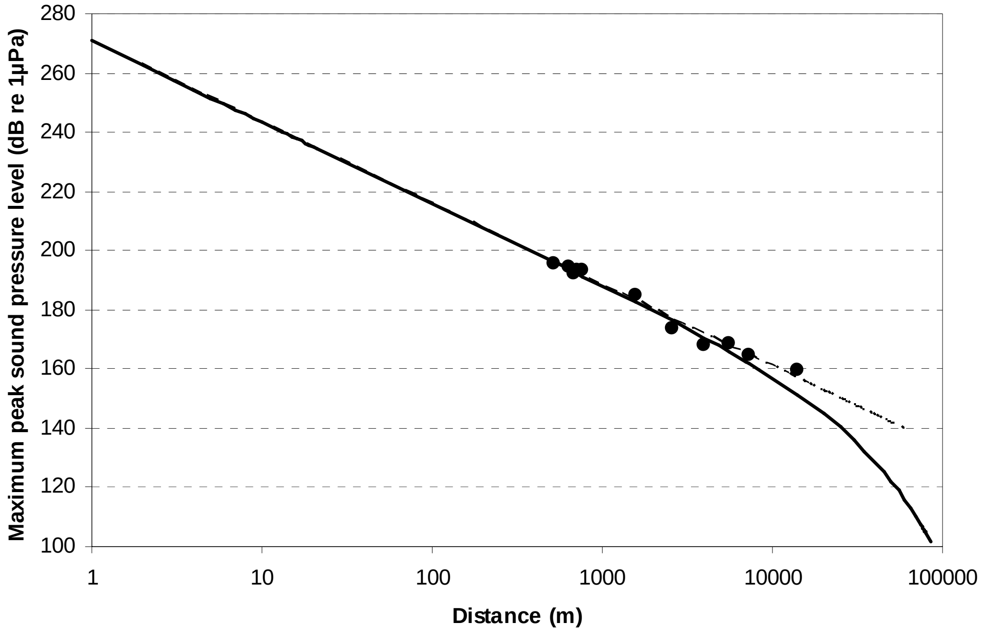

Figure 5. Relationship between maximum peak SPL (dB re 1µPa) and distance (m) from the source of the underwater noise during the piling of monopile B10. The dashed line represents the fitted linear model of the measured values (closed circles). The solid line represents the maximum peak SPL as a function of distance, taking into account both attenuation and absorption.

The regression model (Maximum peak SPL = -27.4 log(d) + 270.7 dB), in which d is the distance to the source, features a transmission loss of 27.4 log(d) (95% CI: 30.5 to 24.3 log(d)). The intercept of the linear regression model at a distance of 1m from the source is estimated at 270.7 dB re 1µPa (95% CI: 260.4 - 281.1 dB re 1µPa). Using the same linear model, the distance at which a background SPL during good weather conditions of 105 dB re 1 µPa is reached, was found to range from 100 to 500 km, with a 95 % confidence interval of 79 - 630 km. However, a more complex model, taking account of the transmission loss (i.e. attenuation) of 27.4 log(d) and an absorption coefficient of 0.0004 dB/m (cfr. Bailey *et al.*, 2010), predicts the distance at which the noise could still be distinguished from background noise at 79 km.

4.4. Discussion

4.4.1. Underwater noise sound pressure level, produced by piling activities

The underwater noise level produced by piling (up to 196 dB re 1µPa at 520m) is much stronger than the background noise or noise generated by shipping in the BPNS (up to 120 dB re 1µPa; Haelters *et al.*, 2009), even at many km from its source, and therefore a reason for concern. Personal experiences (A. Norro) of this underwater noise during diving operations at 15 km distance from the piling location learned that the noise was annoying, but not harmful to the diver. At every stroke however, a shock wave (vibration) was clearly sensible to the divers.

The transmission loss models, as presented in Figure 5, are plausible for the SPL in the far field environment (i.e. > 100m from the source *sensu* Nedwell and Howell 2004). However, not taking into account absorption, our estimate based on the linear model is most likely overestimating the distance at which the noise could still be distinguished from background noise. Taking account of noise absorption on the other hand leads to an underestimation of SPL at our measurement point at 14 km distance, when the lowest blow energy (710 kJ) was used. As a consequence, at this moment our data do not allow for a more precise estimate of the distance at which the noise could still be distinguished from background noise. However, it can reliably be stated that the noise could still be discriminated from the background noise at a distance of at least tens of kilometers. Such distance means that the underwater noise produced by piling activities is measurable within the whole BPNS and even within part of the marine environment of all our neighbouring countries. However, the estimate of this distance changes with the choice of the absorption coefficient, and will depend on several factors, an important one being weather conditions affecting the background noise level.

The use of the linear transmission loss model for the near field environment and hence the estimation of the SPL at the source, is further prone to many uncertainties, as the area close to the source is the seat of complex interactions between various components of the source, which in itself is not a point source. As such, the extrapolation is frequently not considered legitimate in the near field environment. The SPL estimate of 270.7 dB re 1 µPa (95 % CI 260.4 - 281.1 dB re 1 µPa) at 1 m from the source should be considered a rough indication of the apparent source SPL, and should be interpreted with care.

The difference in the form of the spectra, as observed between A02 and B10, could be explained by differences in e.g. the size of the monopile, the local sedimentary environment, the blow energy and the topographical position on the sandbank, each having a specific influence. For example, it should be noted here that our measurements were made with a sand ridge between the source and the hydrophone, which can strongly affect both the propagation and the attenuation of the underwater noise (Urick, 1983; Lurton, 2002; Medwin, 2005).

While a standardisation of measuring, analysing and expressing underwater noise is considered necessary, and is being developed (de Jong *et al.*, 2010; EU, 2010), this standardisation is still at an early stage of acceptance and general use. Although the current lack of standardisation has to be taken into account when comparing our measurements with those from other studies, such comparison can already shed a light onto the major commonalities of underwater noise, produced by offshore wind farm piling activities. At the Barrow site in the U.K., for instance, Nehls *et al.* (2007) found a maximum peak SPL of 193 and 199 dB re 1µPa normalized at 500 m from the piling of a monopile with a diameter of 4.7 m (stroke energy unknown), which is highly similar to the 196 dB re 1µPa measured in this study at 520 m from the piling of a 5 m-diameter monopile with stroke energy of 990 kJ. The spectral analysis, presented by Nehls *et al.* (2007), further revealed a similar maximum SPL at about 200 Hz, with a secondary peak at about 1 kHz. It should however be noted that the secondary peak observed in this study and by Nehls *et al.* (2007) is not always present, as demonstrated for the Q7 wind farm (the Netherlands) by de Jong *et al.* (2008a). In terms of amplitude of the spectra, Nehls *et al.* (2007) as well as de Jong *et al.* (2008a) presented figures of about 170 dB re 1µPa at about 200 Hz for a similar distance of about 850 m. Our measurements were made further away, which explains the lower SPL values ranging from 150 to 160 dB re 1µ Pa at 100-200 Hz. The importance of low frequencies (Figures 3, 4) were also observed by De Jong *et al.* (2008) and may result from a high energy stroke.

Our measurements of the increases in UW noise level have clearly demonstrated that they are a reason for concern for the environment. They clearly warrant the mitigation measures proposed in the EIA report (MUMM, 2007) and taken up in the license for construction. Some of the measures proposed prevent the exposure of sensitive species to excessive noise, such as the use of acoustic warning devices, the use of a ramp-up procedure, or the avoidance of piling operations during periods of the year with high numbers of porpoises present in the vicinity of the construction area. Other methods that are available or are being investigated in the framework of other offshore wind farm projects tackle the noise output itself; it has been demonstrated that the noise emitted is significantly lower when using methods such as bubble curtains around the piles, the use of a telescopic double wall steel tube, the use of inflatable sleeves, or the drilling of the piles instead of ramming (Nehls *et al.*,2007; Nedwell and Brooker, 2008). Such measures and methods should be continued to be considered for future OWS projects in Belgian waters.

4.4.2. Impact on marine life, *in casu* marine mammals

Only few direct impact studies of pile driving on marine mammals have been made in the field. However, these studies have clearly demonstrated that effects can occur up to tens of kilometers from the piling site. Some studies have investigated audibility to discomfort noise levels in marine mammals in captivity, including porpoises, bottlenose dolphins and seals (David, 2006; Kastelein *et al.*, 2005; Mooney *et al.*, 2009; Verboom & Kastelein, 2005). Such levels can be compared to actual noise levels measured during pile driving. In combination with baseline studies of the marine mammals occurring in the areas concerned, an assessment of a potential impact can be made.

Field studies using Porpoise Detectors (PoDs) during pile driving have indicated effects on porpoises (decrease in acoustic detections) up to (at least) 25 km from the pile driving site, and lasting for hours to days after each piling (Brandt *et al.*, 2009; Carstensen *et al.*, 2006; Diederichs *et al.*, 2009; Henriksen *et al.*, 2003; Tougaard *et al.*, 2003; 2005; 2009a; 2009b). Lucke (2010), who performed aerial surveys before and during pile driving, detected an absence of porpoises in an area of over 1000 km^2 (= radius of about 18 km) around a piling site during piling activities; before this activity, porpoises commonly occurred in the area. Several studies indicated that also during other construction activities the abundance of porpoises in the area had decreased (Brandt *et al.*, 2009; Carstensen *et al.*, 2006; Tougaard, *et al.*, 2006a; b).

Although many criteria for sound levels potentially leading to PTS and TTS for porpoises have been presented, none have been widely accepted. Difficulties remain in the lack of a standardised description of noise (De Jong *et al.*, 2010), and in the presentation of noise exposure in its different aspects: not only the absolute level (SPL, peak to peak) of noise is relevant for cetaceans, also the Sound Exposure Level (SEL) integrated over a single noise event and the cumulative exposure over time, such as exposure to repetitive pulses during pile driving (De Jong & Ainslie, 2009; Madsen, 2005;). Finally a frequency weighting of the sound cetaceans are exposed to can be applied, taking account of their audiogram; this means that it is weighted against the inverse shape of the audiogram, and in some cases is corrected also for the non linearity of intense sound loudness (Nedwell *et al.*, 2007; Southall *et al.*, 2007; Verboom & Kastelein, 2005). This better accounts for the loudness of a sound as experienced by marine mammals, but complicates matters more, given that the audiograms are different for each species, and are not well known for many.

Verboom & Kastelein (2005) have proposed, on the basis of experiments, dose-response relationships for porpoises; the severe discomfort level, TTS level and PTS level were respectively 125dBw, 137 dBw and 180 dBw re 1µPa (dBw: weighted against the inverse shape of the audiogram of the porpoise). Southall *et al.* (2007) have calculated for PTS and TTS in 'high frequency cetaceans', amongst which Delphinidae, levels of 198 dBw respectively 183 dBw re µPa^{2}s (weighted against a general audiogram for high frequency species and the non linearity of intense sound loudness). The US National Marine Fisheries Service (NMFS, 2003) has considered a limit for exposure for cetaceans of 180 dB re 1µPa (rms), without a firm basis nor frequency weighting (in Nedwell & Brooker, 2009; Madsen *et al.*, 2006), while the German Federal Environment Agency (UBA) has defined, on the basis of studies by Lucke (2009), that a threshold of 160 dB re 1 mPa$^2\cdot$ s (SEL) and 190 dB re 1µPa (SPL) should not be exceeded at 750 m from a piling site.

At the Blighbank construction site, the maximum peak SPL exceeded 192 dB re 1µPa up to around 800 m from the source; at 14 km it was 160 dB re 1µPa, and an extrapolated noise level at a distance of 20 km would be 144 dB re 1µPa. While it was not possible to make direct observations of impacts during the pile driving at the Blighbank, the observed increases in underwater noise level were similar to those measured in other studies (Betke, 2010; De Haan *et al.*, 2007; Nedwell *et al.*, 2004; Nedwell & Howell, 2005; Nedwell & Brooker, 2009; Tougaard *et al.*, 2009; overview in Bloor, 2009). The measured levels cannot readily be interpreted into distances for TTS and PTS levels in porpoises. However, comparing the source level to the source level measured at other piling sites, and the observed effects, it is likely that effects on porpoises occurred up to at least 25 km from the sound source. The noise would have been audible for porpoises at a larger distance, but it is not clear if this has effects. It cannot be expected that PTS would have occurred in some animals, given the presence of noisy vessels at the site before pile driving - already considered as a 'ramp-up procedure' in itself by Leopold & Camphuysen (2009), and the use of an alerting device half an hour before the start of pile driving, preventing injury in the form of PTS or TTS. However, for a similar piling at the Q7 offshore wind farm, De Jong & Ainslie (2008b) estimated that the noise level was well above the discomfort threshold up to 5.6 km from the piling site (the largest distance at which noise was measured), and that at distances closer than 500 m the levels were higher than the TTS criterion as established by Verboom & Kastelein (2005). Gordon *et al.* (2010) have proposed a model in which the SEL is assessed against the swimming speed of porpoises and proposed TTS and PTS levels, and have concluded that even with pingers or deterrent devices, porpoises may still suffer PTS up to several kilometres from piling sites. Bailey *et al.* (2010) estimated that TTS or PTS could only occur within 100 m from a piling site (piles of 1,8 m diameter, blow energy 510 kJ), while strong avoidance reactions would occur within 20 km from the piling site.

The number of porpoises disturbed by the pile driving at the Blighbank site was probably limited, given the relatively low densities of porpoises present in this period of the year (Haelters *et al.*, this volume). Presuming a discomfort effect at a distance of 25 km (on the basis of Brandt *et al.* 2009; Diederichs *et al.* 2009; Tougaard *et al.* 2009a), and a density of porpoises of 0.2 animals/km², it can be calculated that 400 porpoises could have been disturbed. With densities of over 1 porpoise/km², as observed in Belgian waters during late winter and early spring (Haelters, 2009), more than 2.000 animals would be disturbed. However, there is only limited knowledge on the seasonal abundance of porpoises in this area, and it is fairly unpredictable. Also, the baseline monitoring of porpoises focuses on Belgian waters, which only partly cover the area possibly impacted.

4.4.3. Future adaptations to the monitoring strategy

Further developments are needed to better investigate the attenuation of underwater sound in a complex bathymetrical environment, such as the BPNS with its numerous sand ridges and a sandbank-swale morphology. It is hence advised to have measurements of the same (piling) event at the same time at different locations. This could be achieved using a moored instrument or a second survey team on a different position. Given the bathymetrical complexity of the BPNS, these measurements should account for geomorphologic privileged directions. Consequently, the underwater noise measurements of the next phase of piling activities should be executed in an along-bank, as well as a cross-bank configuration. Also, noise measurements should be expanded to both shorter and longer distances from the source as the ones described in the current report.

Furthermore, more effort should be directed into concrete impact assessment of pile driving on harbour porpoises in Belgian waters (for more details: Haelters *et al.*, this volume). Agreed standards of noise measurement, analysis and expression, and a common adoption of the level at which PTS, TTS and discomfort occurs in harbour porpoises, would further be useful for a better assessment of the impact, including a cumulative impact at a population level due to the construction of several wind farms in the southern North Sea.

Furthermore, it is advised to be able to visualize the acquired signal and to compute the spectral analysis in real time. This would allow for a real time check for possible overloading of the acoustic signal and hence for an improved efficiency of the time at sea.

4.5. Conclusions and outlook

During this first phase of piling activity at the Blighbank, it has been shown that pile driving drastically increases the underwater noise level. At 520 m from the source a maximum peak SPL of 196 dB re 1 μPa was measured, with a piling blow energy of 990 kJ. The spectral analysis of the underwater noise showed a main peak between 100 Hz and 200 Hz and at about 1 kHz. Our measurements of amplitude and spectra agree well with other measurements of the underwater noise, produced by piling activities at other offshore wind farms.

The ecological consequence of the disturbance for porpoises and other animals such as fish and cephalopods remains unknown. For marine mammals it should be described as an impact on individual animals, up to impacts on a population level. Due to the piling activity at the Blighbank, the ecological impact on harbour porpoises would be that at least the foraging ability of a number animals is temporarily impeded; they could be excluded from a preferred foraging area, and be driven to areas already used by competitors for food. Such effects can have an impact on the fitness of individual animals, and while this could be limited in the case of the construction of a single wind farm, cumulative effects will occur when many wind farms are constructed simultaneously or consecutively.

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Chapter 5. Seasonal variation and vertical zonation of the marine biofouling on a concrete offshore windmill foundation on the Thornton Bank (southern North Sea)

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Abstract

In late spring 2008 the first six concrete foundations of the C-Power wind farm were installed at the Thorntonbank, some 30 km off the Belgian coast. In the coming years several hundreds of foundations of various types and materials will be implanted in various wind farms in a designated area of the Belgian part of the North Sea (BPNS). With the construction of windmills, a new habitat of artificial hard substratum is being introduced in a region mostly characterized by sandy sediments. This has increased the habitat heterogeneity of the region and the effect of the introduction of these hard substrata – the so-called reef effect – is regarded as one of the most important changes to the original marine environment caused by the construction of wind farms. Consequently a monitoring programme was set up to study the development of biofouling on the new hard substrata associated with the windmills. Here, we address the species composition, vertical zonation, short term succession, and seasonal variation of the marine biofouling on a concrete offshore windmill foundation on the Thornton Bank.

During eight sampling campaigns between February 2009 and February 2010, scuba divers collected subtidal scrape samples at depths ranging from 4 to 25 m. In addition, the intertidal zone was sampled four times during the same period. During the sampling period, a total of 75 taxa (mostly species) were identified, including 13 spp. exclusively in the intertidal. Forty two spp. had not been previously recorded at the site under investigation. Our results confirm the previously observed vertical zonation with three zones: an intertidal – splash zone, a transitional barnacle-*Jassa* zone and an extensive subtidal zone and illustrate a strong seasonal signal in community structure. In the intertidal, the fine scale zonation became more apparent: by summer 2009 a conspicuous mussel belt was established in the transitional barnacle-*Jassa* zone and a clear zone of the intertidal barnacle (*Semibalanus balanoides*) became apparent in the splash zone. Larger algae were rare. For a number of species it remains unclear whether the observed changes in relative abundance reflect either a recurring seasonal cycle or a more gradual successional change, although a combination of both is more likely. Despite differences in substratum type our preliminary results indicate that the overall structure of the marine biofouling community encountered at the Thornton Bank site is similar to that encountered on the foundations of other offshore wind farms in Germany, Denmark and The Netherlands and on other hard structures in the North Sea. Three of the four non-indigenous species encountered in 2008 were found again in 2009: *Crepidula fornicata, Elminius modestus* and *Telmatogeton japonicus*.

Samenvatting

In de late lente van 2008 werden op de Thorntonbank, ongeveer 30 km uit de Belgische kust, de eerste zes windmolens van het C-Power windmolenpark gebouwd. Tijdens de komende jaren zullen in de daarvoor speciaal voorziene zone in het Belgische deel van de Noordzee (BDNZ) nog meer windmolens gebouwd worden in verschillende windmolenparken. Met de bouw van windmolens wordt een nieuw habitat van artificiële harde substraten gecreëerd in een gebied waar voornamelijk zandige sedimenten voorkomen. Daardoor zal de habitatheterogeniteit van het gebied verhogen. De introductie van harde substraten - het zogenaamde “reef effect” - wordt beschouwd als de belangrijkste verandering die de oprichting van windmolenparken in het oorspronkelijke mariene milieu zal veroorzaken. Daarom werd een monitoringprogramma uitgewerkt om de aangroei van organismen op de nieuwe harde substraten geassocieerd met de windmolens op te volgen en te bemonsteren. Hier gaan we in op de soortensamenstelling, de verticale zonering, de korte termijn successie en de seizoenale variatie van de aangroei op een van de betonnen windmolenfunderingen op de Thorntonbank.

Tijdens acht bemonsteringcampagnes werden tussen februari 2009 en februari 2010 subtidale schraapstalen genomen op dieptes van 4 tot 25 m. Daarnaast werd in dezelfde periode de intertidale zone vier keer bemonsterd. In de stalen werden 75 taxa (meestal soorten) geïdentificeerd waarvan 13 soorten alleen in het intertidaal aangetroffen werden. Tweeënveertig soorten waren nog niet in eerder onderzoek aangetroffen. Onze waarnemingen bevestigden de vroeger waargenomen dieptezonering in drie zones met een intertidale – spatzone, een overgangszone met *Jassa* en zeepokken en een

uitgebreide subtidale zone. Daarnaast konden we in de structuur van de aangroeigemeenschap een sterke seizoenale invloed vaststellen. In het intertidaal werd de onderverdeling van de zonering gedetailleerder: in de zomer van 2009 had zich in de *Jassa* – zeepokken zone een duidelijke mosselzone gevestigd en in de spatzone was een zone met gewone zeepokken (*Semibalanus balanoides*) ontstaan. Macroalgen waren zeldzaam. Voor een aantal soorten blijft het onduidelijk of de waargenomen veranderingen in relatieve abundantie de afspiegeling zijn van een terugkerende seizoenscyclus dan wel van een meer geleidelijke verandering in de successie al is vermoedelijk een combinatie van beide waarschijnlijker. Ondanks verschillen in het substraat tonen onze eerste resultaten aan dat de globale structuur van de aangroeigemeenschap op de funderingen op de windmolens op de Thorntonbank gelijkaardig is aan die aangetroffen op de funderingen van windmolens in Duitsland, Denemarken en Nederland en op andere harde substraten in de Noordzee. Drie van de vier niet-inheemse soorten aangetroffen in 2008 werden in 2009 opnieuw gevonden: *Crepidula fornicata*, *Elminius modestus* en *Telmatogeton japonicus*.

5.1. Introduction

In late spring 2008 the first six concrete foundations of the C-Power wind farm were installed at the Thorntonbank, some 30 km off the Belgian coast. Between September 2009 and February 2010 a further 56 steel monopile foundations were installed on the Bligh Bank. With the construction of windmills in the Belgian part of the North Sea (BPNS), a new habitat of artificial hard substratum is being introduced in a region mostly characterized by sandy sediments. This has enhanced the habitat heterogeneity of the region and 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).

It is well known that submerged artificial hard substrata are rapidly and intensively colonised (e.g. Horn, 1974; Connell & Slayter, 1977). This had been found to be the case with windmills in the North Sea (e.g. Schröder et al., 2005; Kerckhof et al., 2009). Fouling assemblages will develop successively, which may resemble epibioses on natural substrata (e.g. Connell, 2001). The windmills will also permit the establishment of species previously not present in an environment dominated by soft sediment habitats, as well as the further spread of non-indigenous species (stepping stone effect). It is also expected that certain warm water species will take advantage of the increased presence of hard substrata to further spread into the North Sea. Alternatively, the foundations and associated scour protection may allow for the re-establishment of biological communities previously present on nearby gravel beds.

The establishment of a biofouling community is expected to follow a clear successional development: the new structures will be gradually colonized by a number of species. These organisms will each influence the environment in a species-specific way, as such preventing other organisms to get established (i.e. inhibition) or creating the right circumstances for other species to join in (i.e. facilitation) (Connell & Slatyer, 1977). Consequently, the number of individuals of each species in the community will change and gradually new species will arrive that may progressively replace the first inhabitants. This long term process is known as ecological succession. Next to this process also shorter-term and often recurrent variations in species composition, known as seasonality, take place during the year. Both processes constitute the focus of this research.

The main objectives of this investigation were:

- to study the development of the epifouling communities on the concrete foundation in the first and second year after installation (species composition, vertical zonation, seasonal and successional changes)
- to determine to which extent non-indigenous species colonized the new hard substrata

5.2. Material and Methods

5.2.1. Study site

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 & 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).

At present six windmills are built on the bank. The six concrete foundations of these windmills were placed on a line, 500 m from each other, between 27 April and 29 May 20008. Each turbine foundation consists of a base slab, a truncated conical portion, a cylindrical portion and a platform (Demuynck & Gunst, 2008). The conical portion of the turbine foundation rises 14 m above the seafloor and has an outside diameter that varies from 14 m at the seafloor to 6.5 m at the top, i.e. the junction with the cylindrical part. The conical part of the foundation and the sub- and intertidal portion of the cylindrical part are available for colonisation by subtidal and intertidal organisms comprise 651 m^2 subtidal and 92 m^2 intertidal surface area for windmill D5, the foundation where all samples for this investigation were collected. Because of bathymetric variations within the wind farm area, minor deviations in the subtidal surface area of the other windmills (about 17%) exist.

5.2.2. Sample collection and processing

A monitoring programme was set up to sample the hard substrata associated with the windmills (Kerckhof et al., 2008), and the first sampling took place in autumn 2008 (Kerckhof et al., 2009). Sampling was continued in 2009 and 2010. All samples analysed here were collected on the foundation of windmill D5, (co-ordinates WGS 84: 51°32,88'N - 2°55,77'E, installed on 30 May 2008) between January 2009 and February 2010, covering a full seasonal cycle. A total of 27 scrape samples for epibiota were collected consisting of 23 subtidal and four intertidal samples (table 1).

Table 1: Samples collected at the foundation of windmill D5 between January 2009 and February 2010.

Subtidal Samples			**Intertidal Samples**	
Date	**Sample code**	**depth (in m)**	**Date**	**Sample code**
16/02/2009	CP/09/2 S1	25.0	29/01/2009	CP09/1 1
	CP/09/2 S3	20.0		
	CP/09/2 S2	15.0		
19/03/2009	CP09/3 S3	22.5		
	CP09/3 S1	10.0		
03/07/2009	CP09/4 S1	21.0		
	CP09/4 S3	15.6		
	CP09/4 S2	4.0		
16/07/2009	CP09/5 S1	20.5	16/07/2009	CP09/5 1 & 2
	CP09/5 S2	13.5		
	CP09/5 S3	6.5		
12/08/2009	CP09/7 S1	15.0		
	CP09/7 S2	15.0		
	CP09/7 S3	15.0		
24/08/2009	CP09/9 S1	15.0		
	CP09/9 S2	15.0		
	CP09/9 S3	15.0	28/09/2010	CP09/10 1 & 2
22/10/2009	CP09/11 S1	15.0		
	CP09/11 S2	15.0		
	CP09/11 S3	15.0		
24/02/2010	CP10/1 S1	15.0	24/02/2010	CP10/1 1 & 2
	CP10/1 S2	15.0		
	CP10/1 S3	15.0		

Subtidal samples were collected by scraping the fouling organisms with a putty knife from a sampling surface area of 0.25 m x 0.25 m. Due to practical constraints intertidal scrape samples were collected in a non-quantitative manner. All scraped material was collected in plastic bags that were sealed under water and transported to the laboratory for processing – fixation (5% formaldehyde – seawater solution), sieving, sorting, preservation (75% ethanol) and identification. Sieving was done through a 1 mm mesh-sized sieve. The fraction >1 mm was analysed.

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. Densities were expressed as the number of individuals per m². The abundance of colonial organisms was estimated as the degree of coverage, using the categories in EN ISO 19493 (2007). Video footage collected by the divers 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. In the intertidal, the presence of certain macro algae was noted. Depth of the subtidal samples was measured with a pressure gauge from a Liquivision X1 dive computer as the depth from the water surface at sampling time.

5.2.3. Data analysis

Colonial organisms were excluded from diversity analyses, except for species richness (N_0), and two species, *Odostomia turrita* and *Pusillina inconspicua*, were further excluded as these species are usually smaller than 1 mm, and hence not representatively retained on 1 mm sieves.

For the analysis of diversity, Hill's diversity indices (order 0, 1, 2 and infinity) were calculated (Hill, 1973). N_0 attributes the same weight to all species, independent of their abundance. It can be seen as the species richness, the number of species in the sample. N_1 gives less weight to rare species while N_2 gives more weight to abundant species. N_{inf} only takes into account the most abundant species. These indices were calculated using PRIMER 6 (Plymouth Marine Laboratory). We used Principal Component Analysis (PCA) to determine the main structuring variables in our data sets (ter Braak & Prentice, 1988). The percent species abundance data were square-root transformed prior to numerical analysis in order to stabilize their variances. Only species encountered in at least two samples and with a relative abundance of more than 1% were included in the ordinations. Time since installation (time) was included in the PCA analysis only as passive variable, and as such did not influence the ordination (Lepš & Šmilauer, 2003). Multivariate statistics were performed using the package CANOCO v. 4.5 (ter Braak & Šmilauer, 2002).

Two depth transects were chosen to illustrate the main changes in relative abundances of the epifouling communities (February and July, representing respectively winter and summer; Figure 3)

5.3. Results

5.3.1. General diversity

In the sampling period of February 2009 to February 2010, a total of 75 taxa, further called species, were identified from the offshore turbine foundation (full species list can be found in Annex 1). Fifty nine species were discovered in the scrape samples (> 1 mm), four species were only found by the study of the underwater video footage including three Decapoda which had previously been found on the foundations in 2008 and additionally the presence of three macroalgae was noticed by visual inspection of the intertidal zone. Of the total of 75 species, 42 species had as yet not been encountered on the foundations and 33 species were previously detected in 2008. On the other hand 17 of the 50 species found in 2008 (Kerckhof et al., 2009) were not recorded again in this sampling period.

In this sampling period, species belonging to twelve phyla (or correspondingly large taxonomic divisions) were found (Annex 1). In comparison with 2008 four new phyla were present while one was not found again. On the other hand no sponges or tunicates were found.

Several species were present as juveniles only e.g. the North Sea crab *Cancer pagurus* and some juvenile stages of bottom dwelling benthic species were encountered as well. After the winter of 2009, some species such as the bivalves *Aequipecten opercularis* and *Heteranomia squamula* were not found again. In the winter of 2010, new species were present in the samples including a second species of *Tubularia*, *T. indivisa* and the entoproct *Pedicellina nutans*.

In the subtidal zone three phyla: Mollusca, Annelida and Arthropoda – Crustacea, accounted for 73 % of the species richness (Figure 1). The same three phyla, but in a different order, were also the most dominant ones in 2008, accounting for 83 % of the species.

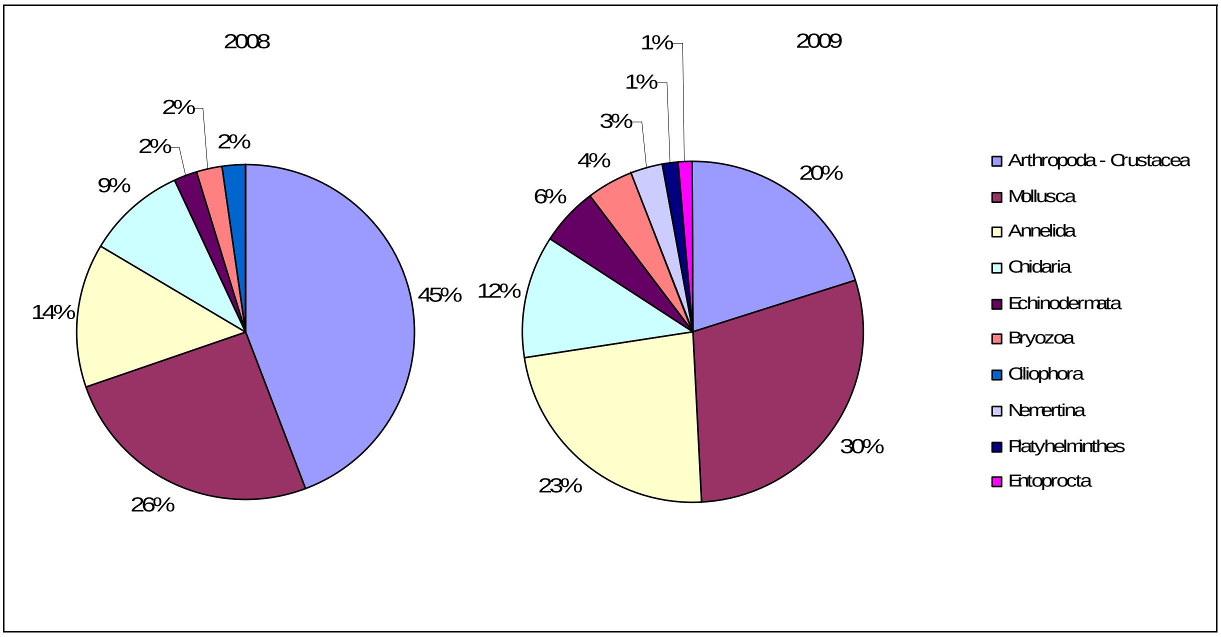


Figure 1. Proportion of the species richness of the phyla in the subtidal zone for 2008 en 2009. Percentages indicate the relative proportion of the respective phylum (n = 3 samples 2008 and 23 samples 2009)

5.3.2. Zonation

The previously observed zonation pattern of three distinct zones (Kerckhof et al., 2009) remained generally apparent. The intertidal – splash zone, formerly almost solely dominated by the presence of the giant midge *Telmatogeton japonicus*, became somewhat more subdivided, with a lower conspicuous zone dominated by the barnacle *Semibalanus balanoides*. Above this barnacle zone, in the splash zone, green algae were sparsely represented while the giant midge *T. japonicus* was found year round. This species also descended into the *Semibalanus* zone. In between the *S. balanoides*, specimens of the New Zealand barnacle *Elminius modestus* were observed. Larger algae were rare, and only a few isolated specimens of *Fucus vesiculosus* and *Porphyra umbilicalis* were noticed.

Most notable was the establishment of a conspicuous mussel *Mytilus edulis* belt in the transitional barnacle – *Jassa* zone by the summer of 2009. In this zone, mussels had covered the initial barnacles *Balanus perforatus* while the tube dwelling amphipods *Jassa* spp. were still present.

Analysis of four subtidal depth-transects shows that species richness and evenness increased with depth. Additionally, independent of depth, species richness generally increased from February to July (Figure 2). Densities increased 10-20 fold from winter (February-March) to summer (July) (Figure 2). Furthermore, the dominance of *J. herdmani* decreases with increasing depth in summer well as in winter (Figure 3). In winter 2009 *Potamoceros triqueter, Actinaria* spp., *Pisidia longicornis* and *M. edulis* were dominant at 20 and 25 m depth. In summer, other taxa, such as *Phyllodoce mucosa, Balanus crenatus* and *Asterias rubens* were most abundant at 15 and 21 meter depth.

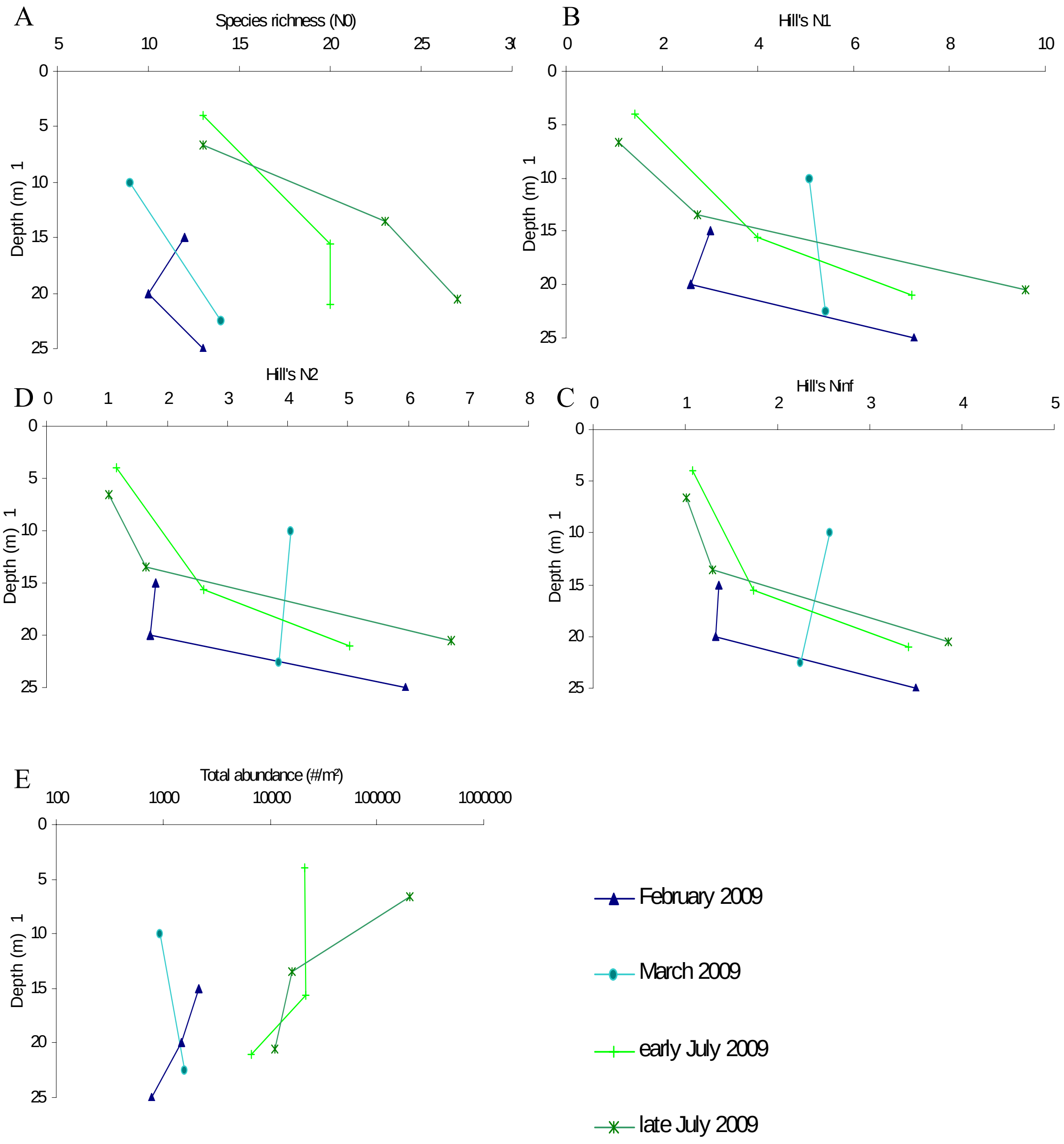


Figure 2. Species richness (Hill's N_0 – A), Hill's N_1 (B), N2 (C) and N_{inf} (D) diversity indices, and abundance (E) for four subtidal depth transects.

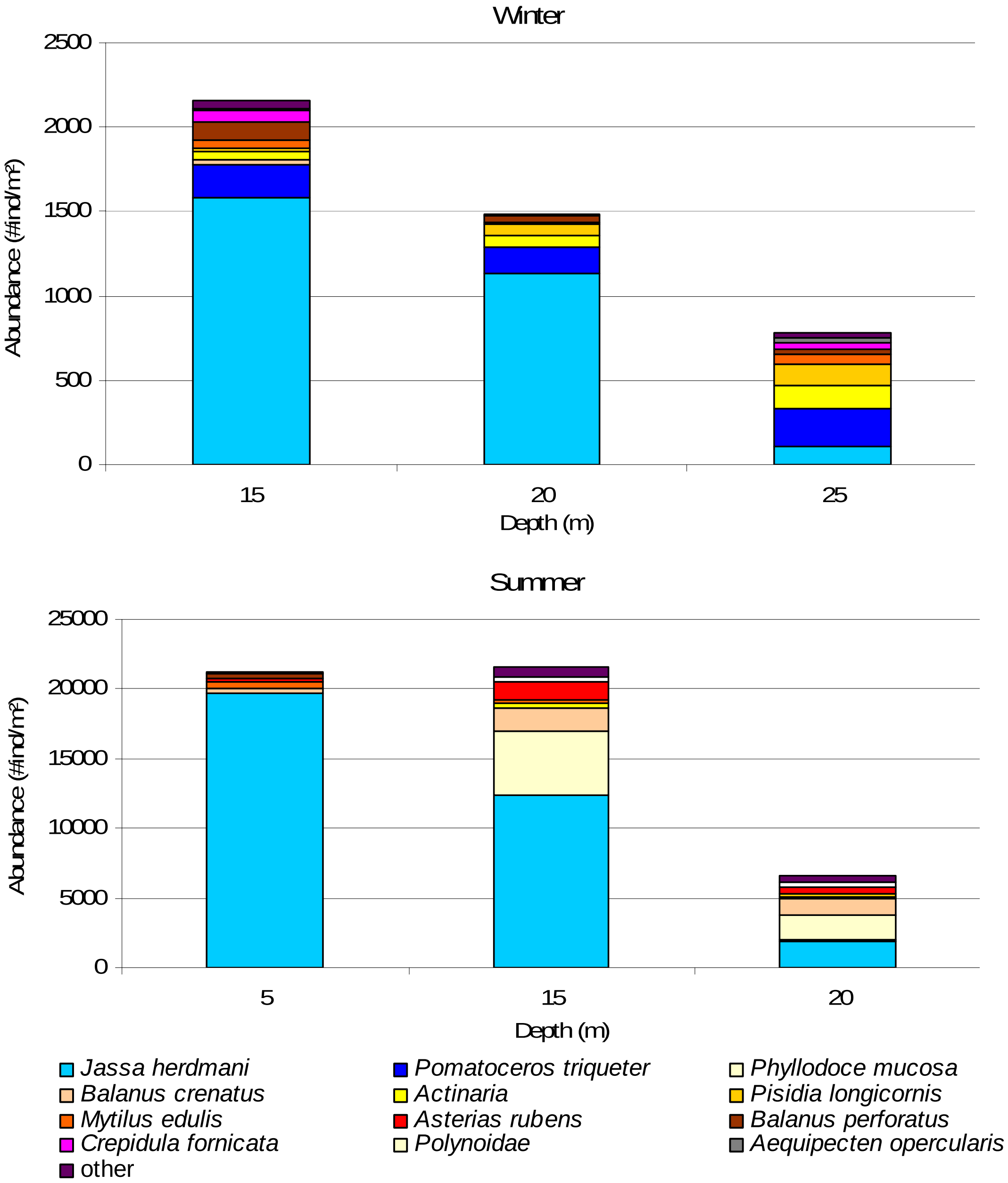
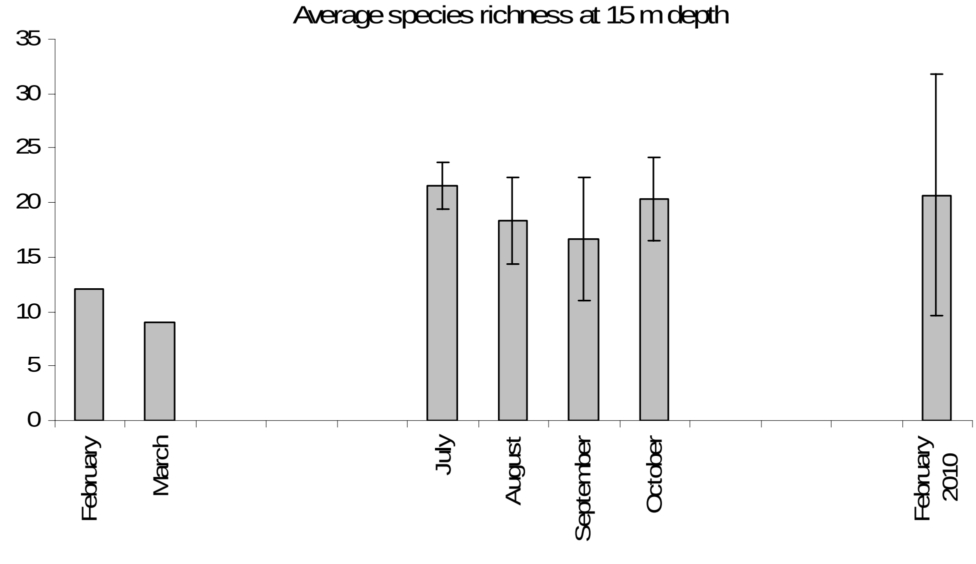


Figure 3. Absolute abundances of major taxa in winter and summer subtidal depth transects.

5.3.3. Seasonal variation

The analysis of eight sets of samples taken at 15 m depth showed a relatively low species richness at the start of the current monitoring period (~10 species in winter 2009; Figure 4). Species richness doubled from March to July 2009 and remains fairly stable thereafter (~20 species). In February 2010 species richness varied strongly between the three replicates (respectively 9, 22 and 31 species were present). A similar seasonal pattern was found for overall abundances, with low densities in February-March 2009 and higher abundances thereafter, mostly caused by high densities of *J. herdmani*.



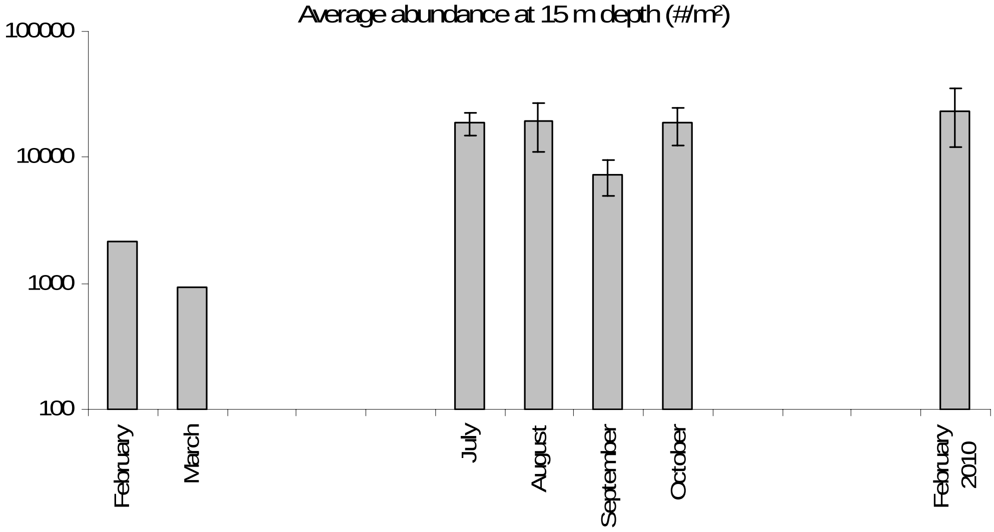
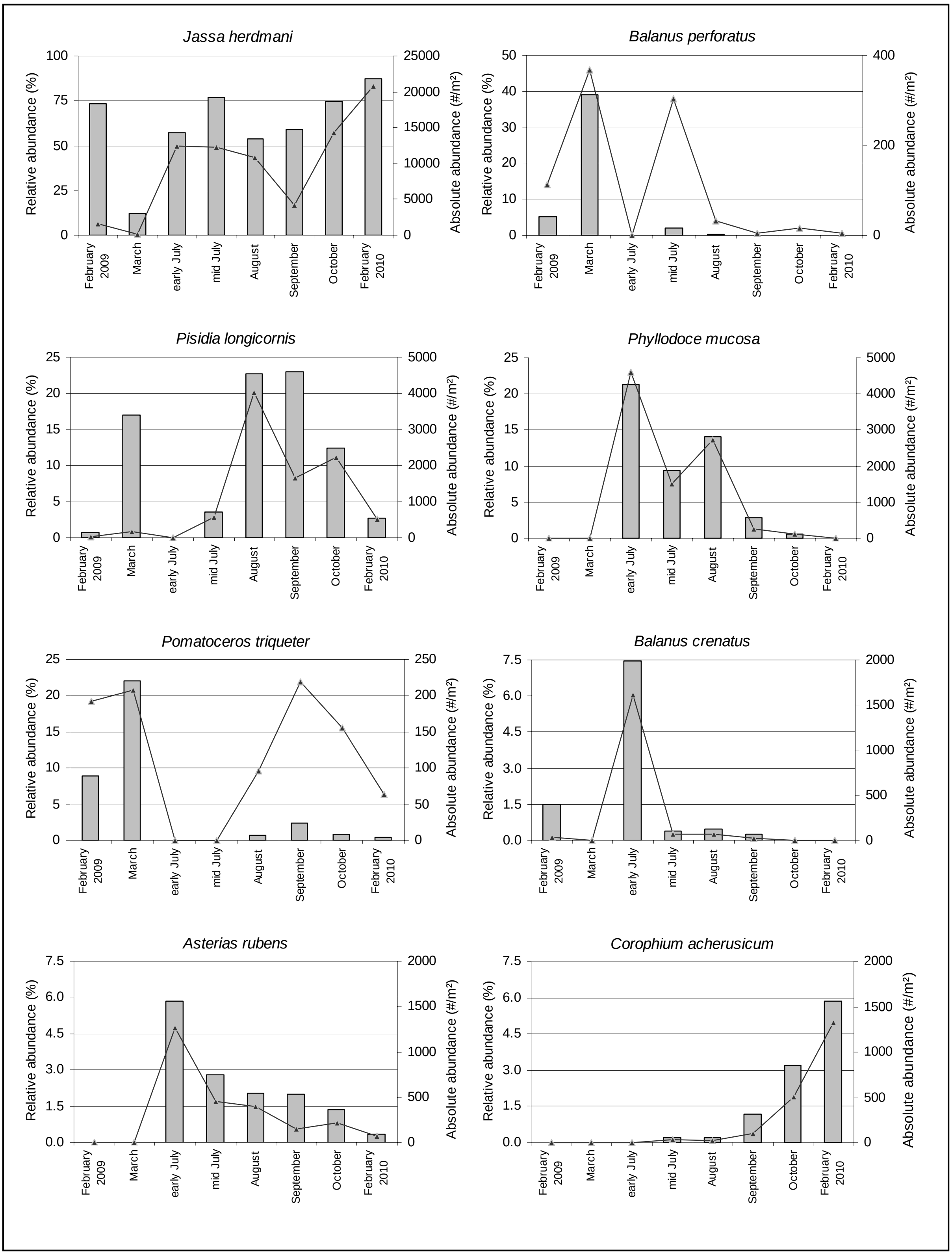


Figure 4. Temporal variation of the average species richness (upper panel spp. /m²) and abundance (lower panel; ind./ m²) at 15 m depth. Values are mean values + standard deviation

The analysis of the relative species abundance (Figure 5) showed the relative decline of certain early colonists such as *P. triqueter* and *B. perforatus,* while new species gradually became more abundant. Other species such as *B. crenatus* and *A. rubens* experienced an obvious peak in abundance in early summer and became less abundant thereafter, while certain free living Polychaetes such as *P. mucosa* (in July and August) and *Eulalia viridis* remained present in the community for a longer period of time. The relative abundance of *P. longicornis* was high in March 2009 and again in August – October 2009.

The relative abundance of *J. herdmani* was high during the whole study period except for a decline in March 2009. Furthermore, the appearance of *Corophium acherusicum,* another tube building amphipod (densities up to 2.000 ind./m² in February 2010), from august 2009 on is noteworthy.


Jassa herdmani
Balanus perforatus
Pisidia longicornis
Phyllodoce mucosa
Pomatoceros triqueter
Balanus crenatus
Asterias rubens
Corophium acherusicum
Relative abundance (%)
Absolute abundance (#/m²)
February 2009
March
early July
mid July
August
September
October
February 2010
0
25
50
75
100
5000
10000
15000
20000
25000
10
20
30
40
200
400
5
15
1000
2000
3000
4000
150
250
1.5
3.0
4.5
6.0
7.5
500
1500

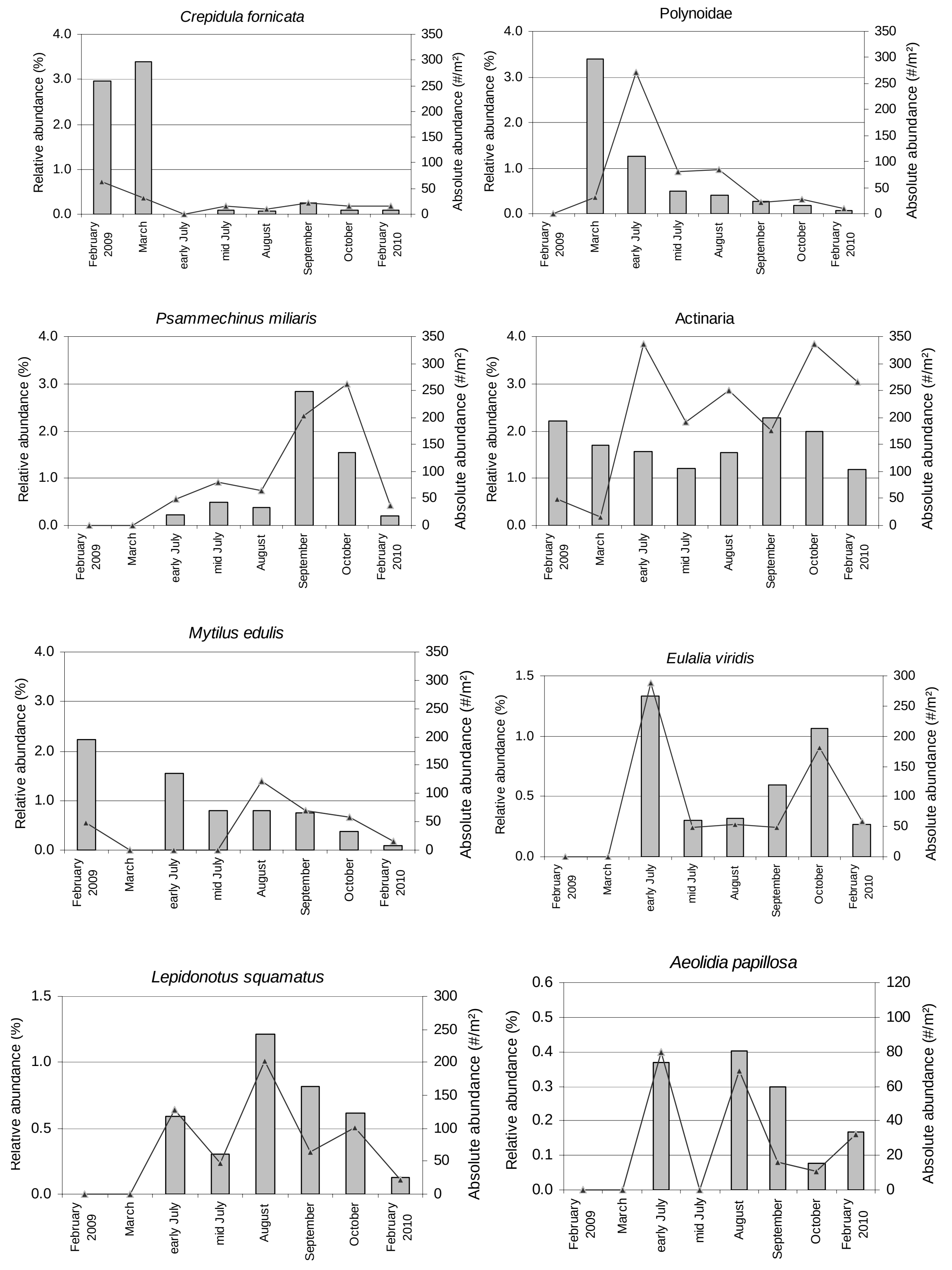


Figure 5. Temporal variation of relative (bars) and absolute abundance (line) of taxa at 15 m depth.

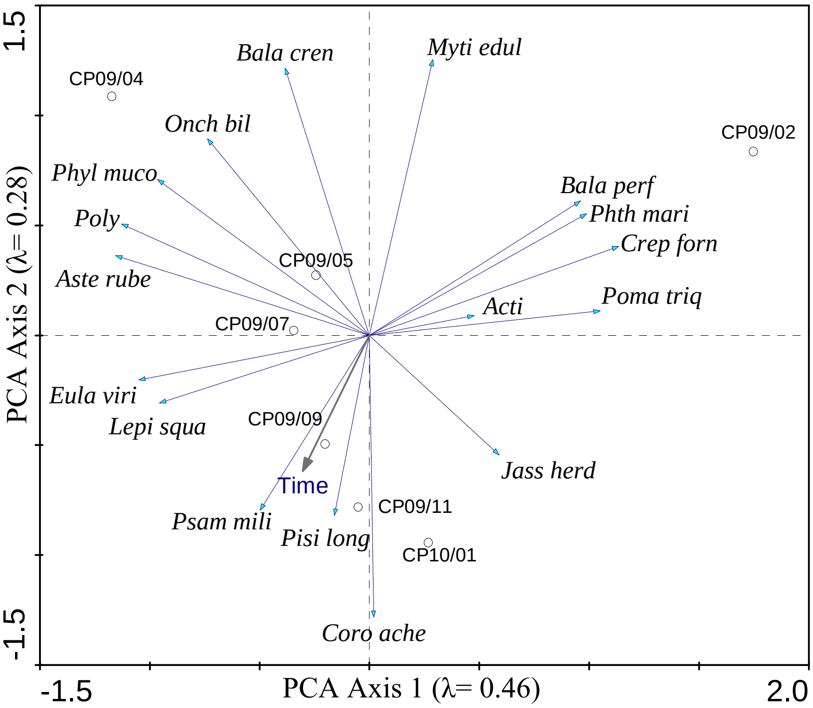


Figure 6. Principal components analysis (PCA) biplot on the centered and standardized species relative abundance data (blue vectors) of seven sets of scrape samples taken at 15 m. Taxon and sample codes: see table 1 and Annex 1. Time (since installation) was projected as supplementary variables, and as such did not influence the ordination.

The first two PCA axes together account for 74% of total environmental variance (Figure 6). PCA axis 1, which explains 46% of the total variation, is positively related with taxa that were most abundant in the February 2009 sample (*P. triqueter, C. fornicata, B. perforatus* and *Phtisica marina*). PCA axis 2, which explains 28% of the variation, is positively related with taxa that were most abundant during early summer 2009 (including *B. crenatus* and *M. edulis*); and negatively related with the taxa that became more abundant in samples collected in autumn 2009 to winter 2010 (including *C. acherusicum, P. longicornis* and *Psammechinus miliaris*). The figure also illustrates that the relative abundance of *J. herdmani* was highest in the winter samples, and lowest in (early) summer samples.

5.4. Discussion - Characteristics of the fouling assemblage

5.4.1. A dynamic community – zonation, succession and seasonality

Being fast and very intensive, with a rapid species turn over, the early colonisation of the foundation of the windmills showed two typical characteristics of the first colonisation phases in an ecological succession (e.g. Horn, 1974; Connell & Slatyer, 1977; Kerckhof et al., 2009).

The time of arrival and the availability of free substratum are extremely important for the organisms. The concrete foundations were installed in late spring 2008, at which time the meroplanktonic propagules of species with an early reproduction had already disappeared from the water column. These species were hence not able to colonise the foundations during this first year and species breeding and settling in late summer and early autumn were thus favoured during the initial colonisation and were able to take advantage of the lack of competition. As a consequence, in the first year we could witness the dominance of one species, the bryozoan *E. pilosa*, which in other conditions would have never become so dominant. During the second year, there was more competition for the available space.

As expected, drastic changes in the assemblage structure were observed during the second year, when the propagules of early reproducers arrived onto the foundations, which increased the competition for space and food. As a consequence some early colonisers such as *E. pilosa*, *P. triqueter* and *P. marina* became less abundant, while others even disappeared completely e.g. *A. opercularis*. Within the sampling period we hence observed seasonal progression rather than succession and the species composition of samples from February 2009 and 2010 was more similar than that of samples taken on other moments.

In the splash zone, formerly completely dominated by *T. japonicus*, a band with the intertidal barnacle *S. balanoides* was established just above the mussel zone in 2009. Mussels and barnacles are the dominant fauna elements in the intertidal shallow subtidal. Similar zonation patterns with a mussel / barnacle belt in the shallow subtidal – intertidal can be seen on artificial hard substrata in the intertidal zone and on other wind farms in the North Sea (e.g. EMU, 2008a; EMU, 2008b; Whomersley & Picken, 2003; Joschko et al., 2008; Bouma & Lengkeek, 2009). *Telmatogeton japonicus* was present year round and formed a monoculture above the barnacle zone, but was also present in the *Semibalanus* zone. We believe that the observed zonation may already resemble the climax zonation for the splash and infralittoral zone.

During the sampling period February 2009 – February 2010 the indigenous barnacles *B. crenatus* and *S. balanoides*, being typical early breeders (Bassindale, 1964) and not present in 2008, were found in large numbers. This was also the case for other common hard substratum species such as the starfish *A. rubens*, and the pioneer hydrozoan *Tubularia larynx*. On the other hand the later breeding barnacles, *B. perforatus* and *M. coccopoma* declined in abundance. The barnacle *B. perforatus*, a warm water species spreading into the North Sea, suffered from mortality caused by predation and smothering, as proven by the presence of many empty specimens. However, larger individuals were able to survive under the mussel cover. There was even a spatfall noticed in autumn 2009 although not as heavy as in 2008.

In the infralittoral - shallow subtidal establishment of a conspicuous belt of the blue mussel *M. edulis* was observed that gradually expanded to greater depths, in the deeper zone however their abundance is limited due to the predation by *A. rubens*.

5.4.2. A rich and diverse community

From 2008 to 2009 species richness increased from 50 species in 2008 to 75 species, including 64 macrofaunal subtidal species (> 1 mm). This is similar to other studies on early colonisation of artificial hard substrata such as van Moorsel (2001), who recorded 44 macrofaunal invertebrates in a study of an artificial reef off Noordwijk (the Netherlands) and Orejas et al. (2005), who identified a total of 44 species in the scrape samples and an additional seven identified on photographs on the FINO 1 research platform in the German Bight. However, it is significantly less than in a study of the long established epifaunal assemblages of two shipwrecks at the BPNS, where Zintzen et al. (2006) found 99 macrofaunal invertebrates in the scrape samples. Species richness may hence continue to increase over the course of the next few years as certain taxa have yet to be recorded from the foundations.

Overall the subtidal community composition changed from one absolutely dominated by a single species (*E. pilosa*) to a more multi-species community. This increase in species evenness may be due to the fact that the three-dimensional structures formed by calcareous structures of polychaete tubes and empty barnacles provide shelter - especially for the young stages of certain species - and additional space for the settlement of other species.

5.4.3. *Jassa*, a key species at the windmill foundations

One of the most abundant species is *J. herdmani,* with maximum densities (of specimens retained on a 1 mm sieve) up to 200.000 ind. /m² (in July 2009). The dominance of *Jassa* spp. has been noted in many other studies dealing with artificial substrata in the North Sea, such as shipwrecks (e.g. Zintzen, 2007) and windmills (e.g. Leonhard & Pedersen, 2006; Orejas et al., 2005), where even higher densities were recorded (max. > 1.317.045 ind./m² (Orejas et al., 2005). This species is most common in the shallow subtidal down to – 15 m. Although *J. herdmani* is a short-lived species, it has an almost year round reproduction period and the species has a high fecundity (Nair & Anger, 1980). Consequently, juveniles were found in nearly all seasons. *Jassa herdmani* builds tubes and constructs mats which smother underlying species such as barnacles in addition to making the available surface less suitable for the settlement of other species. Hence, a negative correlation between *Jassa* abundance and species richness in the depth transects was observed. The presence of the *Jassa* tubes hampers the settlement of larvae of other species. On the other hand *Jassa* provides an important food item for the fish species associated with the hard substrata (Reubens et al., this volume).

The occurrence of another tube building amphipod *C. acherusicum* also deserves our attention. Despite the offshore location of the C-Power site, which places it under the governance of clear Channel water (Kerckhof et al., 2009) there must be enough fine sediment present in the water for *Jassa* and *Corophium* to build their tubes.

5.4.4. Presence of non-indigenous species.

In 2008 four non-indigenous species were found: the slipper limpet *Crepidula fornicata*, the New Zealand barnacle *Elminius modestus*, the giant barnacle *M. coccopoma* and the giant midge *T. japonicus* (Kerckhof et al., 2009). All four species were already known from the area and are opportunists and early colonisers, taking advantage of man-made structures and disturbed conditions for settlement (Kerckhof et al., 2007).

In 2009 only *M. coccopoma* had disappeared. This subtropical species, occurring in the infralittoral fringe, probably suffered from smothering by mussels and *Jassa* and also from the colder winter 2008-2009. Although this species is now part of the North See fauna and individuals are able to survive for several years, most populations typically do not to survive for more than one year as they are overgrown by other species. As a coloniser of newly available substrata, settling in late summer (Kerckhof unpublished), it may in most cases not find suitable surfaces to settle. The three other species all thrived in 2009 with *C. fornicata* present in nearly all subtidal samples. On the video footage its presence was conspicuous all over the foundation. A maximum density of 192 ind./m² was recorded in March 2009 and the overall mean was 41 ind./m². This species is also increasing elsewhere in European waters as well, including the BPNS (Kerckhof et al., 2007).

Despite being non-indigenous, *T. japonicus* is very common on exposed vertical offshore structures, such as buoys and pilings. On the buoys in the BPNS, it forms a distinct belt in the upper littoral and splash zone (Kerckhof, unpublished). This was also the case on the foundation of the windmill under investigation in this study. On buoys, densities can reach over 3000 ind/m² (Kerckhof, unpublished). The species was also present in high numbers on the pilings of the Danish Horns Rev offshore wind farm (Leonhard & Pedersen, 2006), where it formed a monoculture in the high intertidal and splash zone. However Bouma & Lengkeek (2009) did not mention this species for a wind farm off the Dutch coast. The presence of *E. modestus* on the offshore structures of the windmills illustrates the fact, already noted by Kerckhof et al. (2007), that this species is not limited to coastal waters.

5.5. Conclusions

The fouling process on foundations of the C-Power wind farm is comparable with that on other wind farms and on other artificially hard substrata in the North Sea. The observed species assemblages clearly demonstrate a transitional situation with increasing species richness, and a decrease in numbers of early colonisers. Both a medium-term seasonal signal and a long-term successional signal in community composition were observed.

Subtidally, the community changed from one dominated by only one species (*Electra*) to a rather multi-species community wherein it should however be noted that only a limited number of species was really abundant, and many were present as juveniles only.

Only three of the four previously encountered non-indigenous species were found in 2009: the slipper limpet *C. fornicata*, the New Zealand barnacle *E. modestus*, and the giant midge *T. japonicus*.

5.6. Acknowledgements

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Chapter 6. The importance of marine wind farms, as artificial hard substrata, for the ecology of the ichthyofauna

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Scientific divers, relaxing after work

Photo Jan Reubens/UGent

Abstract

A substantial expansion of offshore wind farms in the North Sea has been planned, inducing a growing interest in the possible effects of these artificial habitats on the marine environment. To date however, little research has been done to consider the possible effects on the ichthyofauna.

This study provides first insights in the use of the offshore wind turbines by several fish species with a focus on *Trisopterus luscus* (pouting) at the Thorntonbank wind farm (Belgian part of the North Sea).

Scuba diving operated visual surveys, carried out between July and October 2009, revealed a population size of at least 29 000 individuals of pouting, representing a biomass of $3.5 * 10^3$ kg, in the vicinity of a single wind turbine. Line fishing and gillnet fishing were conducted throughout 2009 to investigate food selectivity. The results supported the prime importance of the hard substratum prey species *Jassa herdmani* and *Pisidia longicornis* in the diet of pouting.

Samenvatting

Een substantiële uitbreiding van offshore windmolenparken in de Noordzee wordt voorzien in de nabije toekomst, wat een groeiende interesse veroorzaakt in de mogelijke effecten van deze artificiële habitatten op het marien milieu. Tot op heden is er echter weinig onderzoek gebeurd naar de mogelijke effecten op de ichtyofauna. Met de constructie van een windmolenpark (C-Power), gestart in 2008, biedt een unieke situatie zich aan om de effecten van artificiële harde substraten op de ichtyofauna te onderzoeken. Deze studie verschaft de eerste inzichten in het gebruik van offshore windturbines van het windmolenpark op de Thorntonbank (Belgisch deel van de Noordzee) door verschillende vissoorten, waarbij enerzijds gefocust werd op de aanwezige visgemeenschap en anderzijds op de trofische relaties tussen steenbolk (*Trisopterus luscus*) en het artificiële rif. Voor de trofische relaties werden dichtheidsschattingen, gebaseerd op visuele observaties, gemaakt en werd het voedingsgedrag van steenbolk nabij de windturbines onderzocht aan de hand van maaganalyses.

In totaal werden zeven verschillende vissoorten aangetroffen, waarvan vier soorten regelmatig: steenbolk, kabeljauw (*Gadus morhua*), horsmakreel (T*rachurus trachurus*) en makreel (*Scomber scombrus*). De visuele observaties, uitgevoerd tussen juli en oktober, toonden aan dat een populatie van minimum 29 000 steenbolken (biomassa van $3.5*10^3$ kg) aanwezig was rond één windturbine. De densiteiten varieerden tussen 7 en 74 specimens/m², met een gemiddelde densiteit van 18±21 individuen/m². Een grote variatie in densiteiten was aanwezig tussen waarnemers en in de tijd. Lijnvisserij werd gedurende gans 2009 uitgevoerd om voedingsselectiviteit te onderzoeken. Een grote variëteit aan prooisoorten was aanwezig in het dieet van steenbolk. De hard-substraatssoorten *Jassa herdmani* en *Pisidia longicornis* bleken hierin de belangrijkste prooisoorten te zijn. Deze soorten komen in zeer hoge densiteiten voor als epifauna op de funderingen van de windmolens.

6.1. Introduction

Marine structures, whether natural or man-made, have the potential to attract and concentrate fishes and/or to enhance local fish stocks (Bohnsack, 1989; Pickering and Whitmarsh, 1997; Leitao *et al.*, 2008; 2009). Several mechanisms may stimulate this behaviour, including (1) shelter against currents and predators (Jessee *et al.*, 1985; Bohnsack, 1989), (2) additional food and favoured prey types (Pike & Lindquist, 1994; Fabi *et al.*, 2006; Leitao *et al.*, 2007), (3) increased feeding efficiency and (4) provision of nursery and recruitment sites (Bull & Kendall Jr, 1994).

Whether these structures only attract and concentrate fishes or also increase the local productivity, however, is subject to debate (Bohnsack & Sutherland, 1985; Bohnsack, 1989; Polovina, 1989; Pickering & Whitmarsh, 1997). If fishes are merely attracted to the structures due to some behavioural preferences, concentrating them at one site, the structure may act as an ecological trap (Robertson & Hutto, 2006). In addition, the hard structures may promote overfishing by increasing the possible catch per unit effort (CPUE). If the structure however enhances the environmental carrying capacity of the system, they might be able to enhance local productivity as well (Bohnsack, 1989).

The outcome of attraction versus production may differ in different locations and for different species (Bohnsack & Sutherland, 1985). For this reason it is important to interpret the dimensions and distribution areas of the fish populations involved and to determine factors influencing structure (densities) and functionality (production versus dispersion) to quantify the ‘possible’ net production.

Some of the fish species observed in close proximity to artificial hard structures in the Belgian part of the North Sea (BPNS) are *Trisopterus luscus* (Linnaeus, 1758) (pouting), *Gadus morhua* (Linnaeus, 1758) (cod), *Dicentrarchus labrax* (Linnaeus, 1758) (seabass), *Pollachius pollachius* (Linnaeus, 1758) (pollack), *Trachurus trachurus* (Linnaeus, 1758) (horse mackerel) and *Scomber scombrus* (Linnaeus, 1758) (mackerel) (Zintzen *et al.*, 2006; Mallefet *et al.*, 2007).

With the construction of a wind farm in the BPNS, initiated in 2008, a unique situation is offered to investigate the impact of artifical hard substrata, such as the foundations of wind farms, on the ichtyofauna of a predominantly soft sedimented environment.

The primary goals of the present study were to: (1) improve our knowledge on the fish community established and (2) investigate the trophic relationship between pouting and the artificial reefs. Therefore density estimations about pouting were made based on visual observations, and feeding behaviour in the vicinity of the wind turbines was investigated through stomach content analysis.

6.2. Material and Methods

In the present investigation general information is gathered on fish species diversity, density of the fish species present and length-frequency information. Moreover, an estimation of the abundance of pouting in the vicinity of the wind farm is made based on visual information. Additionally pouting caught near the wind turbines are investigated to determine whether the epifauna present at the foundations of these turbines is a key constituent of their diet.

6.2.1. Study site

The C-Power wind farm is located at the Thorntonbank, a natural sandbank 27 km offshore in the BPNS. At present, six gravity-based foundations have been built. In the near future, a total of 54 wind turbines will be constructed on this sandbank, covering an area of approximately 14 km^2. By 2020, more than 200 wind turbines will be present in the BPNS.

Each of the currently installed foundations has a diameter of six metres at the sea surface, expanding to 16 metres at the level of the seabed which lies at a depth of 25 m at high tide. Each foundation is surrounded by a scour protection layer, consisting of two coats. The filter layer is made up by pebble ranging from 2.5 mm up to 75 mm and has a diameter of 48 m (1800 m^2). This layer is overtopped by the armour layer, consisting of a protective stone mattress with rocks ranging from 250 mm up to 750 mm and has a diameter of 44 m (1600 m^2).

The surrounding soft sediment is composed of medium sand (mean median grain size 374 µm, SE 27 µm) (Reubens *et al.*, 2009).

6.2.2. Data collection

6.2.2.1. Species richness, length-frequency and CPUE

Nine sampling campaigns were organised at the C-Power wind farm in 2009 (table 1). Line fishing was conducted to collect fish species, since this is an efficient capture method on hard substrata. Hooks, size nr 4, of the brand Arca were used. Fresh or frozen lugworm (*Arenicola marina*) was used as bait. Angling was performed 1 to 10 metres away from a turbine (i.e. within the erosion protection layer radius) just above the sea bottom, assuring the catching of individuals hovering above the artificial hard substratum. Which turbine (D1-D6) was sampled depended upon technical constraints. It was assumed that no significant differences in species richness, density or length-frequency existed between the turbines, as all six turbines were exposed to similar abiotic conditions. Data were pooled and no distinction was made between turbines.

All fishes were identified, measured (total length) and weighed (wet weight). Catch per unit effort (CPUE) was calculated for each species and for each sampling day. CPUE is a commonly used index for relative fish abundance measurements (Haggarty & King, 2006), although it is often considered to be biased and not necessarily proportional to abundance (Harley *et al.*, 2001). This can partly be controlled by the use of standardized fishing methods, duration and gear. In this research fish bait, time duration, material and number of fishermen involved were standardized. In this way a comparison in CPUE and relative abundances over time could be made.

6.2.2.2. Pouting density estimation

Nine fish surveys were carried out, on the scour protection (-25 m at high tide) of one wind turbine between July and October 2009. Underwater visual censuses were carried out four hours after high tide or two hours before high tide, for 20 minutes. The number of observers varied between 1 and 3, depending on logistic constraints. If tidal window allowed, two dives were performed on the same day. The stationary sampling method (Bannerot & Bohnsack, 1986) was applied. Before each survey the average visibility was estimated by tape measure. This average visibility was used as radius for the area observed and observations were limited to the first metre above the seabed. Pouting was counted and the size of the fish was assessed. If large schools of fish were present, abundance groups were used to count the number of individuals. Counting by abundance units may considerably facilitate the enumeration process and may lessen the chance of error (Bortone & Kimmel, 1991). Fish lengths were assessed by comparing the fishes to a ruler attached to a writing board.

The number of individuals in the area observed was used to determine the total population size on the scour protection. It was assumed that the fish were evenly distributed across the erosion protection layer, which covers an area of 1600 m^2.

6.2.2.3. Stomach analyses

Both line fishing and gill netting were used to collect pouting for stomach content analysis. Sampling was performed throughout the year 2009. For line fishing the same sampling strategy as mentioned in section 2.2.1 was used. Gill nets were used since this is an efficient technique to collect many samples in a short period. A commercial cod net (270 m in length and 1 m high), with a mesh size of 50 mm was used. The net was set for periods of two to four hours.

After being measured (total length) and weighed (wet weight), 94 specimens of pouting were gutted. Their digestive system was preserved in an 8% formaldehyde-seawater solution. All food components in the digestive tract were identified to the lowest possible taxonomic level. Dry weight (60 °C for 48 h) and ash weight (500 °C for 2 h) were measured for all food components.

6.2.3. Data analysis

Dietary composition was assessed by an occurrence (%FO) and abundance (%A) method (Hyslop, 1980). Relative abundance ($\%A_i$) can be either numerical or gravimetrical. For the gravimetrical analysis ash-free dry weight (AFDW) was used.

$$\%FO_i = (N_i/N)*100$$
$$\%A_i = (\sum S_i/\sum S_a)*100$$

N_i is the number of predators with prey type i in their stomach, N the total number of no-empty stomachs, S_i is the stomach content composed by prey i and S_a the total stomach content of all stomachs together (Amundsen *et al.*, 1996).

The feeding coefficient (Q) (Hureau, 1970) and the index of relative importance (IRI) (Pinkas *et al.*, 1971) were used to evaluate the dietary importance of each food category.

The Statistica software package was used for the Analysis of Variance (ANOVA) and the non-parametric tests. The PRIMER v6 software package (Clarke & Gorley, 2006) was used to run a Principal Component Analysis (PCA). For the data matrices a distinction was made between numerical and gravimetrical information. For both datasets relative abundances of prey were used instead of the rough data, to detect patterns in individual diet and foraging behaviour (De Crespin de Billy *et al.*, 2000).

Prey types that appear in only one stomach have a low representativeness and were excluded from the multivariate analyses.

6.3. Results

6.3.1. Species richness, length-frequencies and CPUE

Over all sampling campaigns seven different fish species were caught (table 1): cod (*Gadus morhua*; Linnaeus, 1758), pouting (*Trisopterus luscus*; Linnaeus, 1758), mackerel (*Scomber scombrus*; Linnaeus, 1758), horse *mackerel* (*Trachurus trachurus*; Linnaeus, 1758), saithe (*Pollachius virens*; Linnaeus, 1758), black seabream (*Spondyliosoma cantharus*; Linnaeus, 1758) and bull rout (*Myoxocephalus scorpius*; Linnaeus, 1758). Saithe, black seabream and bull rout were caught only once. These rare species were not analysed in more detail. Mackerel and horse mackerel were caught in summer and early autumn, while cod and pouting (figure 1 and 2) were caught during most of the sampling campaigns. Mackerel length varied between 24 and 31 cm (average 27 cm; SD 2 cm). No significant differences in length were present between the different months (Mann-Whitney U Tests, all $p > 0.05$). The length of horse mackerel ranged from 21 to 29 cm (average 23 cm; SD 3 cm). A significant difference in length was present between July and September (One-way Anova, $p = 0.016$). Cod length varied between 20 and 57 cm (average 36.31 cm; SD 7.95 cm). Length differed significant between seasons (one-way Anova, $P < 0.05$). The average length was lowest in February (23.82 cm) and highest in October (41.71 cm) (figure 1). The length of pouting ranged from 13 to 34 cm (average 23.03 cm; SD 3.52 cm). In summer and early autumn a broader range in length classes was present than in winter (figure 2). Length differed significantly between months, but no clear seasonal pattern in length classes was present.

Table 1. Overview of the nine angling campaigns conducted in the wind farm.

Date	Location	Species
7/01/2009	D3	*Trisopterus luscus, Gadus morhua*
20/01/2009	D4	*Trisopterus luscus, Gadus morhua*
3/02/2009	D4	*Trisopterus luscus, Gadus morhua*
4/02/2009	D2, D4	*Trisopterus luscus, Gadus morhua, Pollachius virens*
4/03/2009	D2	*Trisopterus luscus*
2/07/2009	D3,D4	*Trisopterus luscus, Gadus morhua, Trachurus trachurus, Scomber scombrus*
29/09/2009	D4, D5	*Trisopterus luscus, Gadus morhua, Trachurus trachurus, Scomber scombrus, T. minutes*
27/10/2009	D6	*Trisopterus luscus, Gadus morhua, Scomber scombrus, Spondyliosoma cantharus*
6/11/2009	D4	*Trisopterus luscus*

Catch per unit effort (CPUE) was recorded to get an idea of the relative abundances of fishes present in the vicinity of the wind turbines. Total CPUE ranged between 0 and 28. In winter and early spring CPUE was much lower (0 - 5) than in summer and autumn (8 – 28), although the period of highest CPUE was species-dependent. For cod, CPUE was higher in winter than in summer, while mackerel and horse mackerel did not appear in winter. Pouting was present all through the year. For the latter species CPUE was much higher in summer and autumn (maximum CPUE of 15.6) than in winter and early spring (maximum CPUE of 2).

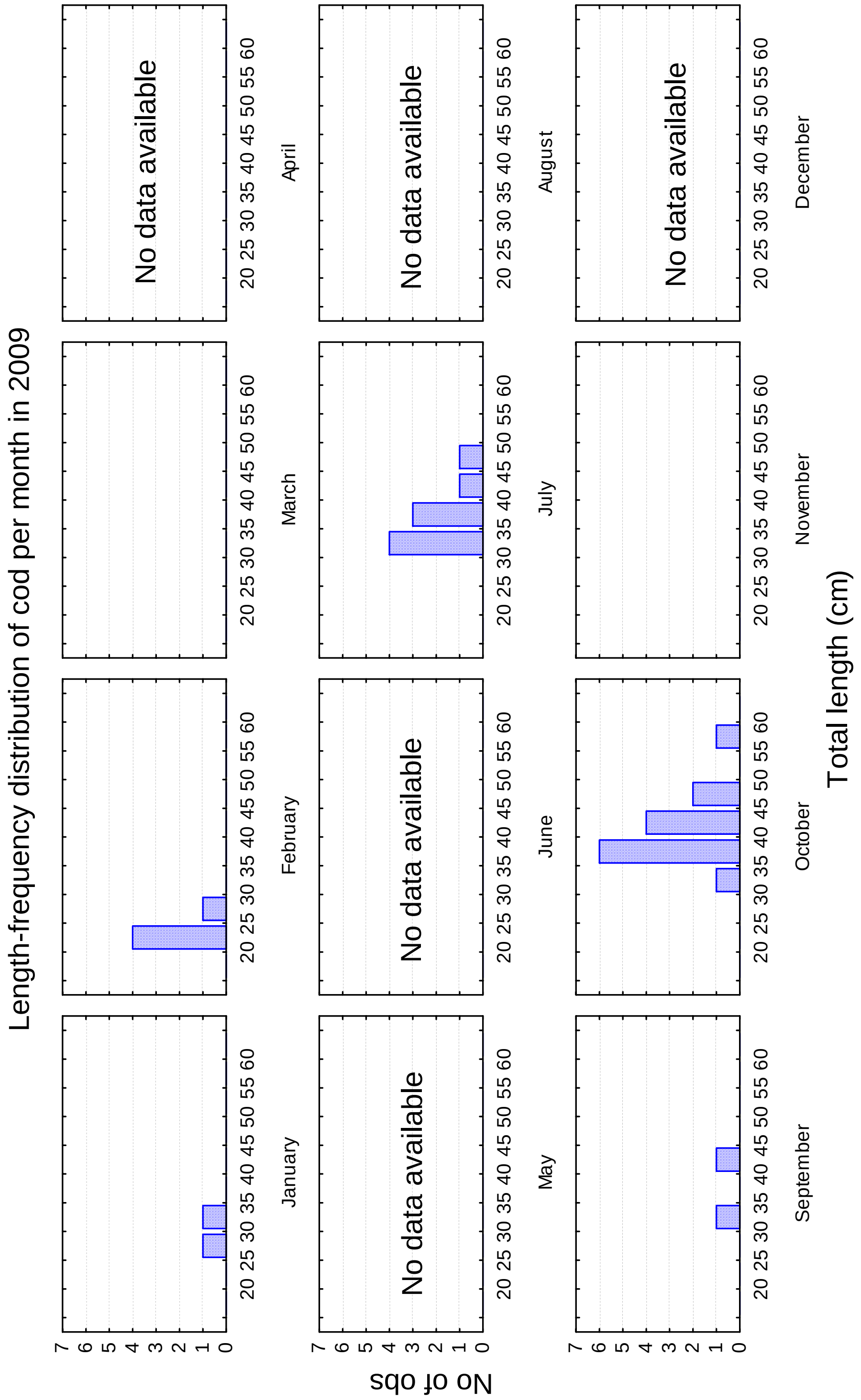

Figure 1. Length-frequency distribution of cod per month in 2009.

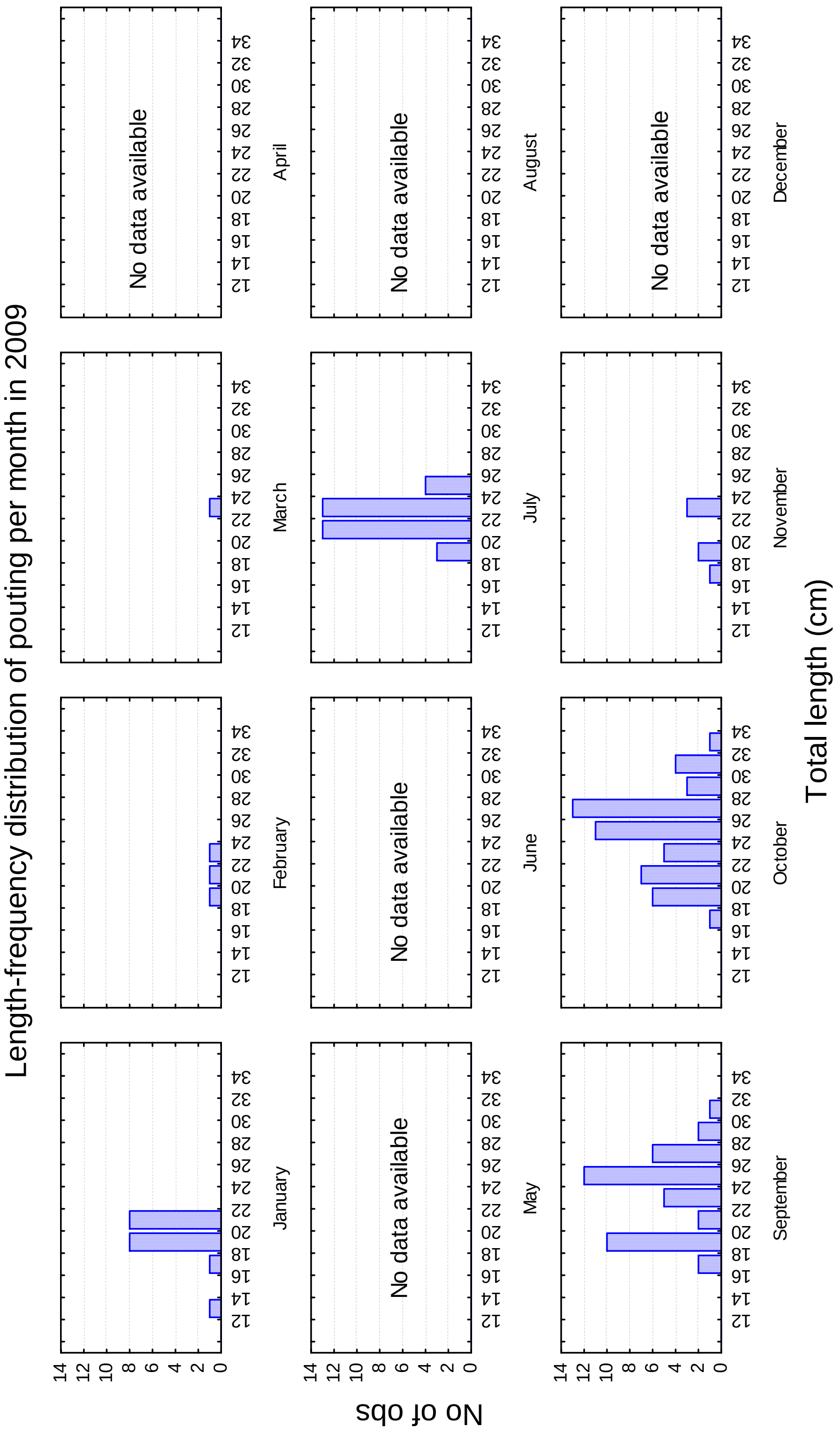

Figure 2. Length-frequency distribution of pouting per month in 2009.

6.3.2. Pouting densities

The visual surveys highlight the value of the artificial hard substrata for pouting. This species was present at all surveys near the wind turbine foundation (100% FO). Mean densities varied between 7 and 74 specimens/m² (figure 3) with an average density of 18±21 individuals/m² on the scour protection. This represents an average local population of 29 000 individuals near one wind turbine foundation.

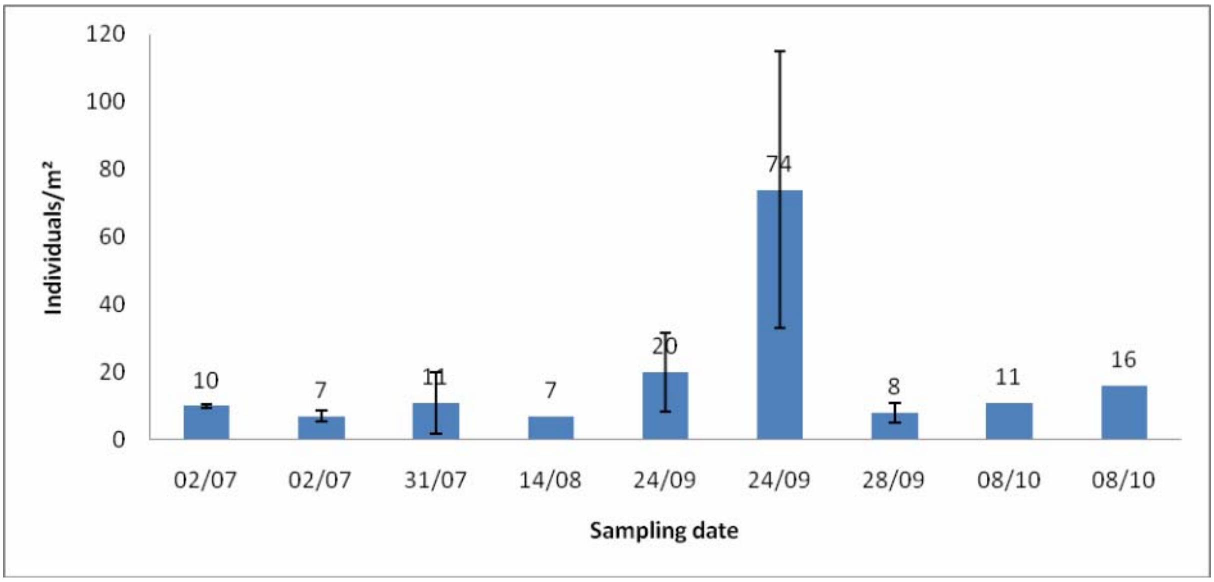

Figure 3.Overview of the nine visual surveys performed at one wind turbine. Mean pouting densities with standard error.

A large variation in densities, however, was detected both between observers (standard error flags figure 3) and over time. Specimens estimated size ranged between 15 and 35 cm with an average of 20 cm. In situ visual census revealed a presence of both juveniles (< 22 cm total length) and adults at the artificial reef. Based on a Length - Wet weight relationship (Merayo & Villegas, 1994), the population had a minimum biomass of 3.5 x 10^3 kg.

Similar abundances of pouting may be present near the other foundations as mean CPUE of comparable magnitudes (spring 0 - 2.5; summer 8 - 15.5) were recorded throughout the year at the different locations. Once the wind farm has reached full capacity it could harbour a population of pouting with a total biomass reaching 190 * 10^3 kg.

6.3.3. Stomach analyses of pouting

Fish caught by line and gill net fishing weighed 95 g up to 195 g and lengths varied between 18.4 cm and 24.2 cm. Of the 94 stomachs analysed, twelve were empty (12.7%). The diet of *T. luscus* contained a wide variety of food items: 46 prey types were identified, although 20 occurred only once in the stomachs analysed. Of the 46 prey types, twelve are hard substratum associated while nine are restricted to soft sediments (Table 2). *Jassa herdmani*, *Jassa* mats, *Pisidia longicornis*, Brachyura spp. and detritus were the prey types with the highest frequency of occurrence %FO. *Liocarcinus holsatus*, fish scales, *Phtisica marina*, Nematoda spp. and *Mytilus edulis* were also frequently present in the stomachs.

Jassa herdmani and *P. longicornis* were the only prey species composing more than 10% of the total numerical prey abundance. For the gravimetric measurements *P. longicornis*, *J. herdmani* and *Jassa* mats composed more than 10% of the total AFDW (table 2). Q and IRI indicated that *J. herdmani* and *P. longicornis* were the most important prey species contributing to the diet of pouting. Both species are restricted to hard substrata.

Pisidia longicornis, *J. herdmani*, detritus and *Jassa* mats were the most differentiating prey types (variables) in the diet of pouting based on gravimetric information (figure 4). Numerically, *J. herdmani* and *P. longicornis* dominated the gut contents (figure 5). Differentiating as well, but to a lesser extent were Nematoda spp. and Pisces spp. In both the gravimetric and numerical analyses many samples were positioned at the edge of one of the explanatory variables, demonstrating high selectivity for a particular prey.. The samples positioned near the origin or amid the explanatory variables expressed less selectivity for prey and/or foraging on rare prey species.

Table 2. List of prey items present in the stomachs of pouting (Trisopterus luscus). Frequency of occurrence (%FO), densities (%dens), ash-free dry weight (%AFDW), feeding coefficient (Q) and index of relative importance (IRI). N/A indicates that no quantification could be made or the information is missing. H Taxa living on hard substrata. S Taxa living on soft substrata. B Taxa found on both substrata. N/A Not applicable.

	SPECIES	**%FO**	**% dens**	**% AFDW**	**Q**	**IRI**
	Hydrozoa					
H	Unidentified sp.	3.66	0.03	0.01	<0.01	0.17
H	Halecium sp.	1.22	N/A	0.01	N/A	N/A
	Nematoda					
N/A	Unidentified sp.	9.76	0.57	0.02	<0.01	5.71
	Polychaeta					
N/A	Unidentified sp.	8.54	0.17	1.36	0.23	13.00
	Crustacea					
N/A	Unidentified sp.	3.66	0.03	0.04	<0.01	0.27
	Cirripedia					
H	Unidentified sp.	8.54	0.23	0.03	<0.01	2.23
H	Balanidae sp.	3.66	0.17	0.37	0.06	1.98
	Mysidasea					
S	Acanthomysis longicornis	1.22	0.03	<0.01	<0.01	0.05
S	Gastrosaccus spinifer	3.66	0.17	0.02	<0.01	0.67
	Amphipoda					
N/A	Unidentified sp.	1.22	0.03	<0.01	<0.01	0.04
B	Amphilochus neapolitanus	1.22	0.07	<0.01	<0.01	0.09
B	Stenothoe marina	1.22	0.03	<0.01	<0.01	0.04
B	Corophium sp.	1.22	0.03	<0.01	<0.01	0.04
H	Jassa herdmani	64.63	84.07	18.48	1553.26	6627.86
H	Jassa mats	67.07	N/A	10.24	N/A	N/A
H	Caprella sp.	1.22	0.03	<0.01	<0.01	0.04
H	Phtisica marina	9.76	0.84	0.03	0.02	8.42
S	Megaluropus agilis	1.22	0.03	<0.01	<0.01	0.04
	Decapoda					
N/A	Unidentified sp.	3.66	0.10	0.17	0.02	1.00
	Natantia					
N/A	Unidentified sp.	6.10	0.17	0.29	0.05	2.79
S	Processa edulis crassipes	1.22	0.13	0.31	0.04	0.54
S	Processa modica	1.22	0.03	0.10	<0.01	0.17
N/A	Crangonidae sp.	1.22	0.03	0.07	<0.01	0.13
S	Crangon crangon	1.22	0.03	0.05	<0.01	0.10
	Reptantia					
N/A	Unidentified sp.	2.44	0.07	0.14	0.01	0.50
B	Paguridae sp.	2.44	0.17	0.80	0.13	2.36
B	Pagurus bernhardus	2.44	0.10	1.39	0.14	3.64
N/A	Brachyura sp.	12.20	0.37	1.23	0.45	19.48
H	Pisidia longicornis	35.37	10.45	46.55	486.69	2016.16
H	Macropodia linaresi	1.22	0.03	0.01	<0.01	0.05
S	Corystes cassivelaunus	1.22	0.03	0.09	<0.01	0.15
B	Portunidae sp.	2.44	0.13	1.57	0.21	4.15
B	Liocarcinus sp.	1.22	0.03	2.07	0.07	2.57
B	Liocarcinus holsatus	9.76	0.47	5.22	2.44	55.46
B	Carcinus maenas	1.22	0.03	0.14	<0.01	0.21
	Bivalvia					
N/A	Unidentified sp.	1.22	0.03	0.07	<0.01	0.13
H	Mytilus edulis	9.76	0.77	0.02	0.02	7.65
	Bryozoa					
H	Unidentified sp.	3.66	N/A	1.36	N/A	N/A

	Echinodermata					
H	Asterias rubens	1.22	0.03	0.01	<0.01	0.06
N/A	Echinoidea sp.	1.22	0.03	<0.01	<0.01	0.04
	Pisces					
N/A	Unidentified sp.	4.88	0.13	2.01	0.27	10.47
S	Callionymus lyra	2.44	0.07	0.37	0.03	1.07
S	Callionymus reticulatus	1.22	N/A	1.72	N/A	N/A
	Others					
N/A	Detritus	10.98	N/A	2.66	N/A	N/A
N/A	Plant material	2.44	N/A	0.26	N/A	N/A
N/A	Fish scales	9.76	N/A	0.08	N/A	N/A

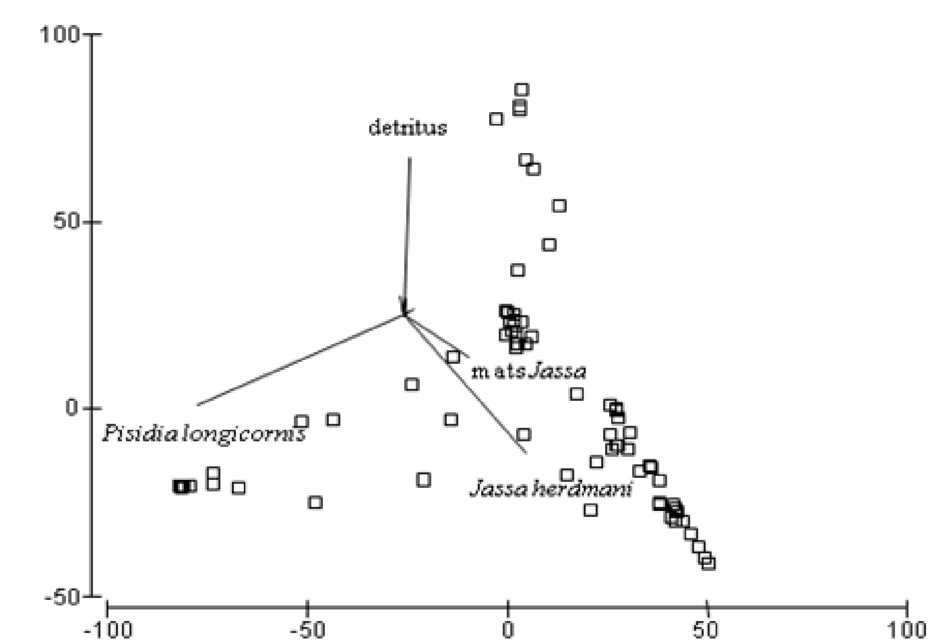

Figure 4. Gravimetrical PCA based on AFDW ratio of the most important prey items (only the most explaining prey types are indicated). Axes 1 and 2 explain 31 % and 18 % of the total variation respectively.

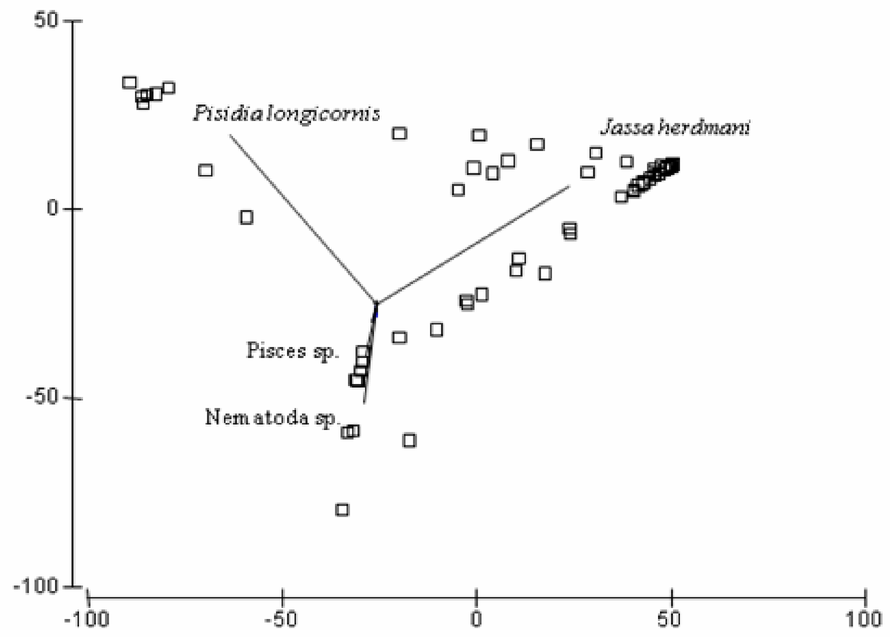

Figure 5. Numerical PCA based on density ratio of the most important prey items (only the most explaining prey types are indicated). Axes 1 and 2 explain 57 % and 18 % of the total variation respectively.

6.4. Discussion

6.4.1. Species richness, length-frequencies and CPUE

The fish species observed in the vicinity of the wind farm are in agreement with the species expected to be present (Farm, 2006; Zintzen *et al.*, 2006; Mallefet *et al.*, 2007). The same species are frequently observed near other types of hard structures, such as shipwrecks, in the BPNS. Despite being attracted to hard substrata, seabass was the only species expected that was not observed near the wind turbines. This species, however, is very bashful and sensitive to noise (pers. comm. With fishermen), which might explain why seabass was not observed nor caught.

Mackerel was present during summer and early autumn. In winter this species stays in deeper water (ICES, 2006). According to their length (ICES, 2006), which ranged from 24 to 31 cm, the mackerel were between one and two years old. Consequently, most individuals were mature. Horse mackerel were present during summer and early autumn, which is in agreement with Vandendriessche *et al.* (2009). Much larger specimens (21 – 29 cm) of horse mackerel however were found near the turbine foundations in comparison with individuals (6 - 15 cm) found on soft sediment in the surrounding area (Vandendriessche *et al.* 2009). It seems therefore that older individuals preferred the vicinity of the hard substrata. For cod, age varied between one to four years old (Heessen, 1983). In January and February most cod present were one to two years old, while in summer and autumn most cod were two to four years old. Some cod mature in their second year of life, but it is not before the age of six that all are mature (ICES, 2006). Consequently, most cod present were juveniles, which is in agreement with the observations made at the wind farm Horns rev (Farm, 2006). According to their length (Merayo & Villegas, 1994), which ranged from 13 to 34 cm, the pouting were between zero and four years old. The majority, however, were between one and three years old. Compared to pouting present on the soft sediment in the surrounding area (Vandendriessche *et al.* 2009), larger and older fish were present near the hard substrata.

No information is available from CPUE data on other hard substrata in the BPNS. Compared to the soft sediments (Vandendriessche et al. 2009) densities are highly enhanced for cod, pouting and horse mackerel near the artificial hard substrata of the wind turbines, indicating the aggregation effect of the turbines. For mackerel no information is available. It should be stated, however, that density estimation on the hard and soft substrata are gathered in a different way, which may influence CPUE data. Near the hard substrata the sampling was done by line fishing, while on the soft sediments beam trawl was used to catch fish. It may be that pouting respond in a different way to beam trawl gear versus hook and line.

6.4.2. Pouting densities

In the BPNS pouting is frequently observed at artificial hard structures (Zintzen *et al.*, 2006; Mallefet *et al.*, 2007), which is consistent with the results obtained by the current research. Visual observations by scuba divers indicated that a large local population of pouting was present in the vicinity of the wind turbine investigated throughout summer and early autumn. Generally, limited pout density variations were found throughout the study period (7 up to 20 individuals/m²), except for the observations on the second dive the 24th of September. That dive, however, low visibility (1.2m) hindered observations, which may have caused an overestimation of pout densities (Sanders Jr *et al.*, 1985; Sayer & Poonian, 2007).

If an extrapolation is made, the wind farm may host more than 1.5 million pouting, representing a minimum biomass of 190 * 10^3 kg, once it reaches its full capacity (54 wind turbines). In comparison, between 2000 and 2006 roughly 400 to 500 * 10^3 kg of pouting were landed in the Belgian harbours annually (Fishstat Plus, FAO 2008).

Pouting densities on the soft sediments in the surrounding area of the wind farm are low (< 0.001 specimens/m², based on beam trawl data) (Vandendriessche *et al.* 2009). Though, pouting may respond in a different way to beam trawl gear versus divers. Piet *et al.* (2009), however, assumed 19% catch efficiency of round fish for beam trawl. This demonstrates that pouting densities were highly enhanced near the wind turbines artificial reef in comparison with those on the soft sediments.

It is interesting to note that the population size near the wind turbines was probably even larger than estimated: (1) visual census methods are known to underestimate abundant fish species (Sale & Douglas, 1981; Brock, 1982; Bannerot & Bohnsack, 1986); (2) although pouting is observed too in high densities near the foundation, the estimation was restricted to the erosion protection layer, as abundances near the former are more difficult to estimate; (3) using a stationary observation method in low visibility waters induces an extra source of underestimation. Individuals located at the outer edges of the visibility range are more difficult to detect and are often overlooked. The population size is hence to be considered a minimum estimate.

No literature is available on the densities of pouting present on other artificial hard substrata in the BPNS.

6.4.3. Stomach analyses of pouting

Stomach content analysis was performed on 94 pouting. As indicated by the weights and lengths (Merayo & Villegas, 1994; Heessen & Daan, 1996), these fishes belonged to year class 1 and 2.

Based on the overall outcome of the analyses *J. herdmani*, *P. longicornis* and *Jassa* mats were found to be the most abundant and differentiating prey types in the diet of pouting. It is interesting to note that *J. herdmani* is a tube-dwelling amphipod. The tube-mats themselves (here called *Jassa* mats) can be considered as a particular kind of detritus. These tube-mats were ingested in high quantities (table 2). Visual observations revealed that pouting does not pick the individual *Jassa* specimens out of the tube mats, but bite off a mouthful of mat together with *Jassa*. It is assumed that the mats themselves are of lesser importance in the diet of pouting. Detailed investigation of the nutritional value of both *Jassa* and the tube mats however should be performed to validate this assumption.

J. herdmani and *P. longicornis* are established in very high abundances on the wind turbine foundations (Kerckhof *et al.* 2009). In other wind farms in the North Sea and on shipwrecks these prey species are also frequently available in high abundances (Schröder *et al.*, 2006; Mallefet *et al.*, 2007). The foundations of the wind turbines are densely colonized and have high species diversity (Kerckhof *et al.* 2009), indicating food is plentiful for various predators. Many prey types found in the diet of pouting (table 2) are established on the wind turbines (Kerckhof *et al.* 2009).

In the present investigation seasonal availability of prey species was not brought into account. Kerckhof *et al.* (2010) however, found that several epibionts show seasonal trends in their abundances at the wind turbine foundations. Densities of *P. longicornis*, which is key component in the diet of pouting, for instance peak in late summer and autumn. As seasonality in prey availability may explain part of the variability in the stomach content data it will be accounted for in future research.

Our results suggest that pouting benefits from the artificial hard substrata of the wind farm. Pout densities are highly enhanced in comparison with those on the soft sediments. Food is plentiful on the hard substrata and many prey types found in the stomachs are also present on the turbines as epifauna. The dominant food items *J. herdmani* and *P. longicornis* in the diet of pouting are established in very high densities on the turbine foundations.

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Chapter 7. Monitoring the effects of offshore wind farms on the soft substratum macrobenthos: Year-1 Bligh Bank and Year-2 Thorntonbank

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Photo’s Delphine Coates / UGent

Abstract

To enhance the production of renewable energy in Belgium, offshore wind farms are being constructed on the Thorntonbank and Bligh Bank in the Belgian part of the North Sea (BPNS). Knowledge on the soft-sediment macrobenthos in these offshore areas has increased by carrying out baseline studies (Year-0) at the Thorntonbank and Bligh Bank during respectively, 2005 and 2008 (De Maersschalck *et al*, 2006; Reubens *et al*, 2009b). To detect any changes in biotic (macrobenthic density, diversity, biomass and species dominance) and abiotic (median grain size, total organic enrichment and mud content) variables a BACI (Before After Control Impact) strategy is applied. The aim of following monitoring project is to evaluate the Year-2 situation at the Thorntonbank and the Year-1 situation at the Bligh Bank and increase the knowledge on the temporal and spatial variability of the macrobenthos in these areas.

Samples at the Bligh Bank and Goote Bank do not show any significant changes in sediment composition in comparison to the baseline study in 2008. Sediments are characterised by medium, coarse sands (250-500µm) with a very low mud content (max. mean of 0.121 ± 0.082 %) and low percentages of total organic matter (0.818 ± 0.053%). The macrobenthic densities are significantly lower than 2008 with a range from 770 to 1060 ind./m². Species richness (N_0) illustrated a comparable range to 2008 from 1 to 24 species/m² and broader ranges in biomass (3.48 – 37419.65 mg/m²) were also found for the Bligh Bank and Goote Bank. *Nephtys cirrosa* is the dominant species at all locations with *Bathyporeia guilliamsoniana* as a second dominant species on the edge area of the Bligh Bank.

Samples taken at the Thorntonbank and Goote Bank do not show any significant changes in sediment composition in comparison to the baseline study in 2005 either. Sediments are characterised by medium, coarse sands (250-500µm) with low percentages of total organic matter (0.818 ± 0.053%) and without the presence of mud at the Thorntonbank. The macrobenthic densities vary from 770 to 1930 ind./m² and are only significantly lower compared to 2005 for the eastern concession area on the Thorntonbank (TBI B). Species richness ranges from 1 to 24 species/m² and biomass from zero to 21690.13 mg/m². All locations are dominated by the polychaete *Nephtys cirrosa* and also by *Spiophanes bombyx* at the reference site on the Thorntonbank.

Overall, we can conclude that the results for the Year-2 situation at the Thorntonbank and the Year-1 situation at the Bligh Bank, illustrate the natural temporal variability that can appear in macrobenthic communities. In order to detect any (cumulative) impacts of the offshore wind farms, the long term monitoring must therefore be continued over a longer period.

A recommendation has been made to reduce the amount of sampling sites for the long-term monitoring campaign in the future and subsequently increase the amount of replicas and the reliability of the results. Furthermore, a targeted monitoring around one turbine on the Thorntonbank will be carried out during 2010 to detect any impacts on the soft-sediment macrobenthos due to the increased epifaunal communities colonizing the turbines (Kerckhof *et al*, 2009).

Samenvatting

Om de productie van hernieuwbare energie in België te verhogen worden offshore windmolenparken op de Thorntonbank en Bligh Bank, in het Belgisch deel van de Noordzee, gebouwd en geëxploiteerd. Een verhoogde kennis van het zachte substraat macrobenthos werd in de laatste jaren bereikt door het uitvoeren van baseline (Jaar-0) studies op zowel de Thorntonbank en Bligh Bank en dit tijdens respectievelijk 2005 en 2008 (De Maersschalck *et al*, 2006; Reubens *et al*, 2009b). Om veranderingen in biotische (macrobenthische densiteit, diversiteit, biomassa en soorten dominantie) en abiotische (mediane korrelgrootte, totaal organisch materiaal en slib gehalte) variabelen waar te nemen wordt een BACI (Before After Control Impact) strategie toegepast. Het doel van volgend monitoringsproject is het evalueren van de Jaar-2 situatie op de Thorntonbank en de Jaar-1 situatie op de Bligh Bank en een verhoging van de temporele en ruimtelijke kennis van het macrobenthos in dit gebied.

Stalen genomen op de Bligh Bank en Goote Bank vertonen geen significante verschillen in sediment samenstelling vergeleken met de Jaar-0 studie uitgevoerd tijdens 2008. De meeste stalen

worden gekenmerkt door medium zand (250-500µm) met een zeer laag slib gehalte (max. mean of 0.121 ± 0.082 %) en een laag percentage in totaal organisch materiaal (0.818 ± 0.053%). De macrobenthische densiteiten waren significant lager ten op zichte van 2008 met een variatie van 770 tot 1060 ind.m². Een vergelijkbare soorten rijkdom (N_0) met 2008 werd waargenomen van 1 tot 24 species/m² en bredere variaties in biomassa (3.48 – 37419.65 mg/m²) werden waargenomen op de Bligh Bank en Goote Bank. *Nephtys cirrosa* is de meest dominante soort op alle locaties met *Bathyporeia guilliamsoniana* als tweede dominante soort in het randgebied op de Bligh Bank.

Stalen die genomen werden op de Thorntonbank en Goote Bank vertonen ook geen significante verschillen in sediment samenstelling met de Jaar-0 studie uitgevoerd tijdens 2005. Sedimenten worden gekenmerkt door medium zand (250–500µm) met een laag percentage aan totaal organisch materiaal (0.818 ± 0.053%) en zonder slib gehalte. Macrobenthische densiteiten variëren van 770 tot 1930 ind./m² en is enkel significant lager vergeleken met 2005 voor het oostelijk concessie gebied op de Thorntonbank (TBI B). Soorten rijkdom varieert van 1 tot 24 spp./m² en biomassa van nul tot 21690.13 mg/m². Alle regio's worden gedomineerd door de polychaet *Nephtys cirrosa* en door *Spiophanes bombyx* in het referentie gebied van de Thorntonbank.

In het algemeen kunnen we concluderen dat de resultaten van de Jaar-2 studie op de Thorntonbank en de Jaar-1 studie op de Bligh Bank de natuurlijke, temporele variabiliteit van macrobenthische gemeenschappen weergeven. Om de cumulatieve effecten van offshore windmolenparken waar te nemen zal de lange termijn monitoringsproject voortgezet moeten worden over een langere periode.

Er wordt aanbevolen de hoeveelheid staalname stations te reduceren in de monitoringscampagnes in de toekomst zodat het aantal replicas en de betrouwbaarheid van de resultaten kunnen verhoogd worden. Om enige effecten waar te nemen van de koloniserende epifauna gemeenschappen (groeiende op de harde substraten) op het zachte substraat macrobenthos (Kerckhof *et al*, 2009), zal een gerichte staalname uitgevoerd worden rondom één turbine op de Thorntonbank tijdens 2010.

7.1. Introduction and objectives

Macrobenthic communities are highly dependent of the sedimentological characteristics such as median grain size and organic matter content and the hydrographic regimes of the seabed (Pearson & Rosenberg, 1978; Wilhelmsson & Malm, 2008). Since major offshore wind farm projects have been established across the world it is very important to understand the subsequent changes in the marine environment. Introducing anthropogenic structures such as wind turbines and artificial reefs increases for example the amount of epifaunal organisms associated to the hard substrata (Kerckhof *et al*, 2009; Köller *et al*, 2006; Petersen & Malm, 2006). Building 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 will increase in speed around the turbines causing upwelling and transportation of soft sediments and the production of scouring pits that 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). However, this does not eliminate the possibility of secondary erosion occurring around the scour protection systems, causing changes in the sediment composition and the macrobenthic communities (Köller *et al*, 2006; Whitehouse *et al*, 2008).

To detect any changes in biotic (macrobenthic density, diversity, biomass and species dominance) and abiotic (median grain size, total organic enrichment and mud content) variables, due to the construction of wind turbines on the Thorntonbank and Bligh Bank, samples are taken yearly on the impact and reference sites during autumn. Due to the increasing amount of planned wind farms (C-Power, Belwind and Eldepasco) in the Belgian part of the North Sea (BPNS), cumulative impacts on the macrobenthos could occur in the near future. Sedimentation rates of organic material could increase as a direct effect of the increasing amount of epifaunal communities on the hard substrata, leading to altered sediment permeability and macrobenthic communities (Kerckhof *et al*, 2009; Maar *et al*, 2009). The exclusion of beam trawl fishery inside wind farms and the increase in fishing activities alongside the concession areas could alter macrobenthic communities due to their role in the diet of demersal fish communities (Reubens *et al*, 2009b).

The main objectives of this study are to determine any impact on the soft-sediment macrobenthos and investigate the Year-2 and Year-1 situation for the Thorntonbank and Bligh Bank, respectively. Knowledge of the natural spatial and temporal patterns within the macrobenthic communities on the Thorntonbank and Bligh Bank will be created to be able to perform an in depth assessment of the impact of future wind turbines.

7.2. Materials and methods

7.2.1. Research strategy

The year-1 and year-2 situations of respectively, the Bligh Bank and the Thorntonbank were sampled during the autumn (21 - 24 September) of 2009 together with reference samples on the Goote Bank (Figure 1). To detect possible evolutions in the soft sediment macrobenthos, the impact areas were compared to the control sites and the baseline situations. The results obtained on the Bligh Bank were analysed in comparison to the Goote Bank (reference bank) and the baseline situation reported by Reubens *et al*, 2009. Results obtained on the Thorntonbank were analysed in comparison to the control site on the Thorntobank (TBC) and the Goote Bank together with the baseline situation analysed during 2005 (De Maersschalck *et al*, 2006) and the Year-1 during 2008 (Reubens *et al*, 2009b).

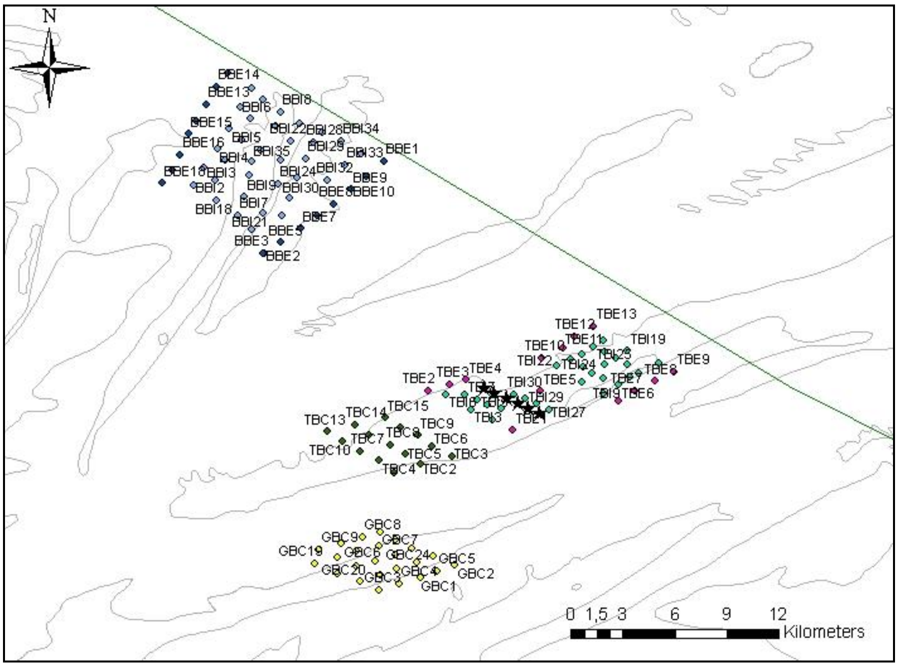

Figure 1. Sampling locations of 2009 on the Thorntonbank: Impact site (TBI), edge area (TBE), control area (TBC) and the first six wind turbines (stars). Sampling locations on the Bligh Bank impact site (BBI) and edge area (BBE) and the reference Goote Bank (GBC).

7.2.2. Methodology

The macrobenthos was sampled from the research vessel RV Belgica by means of a Van Veen grab (surface area 0.1026 m²). Before opening the Van Veen grab, one core sample (diameter 27 mm) was taken for physical-chemical analysis and the depth of the anoxic layer (change in sediment color indicating the presence of a H_2S layer) was measured with a ruler. The collected sediment was subsequently sieved over a 1 mm sieve table. The remaining residue was collected and fixed in an 8% formaldehyde-seawater solution.

7.2.2.1. 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 – 2000 µm. Refer to Reubens *et al*, 2009 for detailed Information on the different fractions.

The total amount of organic material (TOM %) was determined per sample by applying the following equation: TOM % = [(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 (Heiri *et al*, 2001). For every sample, the used crucible was weighed (CrW) in order to determine the TOM %.

7.2.2.2. Biotic analysis

7.2.2.2.1. Macrofauna analysis

Samples were stained with 1% Rose Bengal and rinsed over a 1 mm sieve. The macrobenthic organisms were removed from all debris, identified upon 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). A standardized species list can be found in Annex 2 – Systematic species list of soft substratum macrobenthos. The most recent systematic-taxonomic literature as well as species lists for the BPNS were consulted (Adema, 1991; De Bruyne, 1994; Degraer *et al*, 2006; Fish & Fish, 1996; Hartmann-Schröder, 1996; Hayward & Ryland, 1995; Jones, 1976; Lincoln, 1979; Naylor, 1972; Tebble, 1966).

7.2.2.2.2. Diversity and Biomass

For the determination of diversity, Hill’s diversity indices were calculated (Hill, 1973). In this study, the most frequent indices (order 0, 1, 2 and infinity) were calculated with the Primer v6 (Plymouth Routines in Multivariate Ecological Research) programme (Clarke & Gorley, 2006). N_0 or the species richness (the number of species per sample) attributes the same weight to all species, independent of their abundance. N_1 gives less weight to rare species while N_2 gives more weight to abundant species. N_{inf} or the dominance index, only takes the most common species into account.

The total biomass per species was obtained in three ways. The first method involved the conversion factors of (Brey, 2001). These allow a determination of the ash free dry weight (AFDW) biomass through a conversion of the wet weight (WW). The biomass of Amphipoda, Mysida, Decapoda and *Nephtys cirrosa* was calculated by means of a second method: length/weight regressions. When neither conversion factors nor regressions 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 (bigger 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).

7.2.2.3. Data analysis

The following data were collected per sample station: date, location, depth, time, weather conditions, sediment composition, macrobenthic species, 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). A few values were determined following standardized methods for macrobenthos of the Belgian part of the North Sea (Degraer, 1999). These values are: diversity (species richness and Hill's diversity indices), density (ind./m²) and biomass (g ash free dry weight (AFDW)/m²).

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. Before the univariate statistical procedures were carried out (Statistica 7), the three criteria for parametrical tests (normality, homogeneity and independent variances of the mean) were tested. If the criteria were met, the data was analysed for statistical differences using ANOVA and the post-hoc Tukey HSD test to determine significant differences ($p < 0.05$) between groups. However, mostly the criteria were not fulfilled and the data was analysed using the non-parametric Mann-Whitney U-test for independent groups and the Wilcoxon Matched Pairs test for dependent groups. Multivariate analyses were carried out with the Primer v6 programme. Pre-treatment was carried out on the data by performing a square-root transformation before analysis. Similarity between different samples is based on the occurrence or absence of species and their densities (Bray-Curtis similarity). The Bray-Curtis similarity matrices were used to build up non-metric multidimensional scaling (MDS) plots. MDS plots give reliable 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 us to detect which species contribute to the distinctness of certain communities as it gives similarity and dissimilarity percentages. Furthermore, an Anosim analysis allows us to detect differences between groups.

Furthermore, a reference collection of all 152 identified species was created; all new species will be added to the reference collection in the future, after every offshore wind farm monitoring campaign.

7.3. Results

7.3.1. Abiotic analysis

7.3.1.1. Median grain size

The mean (± standard error) median grain size illustrates a distribution from 338 ± 11 µm in the control area on the Thorntonbank (TBC) to 456 ± 24 µm in the impact area on the Bligh Bank (BBE). The lowest value was measured on the Goote Bank with a value of 279µm and the highest on the Bligh Bank with 704 µm (Figure 2).

When analysing the Bligh Bank and Goote Bank stations, a significant difference in median grain size between BBE and GBC (Mann-Whitney U-test: $p = 0.000633$) and between BBI and GBC (Mann-Whitney U-test: $p = 0.000337$) was detected.

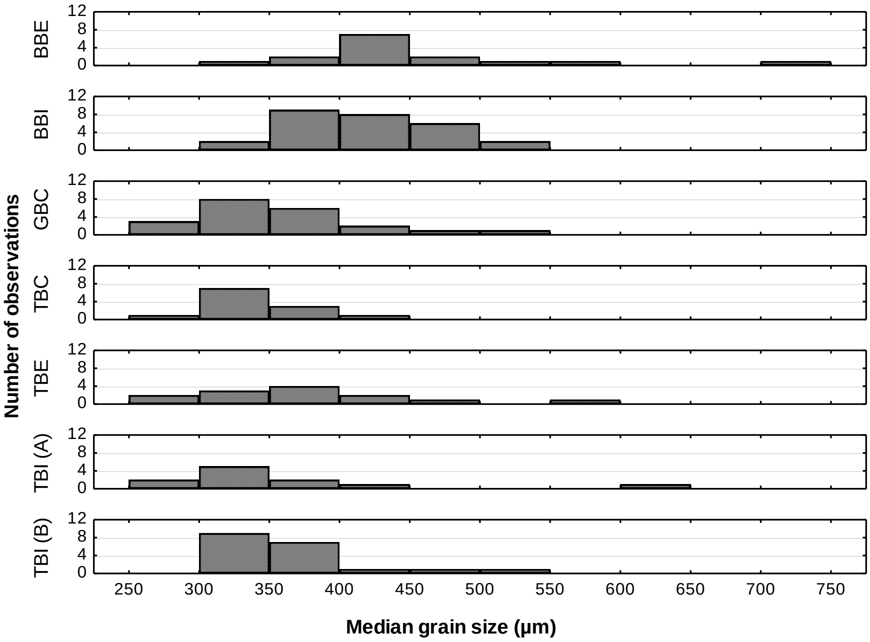

Figure 2. Distribution of median grain size (µm) at the different sampling locations.

A higher similarity in median grain size was measured between the Thorntonbank stations (TBC, TBE, TBI A and TBI B) and the Goote Bank. Only one significant difference (Mann-Whitney U-test: $p = 0.023142$) was measured between the reference site on the Thorntonbank (TBC) and the eastern concession area (TBI B).

A comparison in median grain size with the baseline study on the Thorntonbank during 2005 shows no significant difference with the values in 2009 (Wilcoxon Matched Pairs Test, $p > 0.05$). However, TBI B and TBC show a significant difference (Wilcoxon Matched Pairs Test, $p = 0.040136$ and $p = 0.002218$) in median grain size between 2005 and 2008. TBC also has a significant difference in median grain size between 2008 and 2009 (Wilcoxon Matched Pairs Test, $p = 0.022910$).

The results in median grain size of 2009 show a significant difference compared to the baseline study carried out during 2008 for BBI (Wilcoxon Matched Pairs Test, $p = 0.043474$) but not for BBE (Wilcoxon Matched Pairs Test, $p = 0.826091$).

7.3.1.2. Mud content

Mud content was only detected in five stations on the Bligh Bank and Goote Bank with a range from 0.84% to 1.00%. The maximum mean mud content is shown in BBE with a value of 0.121 ± 0.082%. No significant difference in mud content could be detected between locations on the Bligh Bank, Thorntonbank and the Goote Bank (Mann-Whitney U-tests, $p > 0.05$).

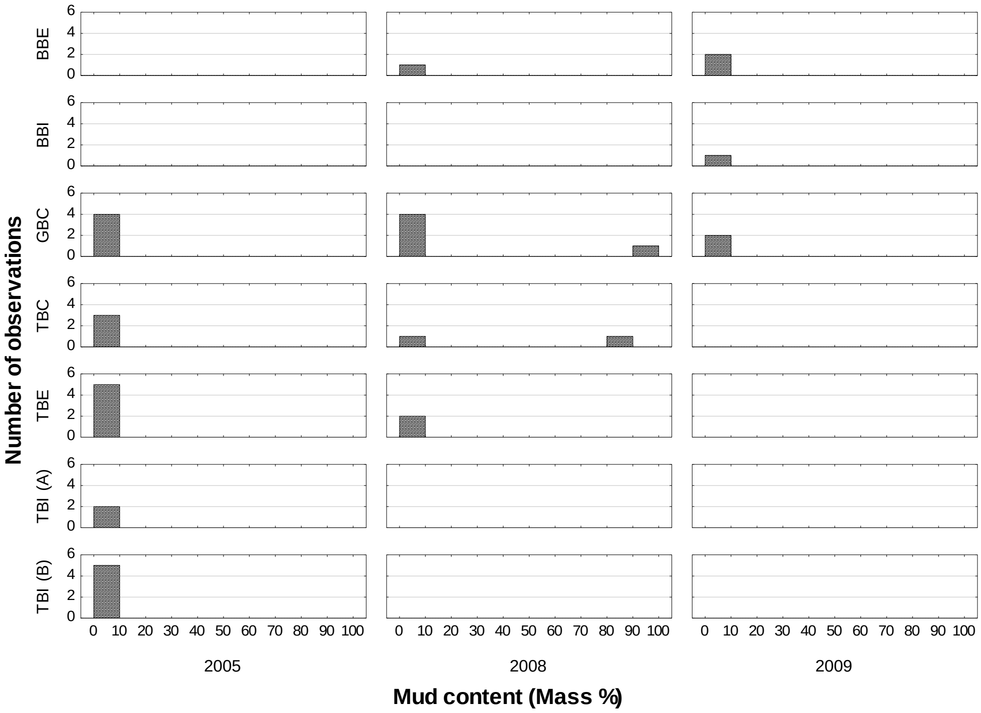

Figure 3. Distribution of mud content (mass %) at the different sampling locations and for the three monitoring campaigns in the autumn of 2005, 2008 and 2009

Figure 3 shows the mud content on the Thorntonbank for the baseline study in 2005. A significant difference is determined between 2005-2008 and 2005-2009 for TBI (B) (Wilcoxon Matched Pairs Test 2005-2008: $p = 0.043115$ and 2005-2009: $p = 0.043115$). Furthermore, a significant difference in mud content (Wilcoxon Matched Pairs Test, $p = 0.043115$) is detected for TBE in 2005-2009.

No significant difference could be measured between the baseline and Year-1 situation on the Bligh Bank (Wilcoxon Matched Pairs Test, $p > 0.05$).

7.3.1.3. Total organic matter

The mean total organic matter has a range from 0.521 ± 0.048% in TBI (B) to 0.818 ± 0.053% in GBC. The lowest value was measured for BBE with a value of 0.296%, the highest value (1.831%) was measured for BBI (Figure 4).

When comparing the Bligh Bank and Goote Bank, a significant difference (Mann-Whitney U-test $p = 0.012891$) is detected between BBE and GBC. The Goote Bank also shows significantly higher total organic matter percentages than all locations on the Thorntonbank (Mann-Whitney U-test, TBI A: $p = 0.030593$, TBI B: $p = 0.000046$, TBE: $p = 0.049203$ and TBC: $p = 0.001959$). Within the Thorntonbank, TBI (B) shows a significant difference in total organic matter with TBE and TBC (Mann-Whitney U-test, TBE: $p = 0.024794$ and TBC: $p = 0.008828$).

No significant difference in total organic matter was measured between 2009 and the baseline studies of the Thorntonbank (2005) and the Bligh Bank (2008) (Wilcoxon Matched Pairs Test, $p > 0.05$).

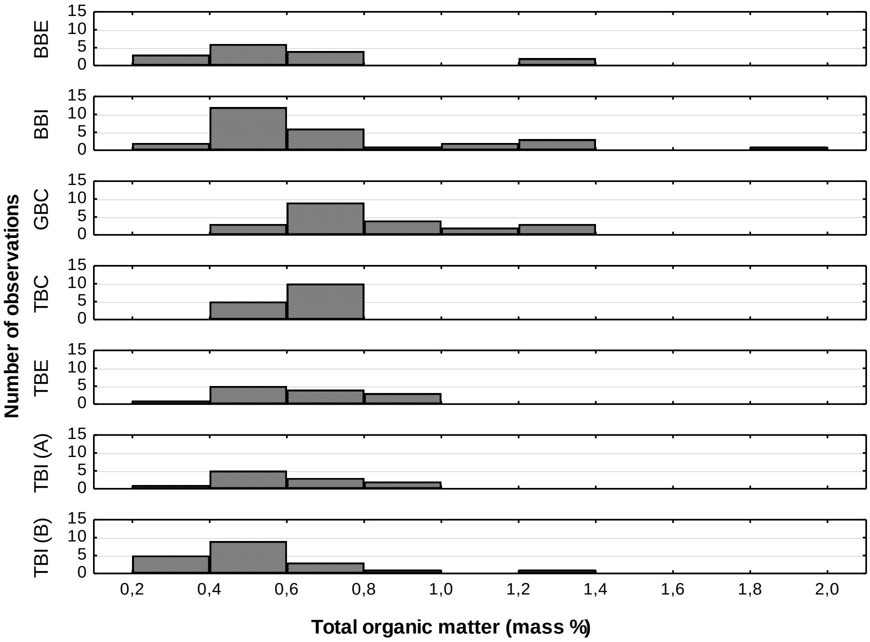

Figure 4. Distribution of total organic matter (mass %) at the different sampling locations

7.3.2. Biotic variables

7.3.2.1. Density

Samples taken at the Bligh Bank and Goote Bank are characterised by low densities with a maximum of 1060 ind./m² at BBI (Figure 5). The lowest mean density was also measured at BBE with a value of 317 ± 59 ind./m² at BBE. Comparable values were found at the control site of the Goote Bank with a range (varying from low to high densities) of 40-770 ind./m² and a mean density of 360 ± 44 ind./m². No significant differences in density were found between the sampling locations at the Bligh Bank and the Goote Bank in 2009 (Mann-Whitney U-tests, $p > 0.05$).

When comparing the baseline study of the Bligh Bank from 2008 with 2009, significant differences were identified for BBI (Wilcoxon Matched Pairs Test, $p = 0.027993$) and BBE (Wilcoxon Matched Pairs Test, $p = 0.045448$).

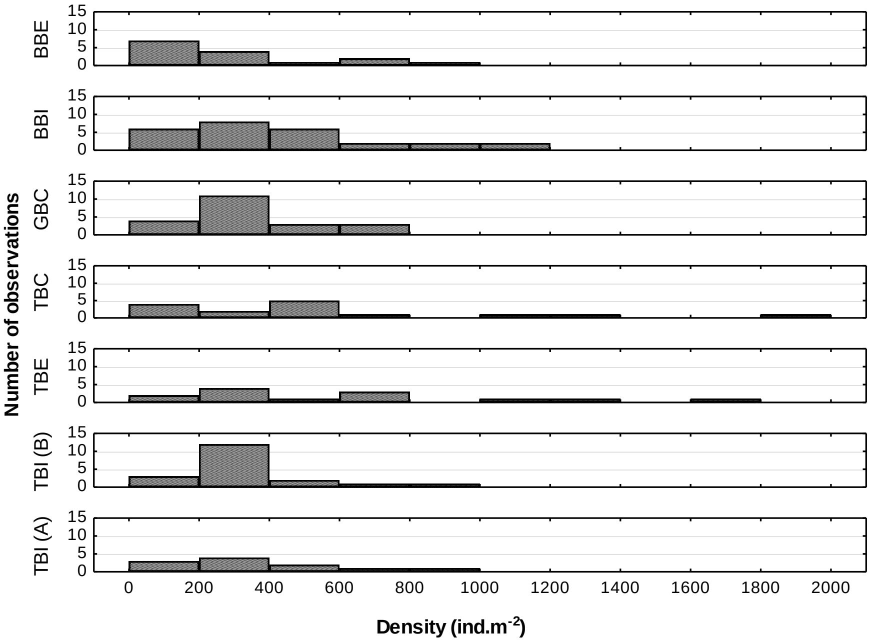

Figure 5. Distribution of total density (ind.m^{-2}) at the different sampling locations

Higher values were detected in the control and edge areas of the Thorntonbank with a maximum of 1930 ind./m² at TBC and the highest mean density (638 ± 137 ind./m²) at TBE (Figure 5). In comparison to the Bligh Bank, the impact areas of the Thorntonbank are characterised by low densities with a range of 10-920 ind./m² for TBI (A) and 90-830 ind./m² for TBI (B). No significant differences in density were found between the sampling locations at the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, $p > 0.05$).

Significant differences in macrobenthic density on the Thorntonbank were detected between the baseline study in 2005 compared to 2008 for TBI (B) (Wilcoxon Matched Pairs Test, $p = 0.014736$) and TBE (Wilcoxon Matched Pairs Test, $p = 0.022910$) and between 2005 and 2009 for TBI (B) (Wilcoxon Matched Pairs Test, $p = 0.024908$).

7.3.2.2. Diversity

7.3.2.2.1. N_0 – Species richness

In contrast to density and last year's diversity results (Reubens *et al*, 2009b), species richness shows a significant difference between BBE and BBI (Mann-Whitney U-tests, $p = 0.002682$) with a low mean species richness of 7.7 ± 1.3 spp./0.1 m² at BBE and a high species richness of 12.5 ± 0.9 spp./0.1 m² at BBI. The impact area of the Bligh Bank also has the broadest range in species richness (ranging from 5 to 24) and the maximum amount of species (Figure 6, Table 1). No significant difference in species richness was detected between the Bligh Bank and Goote Bank (Mann-Whitney U-tests, $p > 0.05$).

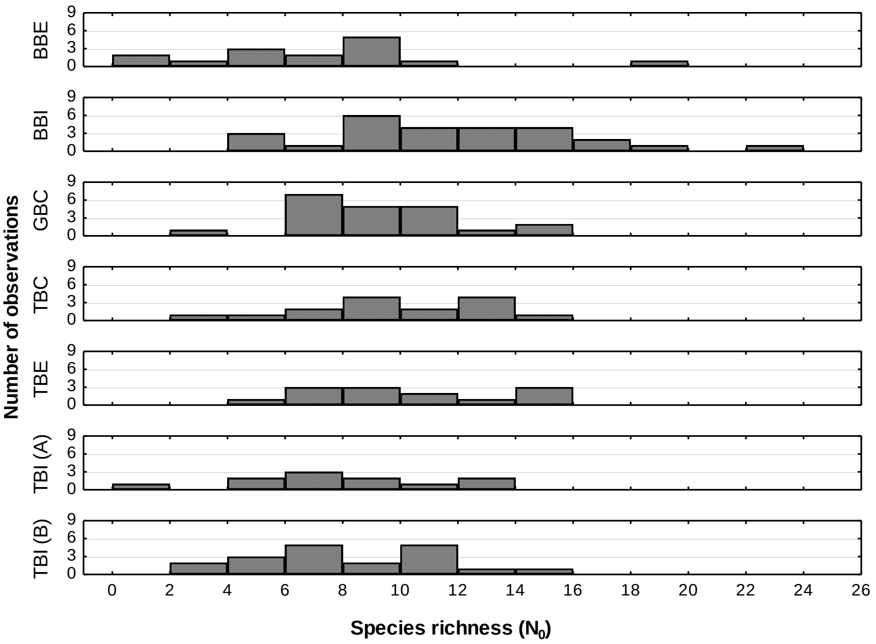

Figure 6. Distribution of species richness (N_0) at the different sampling locations

The Thorntonbank and Goote Bank show a lower number of species and a smaller range in comparison to the Bligh Bank (Figure 6). The highest species richness was measured for TBE and the lowest for TBI (A). A similar range in species richness is detected with 11 for TBC and TBE and 13 for TBI (A) (Table 1). Therefore, no significant differences were found between the Thorntonbank and the Goote Bank (Mann-Whitney U-tests, $p > 0.05$).

Table 1. Descriptive statistic results for the Hill's diversity indices (N_0 or species richness, N_1, N_2 and N_{inf}) at the different sampling locations (Mean ± SE).

	BBE	BBI	GBC	TBC	TBE	TBI (A)	TBI (B)
N_0	7.7 ± 1.1	12.5 ± 0.9	9.8 ± 0.6	10.2 ± 0.8	10.7 ± 1.0	8.4 ± 1.1	9.0 ± 0.8
N_1	4.7 ± 0.7	8.0 ± 0.5	6.4 ± 0.4	5.9 ± 0.3	6.1 ± 0.7	5.2 ± 0.6	5.5 ± 0.5
N_2	3.4 ± 0.5	5.8 ± 0.4	4.9 ± 0.4	4.4 ± 0.3	4.4 ± 0.6	3.9 ± 0.5	4.0 ± 0.4
N_{inf}	2.2 ± 0.2	3.2 ± 0.2	3.1 ± 0.3	2.7 ± 0.2	2.6 ± 0.3	2.5 ± 0.3	2.3 ± 0.2

7.3.2.2.2. N_1, N_2 and N_{inf}

Comparable results to the N_0 index were found for the three remaining diversity indices (Table 1). For all indices on the Bligh Bank and Goote Bank, BBI has the highest mean diversity and BBE the lowest and is therefore significantly different to BBI (ANOVA – Tukey HSD post-hoc test, N_1: p = 0.000545, N_2: p = 0.001019 and N_{inf}: p = 0.008987). BBI also shows the broadest range in diversity for N_1 and N_2 (11.126 and 8.187). GBC has the smallest range in diversity for N_1 and N_2 but the broadest for N_{inf} (4.535). The maximum amount of species occurs on BBI for N_1 and N_2 (15.159 and 11.047) and on GBC for N_{inf} (5.8).

For the Thorntonbank and Goote Bank, comparable results for species richness were obtained (Table 1). The smallest range in species richness is found on the control area of the Thorntonbank (TBC) for all diversity indices. A significant difference in species richness was found between TBI (B) and GBC for the N_2 and N_{inf} indices (Mann-Whitney U-tests, N_2: p = 0.040872 and N_{inf}: p = 0.019779), no significant differences were found between the different locations on the Thorntonbank (Mann-Whitney U-tests, $p > 0.05$).

A comparison between the baseline studies during 2005 for the Thorntonbank and 2008 for the Bligh Bank can be found under paragraph 7.3.3.1.1.

7.3.2.3. Biomass

At the Bligh Bank and Goote Bank, broad ranges in biomass are present, varying from 3.48 at BBE to 37419.65 mg/m² at BBI. Ten samples were classified as outliers or extremes and are not represented in Figure 7. BBI has the highest mean biomass of 4091 ± 1650 mg/m² and GBC the lowest with 1881 ± 602 mg/m² but no significant differences were detected between the Bligh Bank and Goote Bank (Mann-Whitney U-tests, $p > 0.05$).

For the Thorntonbank and Goote Bank, biomass results are slightly lower than the Bligh Bank. Results range from zero to 21690 mg/m² at TBI (A) with a maximum mean biomass at TBC of 3298 ± 1166 mg/m². Ten samples on the Thorntonbank and Goote Bank were also classified as outliers or extremes and are not represented in Figure 7. Only TBE differs significantly from the western and eastern concession areas (Mann-Whitney U-tests, TBI (A): $p = 0.034458$ and TBI (B): $p = 0.026767$).

No significant differences in biomass were detected between the studies carried out in 2005, 2008 and 2009 for the Thorntonbank and Goote Bank and in 2008 and 2009 for the Bligh Bank (Mann-Whitney U-tests, $p > 0.05$).

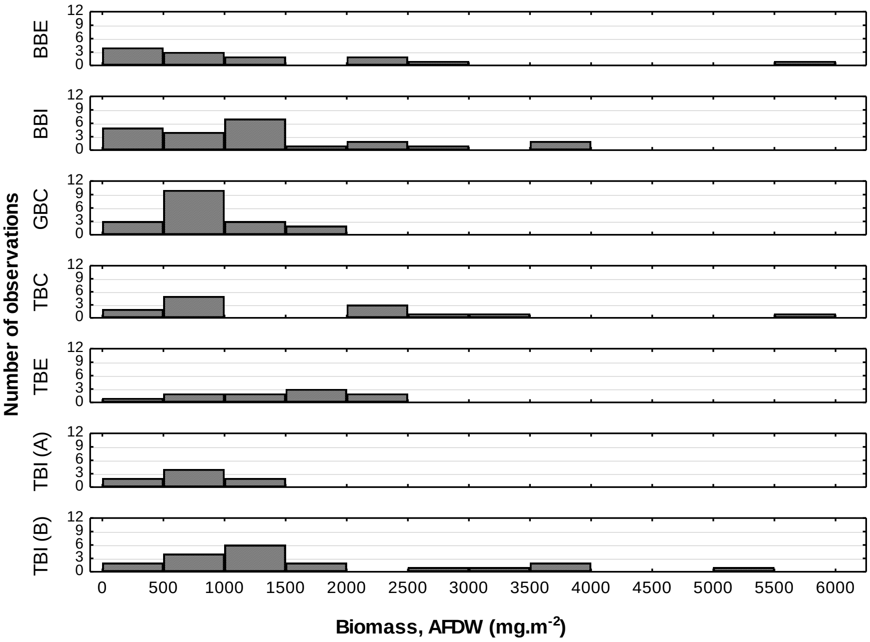

Figure 7. Distribution of Biomass (mg.m^{-2}) at the different sampling locations

7.3.2.4. Species analysis

Dominant species were determined by means of SIMPER analyses and are species with a mean contribution of more than 15% to the mean total density.

Table 2 illustrates the clear dominance of *Nephtys cirrosa* in all samples. However, the edge area of the Bligh Bank also has a dominance of *Bathyporeia guilliamsoniana*. On the Thorntonbank the control area (TBC) also has two dominant species; *Nephtys cirrosa* and *Spiophanes bombyx*.

Table 2. Dominant species in sample locations BBE, BBI and GBC with their mean contribution to the mean total density in terms of percentages

Location	Species	Mean contribution of a species in %
BBE	*Nephtys cirrosa*	51.97
	Bathyporeia guilliamsoniana	18.76
BBI	*Nephtys cirrosa*	30.8
GBC	*Nephtys cirrosa*	32.25
TBE	*Nephtys cirrosa*	44.89
TBC	*Nephtys cirrosa*	39.39
	Spiophanes bombyx	15.5
TBI (A)	*Nephtys cirrosa*	49.14
TBI (B)	*Nephtys cirrosa*	52.25
GBC	*Nephtys cirrosa*	32.25

7.3.3. Multivariate analyses

7.3.3.1. Spatio-temporal analysis on the Bligh Bank

In Figure 8, a non-metric Multi-Dimensional scaling (MDS) plot is illustrated for the macrobenthic densities on the Bligh Bank and the Goote Bank. An analysis of similarities (ANOSIM) illustrates a slight difference between BBE, BBI and GBC (R-statistic of 0.208, 0.264 and 0.192) which is confirmed by the SIMPER analysis (Annex 3). The similarities within a group and dissimilarities between groups are of the same magnitude.

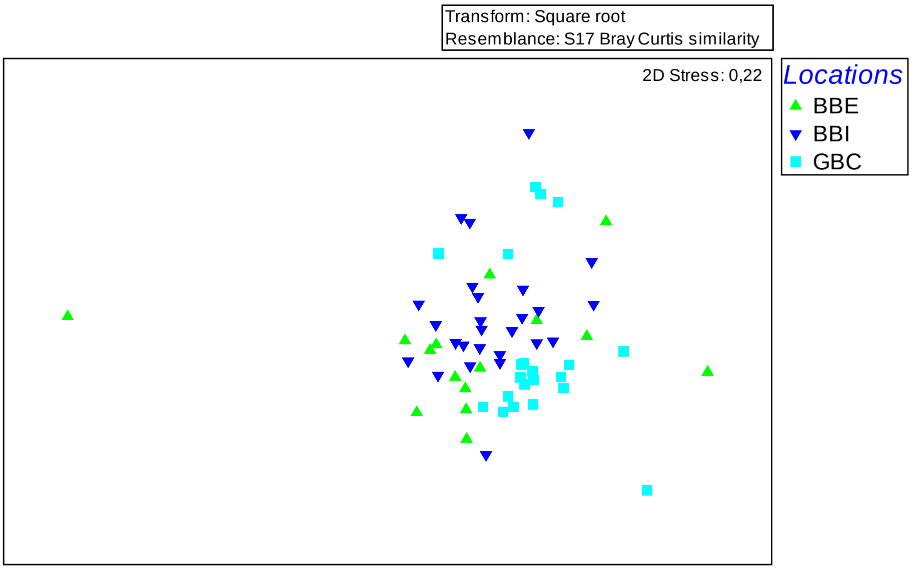

Figure 8. MDS based on macrobenthic densities for BBE, BBI and GBC in 2009

7.3.3.1.1. Comparison between the baseline study (2008) and T_1 (2009)

- Macrobenthic Density

To be able to determine any shifts in macrobenthic densities over the past years, a comparison must be made between the baseline studies and the studies carried out after disturbance. Firstly, an MDS plot was produced based on the macrobenthic densities during the autumn on the Bligh Bank and the Goote Bank for the baseline situation in 2008 and the T_1 situation in 2009 (Figure 9). Station

BBE08 from 2009 was removed from the analysis to prevent hyper clustering op the data points. At first sight, a slight distinction can be made between 2008 and 2009 which is confirmed by the ANOSIM where the Global test has an R-statistic of 0.232. When comparing between groups, GBC has a lower R-statistic (0.209) between 2008 and 2009 than BBE (0.304) and BBI (0.301).

The SIMPER analysis reveals the highest average dissimilarity (80.53 %) for BBE (Annex 3). From 2008 to 2009 an increase in contribution to the average similarity for BBE and BBI was observed for *Nephtys cirrosa* and *Bathyporeia guilliamsoniana*, a decrease was simultaneously observed for *Spiophanes bombyx*. The contribution of *Nephtys cirrosa* to the average similarity at GBC stayed roughly the same between 2008 and 2009, however GBC also showed a decline in the contribution of *Spiophanes bombyx* (Annex 4).

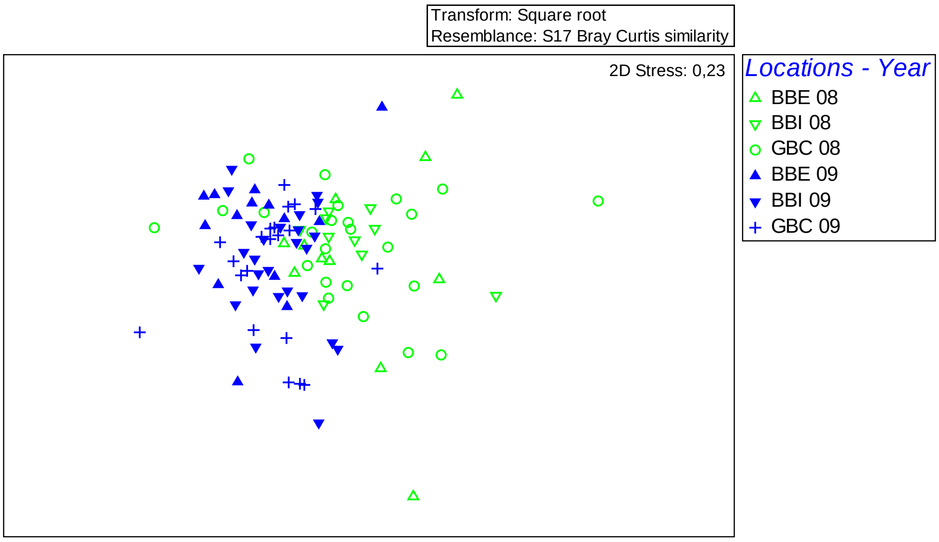

Figure 9. MDS based on macrobenthic densities for BBE, BBI and GBC during the autumn of 2008 and 2009

- Diversity

When analysing the results in diversity at the Bligh Bank and Goote Bank for 2008 and 2009, a very high resemblance was measured using the ANOSIM analysis with a global R-statistic of 0.015 between the two years. Obviously the SIMPER analysis gave smiliar results with a very low dissimilarity percentrage of 12.63%.

- Biomass

The baseline on the Bligh Bank was also analysed to detect any significant differences in biomass with the T_0 situation in 2009. Station BBE08 (2009) was also removed from these analyses to prevent hyper clustering op the data points when creating the MDS plot. The MDS plot is quite similar to the MDS plot based on densities with a slight distinction between 2008 and 2009 (Figure 10). Again, this is confirmed by the ANOSIM analysis with a global R-statistic of 0.226 between 2008 and 2009. When comparing between groups, GBC has the lowest R-statistic (0.146) between 2008 and 2009, BBE (0.352) and BBI (0.215) show higher R-statistics indicating a larger difference in biomass between 2008 and 2009 for these locations.

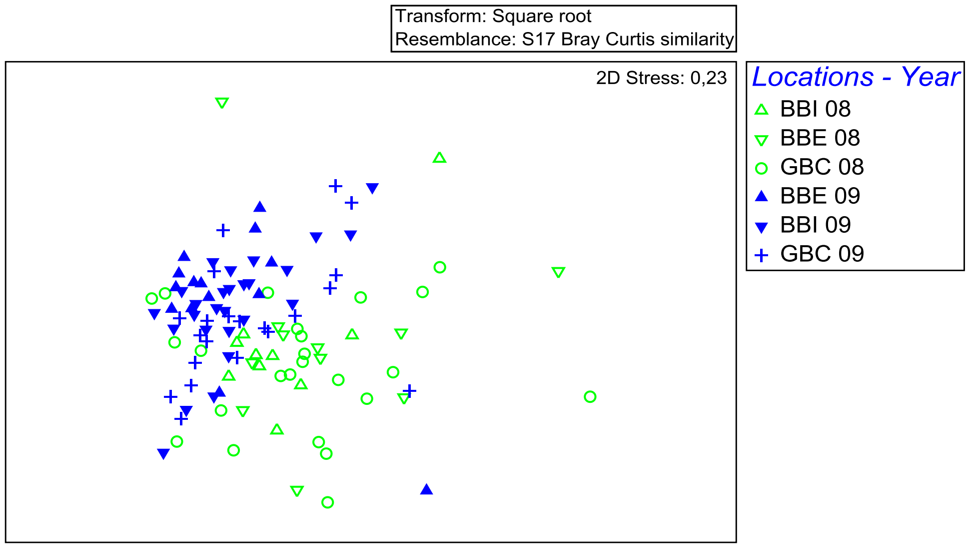

Figure 10. MDS based on macrobenthic biomass for BBE, BBI and GBC during the autumns of 2008 and 2009

Results of the contribution to the average similarity of the group (SIMPER), based on biomass, are provided in Annex 5. Similar results between BBI and GBC were found with a large increase in the *Nephtys cirrosa* and a decrease in *Spiophanes bombyx* biomass contribution. The increase in *Nephtys cirrosa* biomass contribution between 2008 and 2009 was even larger for BBE together with a large decrease in *Nephtys caeca* contribution. However, the decrease in biomass of *Spiophanes bombyx* was smaller for BBE.

7.3.3.2. Spatio-temporal analysis on the Thorntonbank

An analysis of similarities (ANOSIM) illustrated no significant difference between every area on the Thorntonbank (TBE, TBC, TBI A and TBI B) and the Goote Bank as the Global ANOSIM test has a significance level above the 5% limit (6.6%). This is confirmed by the SIMPER analysis where the similarities and dissimilarities within and between the groups are of the same magnitude (Annex 3).

Furthermore, the four sampling stations in close vicinity to the six windmills on the Thorntonbank (TBI 27-30) were grouped separately to determine any smaller scale impacts. However, no clear differences were detected compared to the other groups (Figure 11).

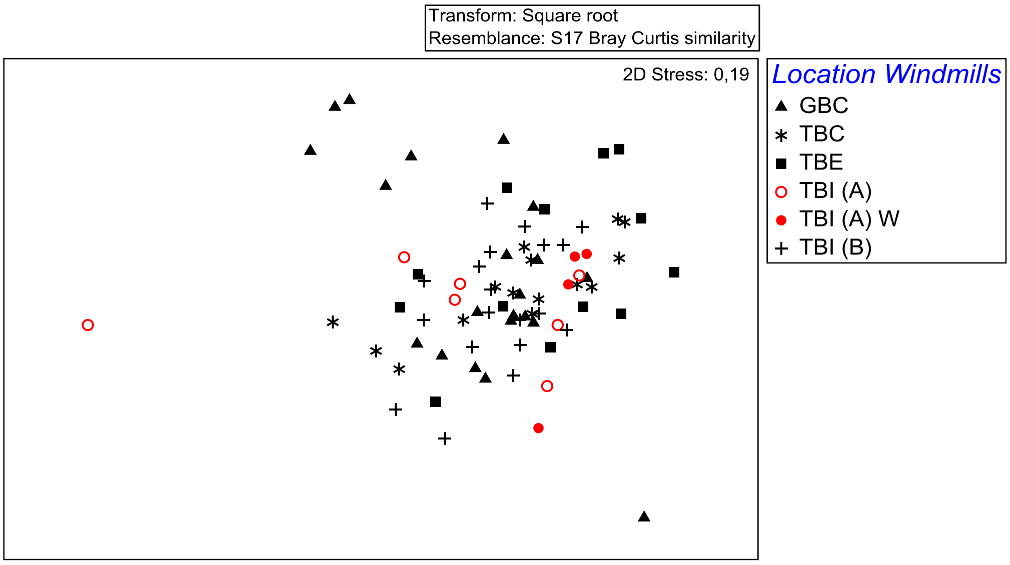

Figure 11. MDS plot based on the macrobenthic densities for GBC, TBC, TBE, TBI (A), TBI (B) and TBI (A) W (the sampling stations in close vicinity to the six windmills)

7.3.3.2.1. Comparison between the baseline study (2005) and theT$_1$ (2008) and T$_2$ (2009) situation

- Macrobenthic density

An MDS plot based on the macrobenthic densities during autumn was carried out on the Thorntonbank and the Goote Bank for the baseline situation in 2005 and the T$_1$ and T$_2$ situations in 2008 and 2009 (Figure 12). Station TBI01 (2009) was removed from the analyses when creating the MDS plot, to prevent hyper clustering of the data points. The MDS plot shows a larger difference between 2005 and 2008 than between 2005 and 2009 which is also confirmed by the ANOSIM analysis with the highest R-statistic (0.31) between 2005 and 2008. An ANOSIM analysis also showed the highest R-statistic values at TBI A between 2005-2008 (0.558) and 2005-2009 (0.436), other R-statistics varied between 0.173 (GBC 05- GBC 08) and 0.376 (TBC 05 – TBC 08).

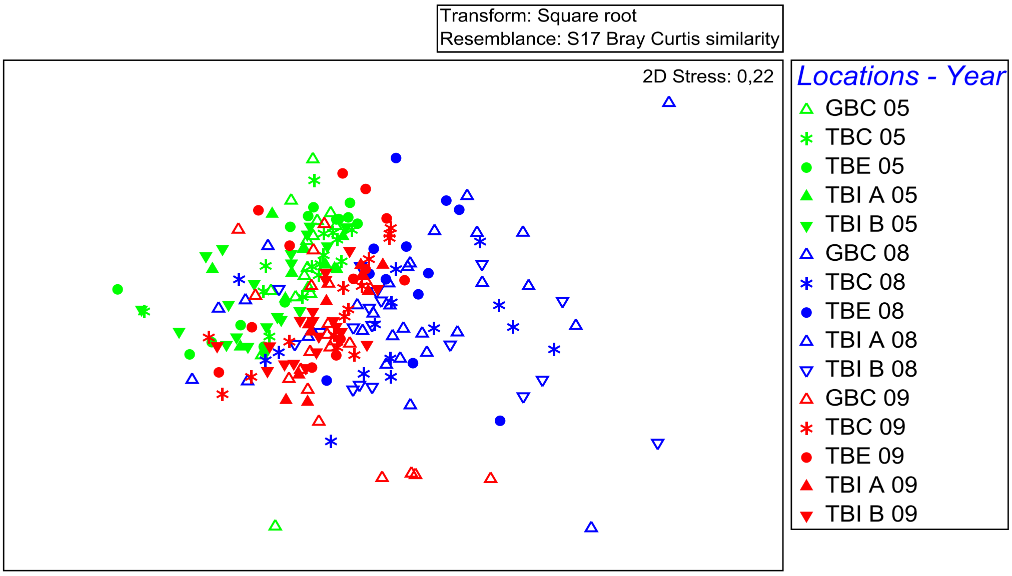

Figure 12. MDS based on macrobenthic densities for GBC, TBE, TBC, TBI (A) and TBI (B) during the autumns of 2005, 2008, 2009

Results of the contribution to the average similarity of the group (SIMPER) are provided in Annex 4. The contribution of *Nephtys cirrosa* to GBC and TBC shows relatively stable results from 2005 until 2009, with a small decline in 2008. For both locations, *Urothoe brevicornis* shows a steep decline in 2008 and 2009 compared to 2005. In contrast, *Spiophanes bombyx* shows a peek in contribution to GBC in 2008 compared to 2005 and 2009. For TBC, the contribution of *Spiophanes bombyx* increased in 2008 and remained at this level in 2009. The decline during 2008 in *Nephtys cirrosa* contribution becomes more pronounced for the TBE, TBI (A) and TBI (B) locations with the largest difference for TBI (B). The contribution of *Urothoe brevicornis* also shows a steep decline for TBI (A) and TBI (B) in 2008 and 2009 compared to 2005. Furthermore, the peek in *Spiophanes bombyx* contribution during 2008 can also be detected for TBE, TBI (A) and TBI (B) with the largest difference in TBE.

- Diversity

Similar results to the Bligh Bank were found for the Thorntonbank and Goote Bank between 2005 and 2009. The R-statistic varied from 0.008 for 2008-2009 up to 0.093 for 2005-2008. The dissimilarity percentages carried out by SIMPER varied from a minimum of 11.04% for 2008-2009 and 13.92% for 2005-2008.

- Biomass

A comparison was also carried out between results obtained on the Thorntonbank and Goote Bank during the autumn of 2005, 2008 and 2009 (Figure 13). Station TBI01 (2009) was removed from these analyses to prevent hyper clustering op the data points when creating the MDS plot. The MDS plot illustrates a strong overlap between the three years. ANOSIM analysis gives the highest R-statistic between 2005 and 2008 (0.319) and the lowest between 2005 and 2009 (0.207). An ANOSIM analysis carried out between locations also showed the highest R-statistic values at TBI A (0.45), TBE (0.46) and TBC (0.414) between 2005-2008, other R-statistics varied between 0.131 (TBI B 05-08) and 0.398 (TBC 08 – TBC 09).

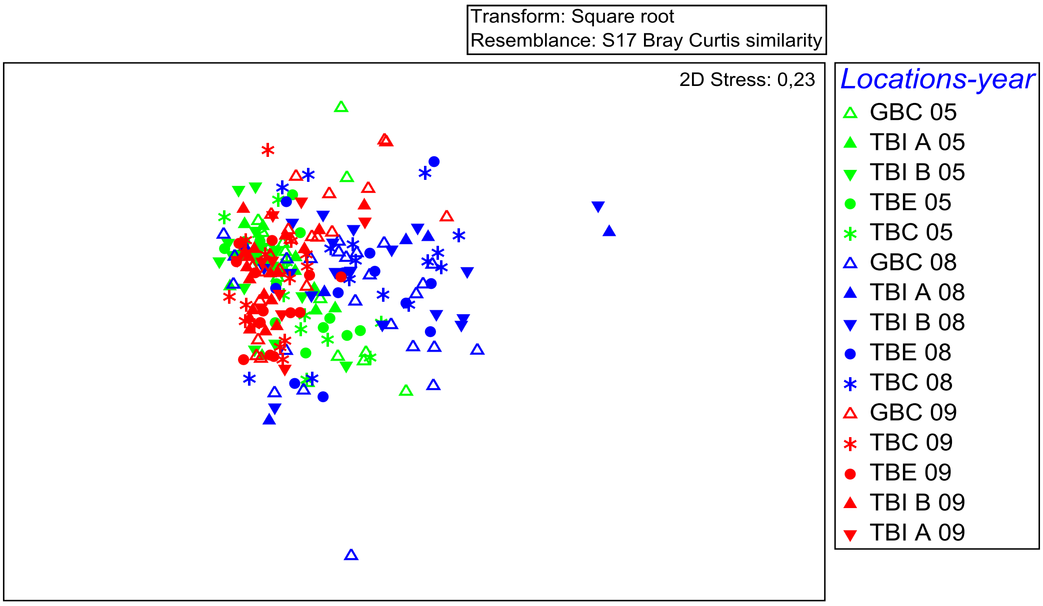

Figure 13. MDS based on macrobenthic biomass for GBC, TBI (A), TBI (B), TBE and TBC during the autumns of 2005, 2008 and 2009.

Results of the contribution to the average similarity of the group (SIMPER) for the Thorntonbank and Goote Bank, are also provided in Annex 5. Similar trends to the analyses based on densities are found for the biomass results. All stations show a sudden decrease in *Nephtys cirrosa* contribution to the average similarity during the autumn of 2008, and a restoration in 2009. Furthermore, the peek in *Spiophanes bombyx* contribution during 2008 is also depicted in the biomass results of every location but to a lesser extent at TBC. A decline in *Urothoe brevicornis* contribution is only detected for the GBC, TBI (A) and TBC locations.

7.4. Discussion

During the autumn of 2009, biotic and abiotic variables were sampled in the wind farm concession areas (Thorntonbank and Bligh Bank) and the reference site (Goote Bank). Results were analysed to detect any changes in the ecological situation of the soft-sediment macrobenthos after impact. A comparison was therefore carried out between the concession and reference sites and between the baseline situations in 2005 for the Thorntonbank and 2008 for the Bligh Bank.

7.4.1. Sediment characteristics

Samples taken at the Bligh Bank and Goote Bank were characterised by medium, coarse sands (250-500 µm) with a very low mud content and low total organic matter content. Lower results in median grain size were obtained at the Goote Bank compared to both areas on the Bligh Bank. The impact area on the Bligh Bank however shows a comparable total organic matter content to the Goote Bank, in contrast to the edge areas with a significantly lower content than the Goote Bank.

Only a significant difference in median grain size was found for BBI in comparison to the baseline situation sampled in 2008 (Reubens *et al*, 2009b).

Samples from the Thorntonbank and Goote Bank were also characterised by medium sands and a low total organic matter content but without the presence of mud at the Thorntonbank. Comparable to the results in 2008 (Reubens *et al*, 2009b), no difference in median grain size was detected between the Thorntonbank and Goote Bank. However, significantly higher contents of total organic matter were measured at the Goote Bank in comparison to the Thorntonbank. The control area on the Thorntonbank (TBC) illustrates a higher similarity in sediment characteristics with the western concession area (TBI A) and the edge area (TBE) but not with the eastern concession area (TBI B).

In comparison to the baseline situation sampled during the autumn of 2005 (De Maersschalck *et al*, 2006), no significant differences in sediment characteristics could be detected. Stations TBI (B) and TBC however, did show a difference between the sampling campaigns in 2005 and 2008 illustrating the high natural fluctuations in sediment characteristics throughout the years.

7.4.2. Macrobenthos

7.4.2.1. Belwind

At the Bligh Bank and Goote Bank, no significant differences were detected for all biotic variables except the diversity indices N_1, N_2 and N_{inf}. The maximum macrobenthic densities were significantly lower than 2008 at all locations (Reubens *et al*, 2009b) and varied from 770 to 1060 ind./m². Species richness (N_0) illustrated a comparable range to 2008 from 1 to 24 spp./0.1 m². Broader ranges in biomass (3.48 – 37419.65 mg/m²) and productivity (0.0692 – 108.359 mg/(day.m²) were also found for the Bligh Bank and Goote Bank. The diversity indices N_1, N_2 and N_{inf} show a significant difference between BBI and BBE. No significant differences in biomass were detected at the Bligh Bank and Goote Bank. A multivariate analysis of the diversity showed a very high resemblance in species richness between 2008 and 2009.

Multivariate analyses in 3.3.1 are based on the macrobenthic densities and only illustrate slight differences between the three locations on the Bligh Bank and Goote Bank. Variations within and between groups are of the same magnitude.

Species are dominated by *Nephtys cirrosa* at all locations (Table 2) and also by *Bathyporeia guilliamsoniana* at BBE with a contribution percentage of 18.76%. These results are slightly in contrast to 2008 where *Spiophanes bombyx* also dominated at GBC during autumn (Reubens *et al*, 2009b). The multivariate analyses also illustrate this difference with the baseline situation in 2008. *Nephtys cirrosa* and *Bathyporeia guilliamsoniana* contributed more to the average similarity of BBE and BBI in 2009 for both density and biomass, while the contribution of *Spiophanes bombyx* in the Bligh Bank and Goote Bank declined during 2009. Only considering biomass, the contribution of *Nephtys cirrosa* to the average similarity also increased at the Goote Bank (Annex 4 & 5).

7.4.2.2. C-Power

No significant differences in density and species richness (N_0) were detected at the Thorntonbank and Goote Bank. The maximum macrobenthic density varied from 770 to 1930 ind./m² and was significantly lower compared to 2005 for TBI (B) and 2008 for GBC. Species richness varied from 1 to 16 spp./0.1 m² and the biomass from zero to 21690.13 mg/m². A significant difference in biomass was measured between the concession areas and the edge area on the Thorntonbank during 2009. Furthermore, a significant difference in diversity indices N_2 and N_{inf} were detected between TBI (B) and the Goote Bank. However, the multivariate analyses based on macrobenthic densities illustrate only a very small difference between the Thorntonbank and Goote Bank.

The macrobenthic density between 2005 and 2008 was also significantly different for TBI (B) and TBE. The eastern concession area TBI (B) also showed a significant difference for the period 2005-2009.

Species are dominated by *Nephtys cirrosa* at all locations and also by *Spiophanes bombyx* at TBC with a contribution percentage of 15.5% (Table 2). Again this is in contrast with the results from 2008 where both *Nephtys cirrosa* and *Spiophanes bombyx* were dominant at TBI (B) and GBC and *Nephtys cirrosa*, *Nephtys caeca* and *Spiophanes bombyx* at TBE. When analysing the multivariate analysis of macrobenthic densities and biomass between 2005 and 2009 an overall trend can be detected with a decline in *Urothoe brevicornis* contribution during 2008 and 2009, a peek in *Spiophanes bombyx* contribution in 2008 and a decline in *Nephtys cirrosa* contribution during 2008 with a recovery in 2009 (Annex 4 & 5). In comparison to the Bligh Bank, the multivariate analysis of the diversity also showed very high resemblances in species richness from 2005 until 2009.

7.5. Conclusions and recommendations

The year-1 results on the Bligh Bank and Goote Bank only showed a significant difference in median grain size for BBI compared to the baseline situation in 2008, significant differences in the abiotic data were detected with the reference site during 2009. Significant differences in macrobenthic densities were found between the Year-0 and Year-1 results on the Bligh Bank; however a similarity in macrobenthic densities between the Bligh Bank and the reference site (Goote Bank) was illustrated during 2009. No direct impacts of the offshore wind turbines at the Bligh Bank can therefore be detected at this moment but we must bear in mind that these Year-1 results were sampled during and not after installation of the wind turbines, therefore illustrating the natural temporal and spatial fluctuations in macrobenthic communities on the Bligh Bank.

A strong similarity between the concession areas on the Thorntonbank and the control areas on both the Thorntonbank and the Goote Bank was illustrated for the biotic variables. Some differences in median grain size and total organic matter could be detected between the concession areas and the reference sites (GBC and TBC), but a comparison with the baseline study in 2005 only showed a significant difference in the variable mud content for TBI (B) and TBE. The temporal variability at the Thorntonbank was illustrated by a significant difference in macrobenthic density for TBI (B) between this year's results and the baseline study in 2005. This was also demonstrated by a peek in *Spiophanes bombyx* and a decline in *Nephtys cirrosa* contribution during 2008. In comparison to last year's results we can suggest a low impact of the six wind turbines at TBI (A) during the second year after implementation.

Overall, the results from the Thorntonbank and Goote Bank of 2005, 2008 and 2009 illustrate the natural temporal variability that can appear in macrobenthic communities. In order to detect any (cumulative) impacts of the offshore wind farms, the long term monitoring must therefore be continued over a longer period. During the coming years, a focus will be made on the macrobenthic communities that appear at a median grain size between 350 and 400µm. Subsequently, a more in depth comparison between stations and years can be carried out. Throughout the past years, the knowledge on soft-sediment macrobenthic communities has increased due to a wide spread sampling strategy at the relevant sites (De Maersschalck *et al*, 2006; Reubens *et al*, 2009b). However, the amount of sampling sites for the long-term monitoring campaign in the autumn of 2010 will be reduced, to increase the amount of replicas and subsequently the reliability of the results. Every area of the Thorntonbank, Bligh Bank and the Goote Bank will contain four sampling stations with five replicas each. A total of 120 stations will be taken during the Belgica sampling campaign in the autumn of 2010 and a total of 72 samples will eventually be analysed in the laboratory, leaving two replicas of every station as back-up. This new design will result in a more in depth monitoring campaign of the soft-sediment macrobenthos with an enhanced reliability of the results. The monitoring design must stay open to changes in the event of unexpected patterns appearing or suspected during future monitoring campaigns.

As macrobenthic communities are highly dependent of the sedimentological characteristics such as median grain size and organic matter content and the hydrographic regimes of the seabed (Pearson & Rosenberg, 1978; Wilhelmsson & Malm, 2008), the question has arisen whether or not the increased epifaunal communities colonizing the turbines (Kerckhof *et al*, 2009) will alter the composition of the sediments at a small-scale and subsequently modify the soft-sediment macrobenthic communities. Studies around the FINO 1 research platform and the Nysted offshore wind farm (Denmark) found altered sediment conditions and macrofauna densities close to the hard substrata (Köller *et al*, 2006; Maar *et al*, 2009), illustrating the importance of sampling campaigns in close vicinity to the wind turbines. As recommended by Reubens *et al*, 2009 a smaller research vessel and divers will be mobilized during sampling campaigns in June and September 2010 in order to detect smaller changes in macrobenthic communities with an emphasis on the presence and impact of organic enrichment. This targeted monitoring could be integrated with the research carried out by Jan Reubens (Reubens *et al*, 2009a) in the future to create a greater understanding of the impacts of offshore wind farms on the Belgian continental shelf.

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Chapter 8. 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)

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Abstract

The consortia C-Power and Belwind obtained an environmental permit to build and exploit a wind farm on the Thorntonbank and Bligh Bank, respectively. To scientifically evaluate the ecological effects of these wind farms, a BACI (Before After Control Impact) strategy is used, based on repeated samplings (spring and autumn, before and after impact) in impact areas (concession zones) and reference areas. The current report describes the situation in 2009 (Year-1 Bligh Bank, Year-2 Thorntonbank) concerning epibenthic fauna, bentho-pelagic and demersal fish.

To assess the natural variability within the wind farm area and to put this in the perspective of the overall variability within the Belgian Part of the North Sea (BPNS), a detailed analysis of the community structure at the wind farm area was carried out for epibenthos, bentho-pelagic and demersal fish. The variability of the three ecosystem components was mainly determined by geographical and seasonal patterns. There were significant differences between the sandbank systems on the Thorntonbank, the Bligh Bank and the sandbank systems on the Gootebank, the Bank Zonder Naam and the most offshore situated stations. Seasonality was the most important structuring factor for bentho-pelagic and demersal fish, while this factor was subordinate to spatial differences for epibenthos. The differences between sandbank tops and gullies were observed in all three ecosystem components but were not consistent over the years, seasons and sandbank systems. Community analyses can provide an indication of impact by signalling shifts in species composition. Based on the situation in 2009, no such signals were observed.

The condition of demersal fish, bentho-pelagic fish and epibenthos was assessed based on the parameters density, diversity, biomass (epibenthos only) and length-frequency for the impact stations, reference stations and fringe stations. The density and biomass values for epibenthos were higher in the reference and fringe areas than in the impact areas, on both the Thorntonbank and Bligh Bank. The same pattern was noted for demersal fish on the Thorntonbank, while on the Bligh Bank the highest densities of demersal fish were consistently found in the impact areas. Those patterns were also observed in the pre-construction assessments for both wind farm areas, so this cannot be attributed to the construction activities. For bentho-pelagic fish this pattern was less clear. Density and biomass showed a high variability between the different years with very low values in 2008 and substantially increased values in 2009 at most stations on and around the Thorntonbank and Bligh Bank. However, in the impact area of the Bligh Bank, there was a decrease (autumn 2009 vs. autumn 2008) both for epibenthos and demersal fish. In the impact area on the Thorntonbank, some alterations within the epibenthos and fish assemblages could be observed; lower densities of sole in spring 2009 and higher densities of horse mackerel in autumn 2009 compared to the reference areas around the Thorntonbank. This might be an expression of the attraction effect of the windmills, competition with newly arriving species or a change in food supply. For the measures diversity and length-frequency, no signals of impact of the windmill construction and exploitation were observed.

Since only six turbines were present on the Thorntonbank during both 2009 campaigns and since construction activities on the Bligh Bank had just been initiated at the time of the autumn campaign, little impact could be noticed. Hence, the 2009 data can be considered as an extended baseline study. In 2010, the total number of turbines in both wind farms will have increased to 62, which probably will result in measurable changes in the near future.

During the 2009 spring campaign, a number of ILVO long term monitoring stations was sampled, in order to examine the suitability of these stations as representatives for the gullies in the vicinity of the concession zones. This analysis was based on comparisons of density, biomass, diversity and species composition. Station 330 is the only station which can be used as proxy for the Thorntonbank gullies. Station 340 is unsuitable as reference for the gullies in the vicinity of the Thorntonbank since this station is situated in a transitional zone between coastal and offshore conditions and since different communities have been observed here in the past. Both station 545 and station 840 showed some similarities with the Bligh Bank gullies, but insufficient to incorporate the stations in the monitoring program of the wind farms.

Samenvatting

De consortia C-Power en Belwind verkregen een milieuvergunning voor de bouw en exploitatie van een windmolenpark op respectievelijk de Thorntonbank en Bligh Bank. Om op een wetenschappelijke basis de ecologische gevolgen van deze windmolenparken na te gaan werd een BACI (Before After Control Impact) strategie gekozen. Deze is gebaseerd op herhaalde staalnames (lente en herfst, voor en na impact) in impactgebieden (concessiezones) en referentiegebieden. Het huidige rapport beschrijft de jaar-1 studie van de Bligh Bank en de jaar-2 studie van de Thorntonbank betreffende epifauna, bentho-pelagische en demersale vissen.

Om de natuurlijke variabiliteit in het windmolengebied te bepalen en in het perspectief te plaatsen van de algemene variabiliteit in het Belgisch deel van de Noordzee, werd een gedetailleerde analyse uitgevoerd van de gemeenschapsstructuur van epibenthos, bentho-pelagische en demersale vis in het windmolengebied. De variabiliteit van de drie ecosysteemcomponenten werd voornamelijk bepaald door geografische en seizoenale patronen. Er waren significante verschillen tussen de zandbanksystemen op de Thorntonbank, de Bligh Bank en de zandbanksystemen op de Gootebank, de Bank Zonder Naam en verder uit de kust gelegen stations. Seizoenaliteit was de belangrijkste structurerende factor voor bentho-pelagische en demersale vis, terwijl deze factor voor epibenthos ondergeschikt was aan de ruimtelijke verschillen. De verschillen tussen zandbanktoppen en -geulen werden in de drie ecosysteemcomponenten waargenomen maar waren niet consistent over de jaren, seizoenen en zandbanksystemen. Gemeenschapsanalyses kunnen aangeven dat er een impact is door veranderingen in soortensamenstelling aan te geven. Gebaseerd op de situatie in 2009 werden dergelijke signalen niet waargenomen.

De toestand van demersale vis, bentho-pelagische vis en epibenthos werd bepaald op basis van de parameters densiteit, diversiteit, biomassa (enkel epibenthos) en lengtefrequentie voor de impactstations, referentiestations en de stations aan de rand van de concessiegebieden (fringe stations). De densiteits- en biomassawaarden voor epibenthos waren hoger in de referentie- en randgebieden, zowel op de Thorntonbank als op de Bligh Bank. Hetzelfde patroon werd waargenomen bij demersale vis op de Thorntonbank, terwijl op de Bligh Bank de hoogste densiteiten aan demersale vis consequent gevonden werden in de impactgebieden. Aangezien deze patronen ook al werden waargenomen in de preconstructie beoordeling voor beide windmolengebieden, kan dit niet toe te schrijven zijn aan de constructieactiviteiten. Voor bentho-pelagische vis was dit patroon minder duidelijk. Densiteit en biomassa vertoonden een hoge variabiliteit tussen de verschillende jaren met - voor de meeste stations op en rond de Thorntonbank en Bligh Bank- zeer lage waarden in 2008 en verhoogde waarden in 2009. Hoewel, in het impactgebied van de Bligh Bank was er een afname (najaar 2009 vs. najaar 2008) voor zowel epibenthos als demersale vis. In het impactgebied op de Thorntonbank werden enkele wijzigingen in de epibenthos- en vissamenstellingen waargenomen; lagere densiteiten van tong in het voorjaar van 2009 en hogere densiteiten van horsmakreel in het najaar van 2009, vergeleken met de referentiegebieden rond de Thorntonbank. Dit zou kunnen wijzen op het aantrekkingseffect van de windmolens, competitie met nieuwe soorten of een verandering in voedselaanbod. Voor diversiteit en lengtefrequentie werd geen impact van de windmolenconstructie en -exploitatie waargenomen.

Aangezien er slechts zes turbines op de Thorntonbank stonden tijdens beide campagnes in 2009 en aangezien de constructieactiviteiten op de Bligh Bank juist begonnen waren op het moment van de najaarscampagne, kon er weinig impact opgemerkt worden. Daarom kunnen de data van 2009 beschouwd worden als een uitgebreide baseline studie. In 2010 zal het totaal aantal turbines in beide windmolenparken toegenomen zijn tot 62, wat waarschijnlijk zal resulteren in meetbare veranderingen in de nabije toekomst.

Tijdens de voorjaarscampagne van 2009, werden een aantal ILVO lange termijn monitoringstations bemonsterd, dit om na te gaan of de stations representatief zijn voor de geulen in de nabijheid van de concessiezones. De analyse was gebaseerd op vergelijkingen tussen densiteit, biomassa, diversiteit en soortensamenstelling. Station 330 is het enige station dat gebruikt kan worden als proxy voor de Thorntonbankgeulen. Station 340 in niet geschikt als referentie voor de geulen in de nabijheid van de Thorntonbank omdat het gesitueerd is in een transitiezone tussen kust- en offshore condities en omdat hier al verschillende gemeenschappen geobserveerd zijn in het verleden (Vandendriessche *et al*, in prep.) Zowel station 545 als station 840 vertoonden enkele gelijkenissen

met de geulen op de Bligh Bank maar onvoldoende om de stations op te nemen in het monitoringprogramma van de windmolenparken.

8.1. Introduction and objectives

Since the structure of epibenthos and demersal fish assemblages is an important indicator for anthropogenic and environmental impacts (Callaway *et al*, 2002), these ecosystem components have been included in the environmental impact assessment of wind farms in the Belgian part of the North Sea (BPNS). Different potential effects and already observed effects on epifauna and fish are described in literature (overviews in Köller *et al,* 2006; Di Marcantonio *et al*, 2007; Petersen *et al*, 2006), and can be subdivided based on the phase a wind farm is in (construction, exploitation or dismantlement) and the nature of the effect (direct or indirect). During the phases of construction and dismantlement, the main direct effects are the loss of organisms, biotopes, and spawning and nursery grounds. Indirect effects can result from sediment disturbance and turbidity, the introduction of hard substrata (turbines and erosion protection) and the production of underwater noise, which can cause damage to, or dislocation or flight reactions of fish. During the phase of exploitation, effects are expected or have already been observed as a result of altered water quality and water flow, sound, vibrations and shadows, and electromagnetic fields from cables. Reef effects have been described in all established wind farms, with an increase of habitat diversity resulting in enhanced productivity and biodiversity. On the other hand, the established artificial reefs may act as stepping stones for the dispersal of sessile organisms, thereby possibly decreasing biodiversity. Other effects include the refugium effect, the barrier effect and the effects expected due to the closure of wind farms for bottom-disturbing fisheries, which may result in the establishment or recovery of spawning and nursery grounds, and the recovery of epibenthic communities. Finally, the presence of artificial hard substrata and their associated fauna may result in an altered food supply, and in changes concerning competition and predation relations.

At present, there are two wind farms under construction, more precisely those of the company C-power on the Thorntonbank and of Belwind on the Bligh Bank. The data of the first two years of impact monitoring (2005 & 2008) on epibenthos and demersal fish showed that the major driving forces of variation between the samples were (1) seasonality, (2) interannual differences, and (3) spatial differences (sandbank tops versus gullies). Significant differences due to the construction of the limited number of windmills or fringe effects due to changes in fisheries pressure were not detected in 2008. However, this does not imply the absence of any effects. The results rather indicated that the (local) effects of the limited construction activities were subordinate to the natural variability within the ecosystem.

In Vandendriessche *et al.* (2009), some technical and strategic bottlenecks were identified and recommendations for future monitoring activities were formulated. Concerning the monitoring of epibenthos and demersal fish, the recommendations were related to sampling strategy (reduction of number of reference samples, the efficacy of shorter fish tracks and the usefulness of other monitoring stations as reference condition) and the treatment of bentho-pelagic fish data. These recommendations and targeted monitoring actions were implemented in the monitoring activities of 2009. Additionally, a detailed analysis of community structure of epibenthos and demersal fish in the wind farm concession areas was incorporated in the present study to promote the understanding of natural variability and hence allow a sound interpretation of local changes related to wind farms or other impact sources.

8.2. Aims

This report investigates the condition of demersal fish and macro-epibenthos in the concession zones and reference zones of the Thorntonbank wind farm at year 2 and of the Bligh Bank wind farm at year 1. These results form the basis of the impact assessment concerning the construction and exploitation of the wind farm under investigation (including the effects of the closure of the concession zones for beam trawling and sand extraction).

The aims of the monitoring activities were:

- assessing the natural variability within the wind farm area and putting this in the perspective of the overall variability within the Belgian Part of the North Sea (BPNS) by means of a detailed and localized community analyses based on the ILVO dataset.
- assessing the status and condition of the demersal fish fauna and the macro-epibenthic fauna of the soft substrata in the concession zones and reference zones of the Thorntonbank wind farm during year 2 (2009) and of the Bligh Bank wind farm during year 1 (2009, early construction phase started in autumn). The results of the Thorntonbank were compared with the reference conditions observed in 2005 and the early construction phase in 2008. The results of the Bligh Bank were compared with the reference conditions observed in 2008.
- evaluating the value of ILVO long term monitoring stations as controls for the impact of wind farm construction and exploitation.
- evaluating the efficacy and practicality of shortened fish tracks compared to the standard tracks done in the past (see Annex 7).

8.3. Materials and methods

8.3.1. Baseline monitoring

In 2008, a high sampling intensity (such as the one used in the Thorntonbank baseline study) was maintained for the evaluation of the Thorntonbank construction impact (T1), and was repeated for the Bligh Bank baseline study (T0). For the 2009 sampling campaigns, a modified sampling strategy was proposed, where all required data were obtained based on a reduced number of tracks within the research areas. A reduction of the number of tracks was justified based on:

- the fact that the construction activities of C-power have been paused until further notice and the planned constructions in the concession zone of Belwind were delayed until summer of 2009;
- the high similarity within the groups of gully samples and sandbank top samples as was demonstrated in Vandendriessche *et al* (2009) for both demersal fish and epibenthos.

In practice, parallel SE to NW tracks were done on the Thorntonbank (northern concession zone), on the Bank zonder Naam[1] and on the Bligh Bank (Table 1). Samples were gathered from sandbank tops and neighbouring gullies. Additionally, sandbank top samples were taken in the Thorntonbank reference zone and the southern concession zone, in order to evaluate the effect of the six already constructed windmills.

With this sampling strategy, the number of tracks in the Thorntonbank and Bligh Bank reference zones were limited, especially during the spring campaign. Therefore, extra community analyses were done to examine the suitability of a number of ILVO long term monitoring stations (sampled during other monitoring assignments) as representative for gullies in the vicinity of the concession zones.

During the autumn campaign, the number of tracks was again increased in the Bligh Bank research area following the start of pile driving activities (Table 1).

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[1] The sampling station on the Bank zonder Naam was added in the light of the permit application by Eldepasco for the construction of a 216 megawatt wind farm. The obtained data will be analysed for the assessment of the T0 situation (planned 2010).

Table 1. Overview of stations in the wind farm area sampled during the spring and autumn campaigns of 2005, 2008 and 2009.

sandbank system	station	description	spring 2005	autumn 2005	spring 2008	autumn 2008	spring 2009	autumn 2009
Goote Bank	**WG1**	reference C-Power gully	x	x	x	x		
	WG2	reference C-Power top	x	x	x	x		
	WG3	reference C-Power gully	x	x	x	x		
Thorntonbank	**WT1**	reference C-Power gully	x	x	x	x		
	WT2	reference C-Power top	x	x	x	x	x	x
	WT3	reference C-Power gully	x	x	x	x		x
	WT4bis	fringe C-Power top	x	x	x	x		
	WT5bis	impact C-Power top	x	x	x	x	x	x
	WT6	fringe C-Power gully	x	x	x	x		
	WT7	fringe C-Power gully	x	x	x	x	x	x
	WT8	impact C-Power top	x	x	x	x	x	x
	WT9	fringe C-Power gully	x	x	x	x	x	x
Bank Zonder Naam	**BZN01**	impact Eldepasco top					x	x
Bligh Bank	**WBB01**	reference Belwind gully			x	x		x
	WBB02	reference Belwind top			x	x		x
	WBB03	reference Belwind gully			x	x		x
	WBB04	fringe Belwind gully			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
Oosthinder	**WOH01**	reference Belwind gully			x	x		
	WOH02	reference Belwind top			x	x		x
	WOH03	reference Belwind gully			x	x		x
other	**330**	reference C-Power gully	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

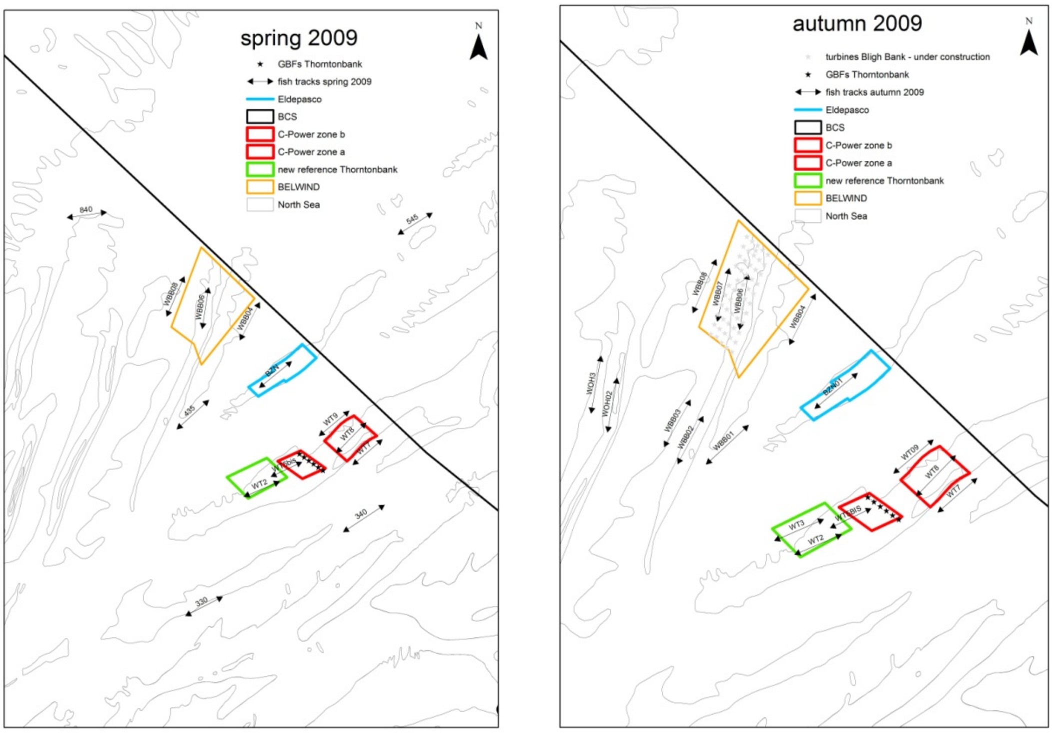


Figure 1. Maps showing positions of the fish tracks taken in the windmill concession areas in spring and autumn 2009.

8.3.2. Sample processing and data analyses

Demersal fish fauna and macro-epibenthos can be defined as the organisms that live on or in close association with the seafloor, and that are caught representatively and efficiently with a beam trawl. Both ecosystem components were sampled onboard the research vessel Belgica with an 8-meter beam trawl with a fine-meshed shrimp net (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 30 minutes (15 minutes for short tracks, see Annex 7) at an average speed of 4 knots over the bottom. As such, a mean distance of 3500 metres (1750 m in short tracks, see Annex 7) was covered. 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.

Since the catch sizes from the 2009 campaigns were generally rather modest, the net contents were processed without the use of a rinsing and sieving machine. 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 'demersal fish' and 'epifauna'. For both ecosystem components density, biomass (epibenthos only), diversity, length frequency distribution and community structure were measured. Since the 2008 community analyses for demersal fish were heavily influenced by the presence and locally high densities of (bentho)pelagic and gregarious fish species, such as herring, sprat, horse mackerel, whiting, bib and poor cod, it was advised to treat the truly demersal fish and the (bentho)pelagic fish separately in future analyses (Vandendriessche *et al*, 2009). This separation was implemented in the analyses of the 2009 data. The distinction between demersal species and (bentho)pelagic species was based on the terminology of FishBase (www.fishbase.org, consultation 01/2010).

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 (Hill, 1973) and on the variable Expected Number of Species (ES(n)). The datasets were reduced to all species observed in more than two fish tracks and occurring with a mean density of more than 0.01 individuals per 1000m². Statistical univariate measures (Kruskall-Wallis ANOVA and Mann-Whitney U tests) were calculated with the programs Statistica 9 (StatSoft Inc., 2009). The community structure of epifauna and demersal fish was analysed using the multivariate techniques MDS (non-metric multidimensional scaling), ANOSIM (analysis of similarities) and SIMPER (similarity percentages procedure) with the software package Primer v5 (Clarke & Gorley, 2001). The multivariate analyses were based on 4th root transformed and reduced datasets of frequency of occurrence and density. For the most abundant species of demersal fish and epibenthos, the length frequency distributions were analysed and visualized. Maps were generated with ArcView 9.3 (ESRI, 2009).

For the impact evaluation concerning the demersal fish and epibenthos of the soft substrata in the windmill concession areas, reference areas and fringe areas (see 4.2), analyses of the parameters density, diversity, biomass and length-frequency were done. For the stations outside the concession areas, a distinction was made between fringe and reference sites, because an increase in fishery activities is expected just outside the borders of the concession areas. Concerning the Thorntonbank, the situation in 2009 (T2) was compared with the situations in 2008 (T1) and 2005 (T0). For the Bligh Bank, a comparison was made between the situation in 2009 (T1) and 2008 (T0). For the assessment of the condition of epibenthos and demersal fish, we took into account the results of the community analyses of section 8.4.1. Reference samples characterised by a different community than the typical community of the sandbank system, were excluded. In autumn 2008, for example, station WT9 was characterised by a community with more coastal characteristics, while all other stations on the Thorntonbank harboured an offshore community. Consequently, WT9 was omitted when comparing impact, reference and fringe stations concerning density, biomass and diversity.

8.4. Results

8.4.1. Community analysis of the wind farm area

8.4.1.1. Situating the wind farm area within the BPNS

For an analysis of the entire BPNS, data from 72 sampling stations spread over the BPNS were used. These were taken during 9 sampling campaigns carried out in the period spring 2004 – spring 2009 (2 campaigns per year: spring and autumn). The community analysis, for which data of epifauna and demersal fish were pooled, revealed 5 distinct communities (3 coastal groups, 2 offshore groups) within the BPNS (Figure 2, taken from Vandendriessche *et al*, in prep).

When superimposing the samples from the wind farm concession area and adjoining reference areas (Figure 2, spring 2004-spring 2009, station 545 not included), it is clear that all samples corresponded with the offshore 1 and offshore 2 communities *sensu* Vandendriessche *et al.* (in prep). These communities were encountered NW of the Kwintebank and the Vlakte van de Raan. 'Offshore 1' samples were mostly found in the most remote parts of the BPNS (except in spring 2006, for which even the most remote stations were characterised by the 'offshore 2' community). The samples belonging to 'offshore 1' all exhibited low densities (average density 37 ind/1000m²), but a relatively high species number and evenness (average N° of species: 24 spp., average N1: 7,3). The top characteristic species were *Echiichthys vipera, Pagurus bernhardus and Ophiura albida.* 'offshore 2' was characterised by the species *Crangon crangon, P. bernhardus and O. albida,* and combined the high densities found in coastal samples with the high diversity found in genuine offshore samples (average density 111 ind/1000m²; mean N° of species: 27, mean N1: 8,3). The spatial range of 'offshore 2' was inconsistent over years and seasons and induced differences between sandbank tops and gullies within the sandbank systems of the offshore region (Vandendriessche *et al,* in prep). A standardized species list can be found in Annex 6.

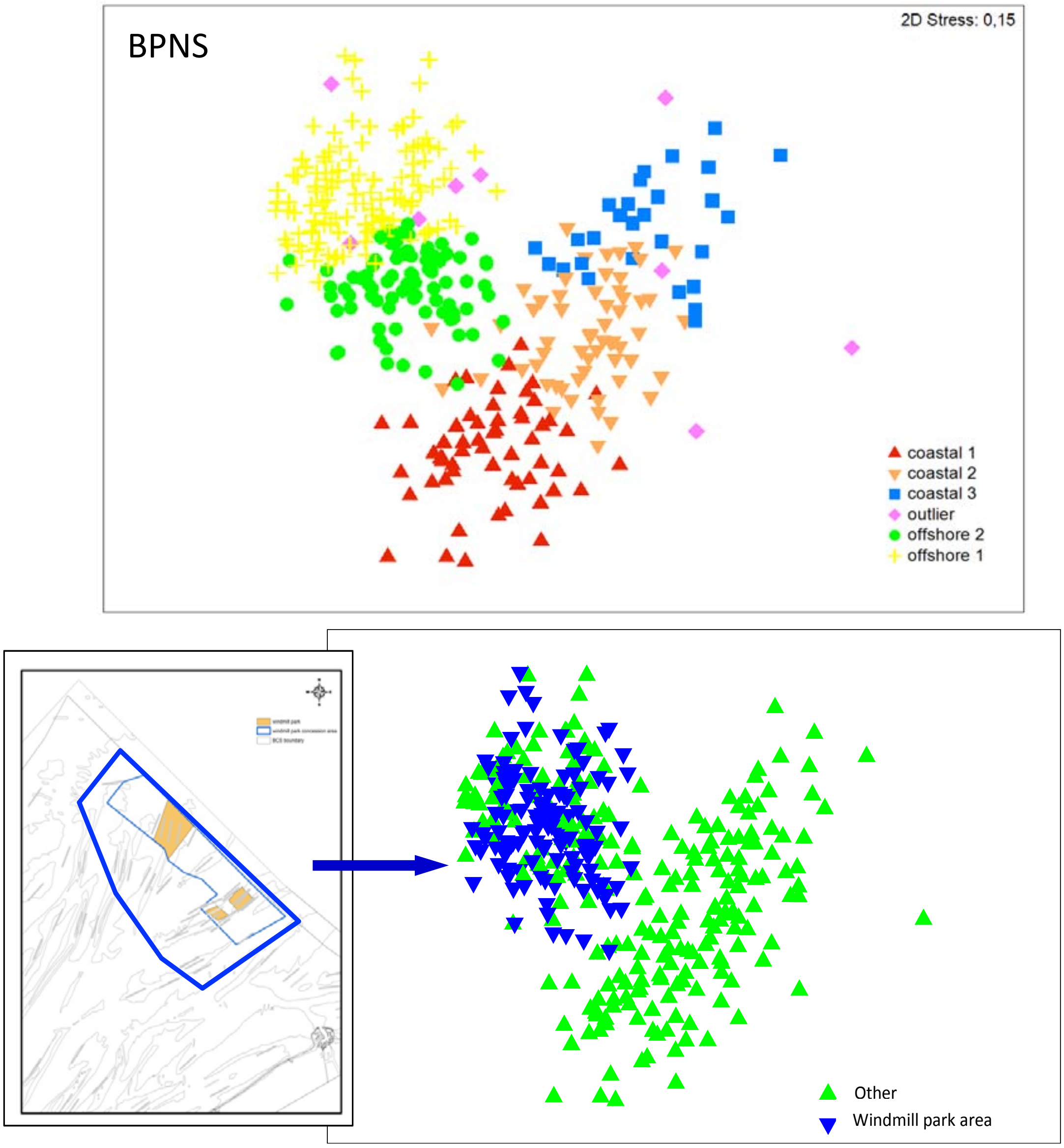
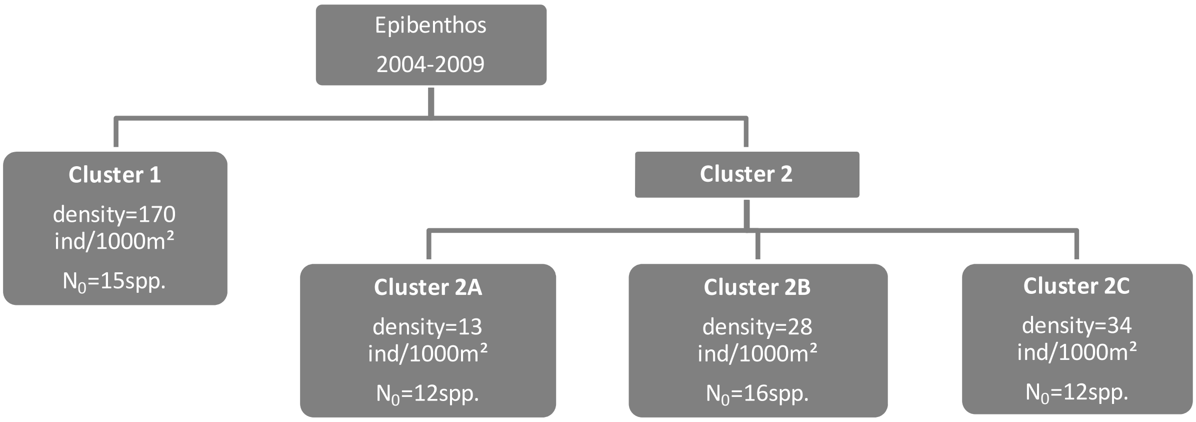


Figure 2. Top: MDS plot of the epibenthos and demersal fish samples of the BPNS for the period 2004 – 2009. Bottom: MDS plot of all BPNS samples with indication of the wind farm samples (including adjoining reference zones) and the other samples.

8.4.1.2. Detailed analysis of the wind farm concession area

- Epibenthos

A cluster analysis based on the epibenthos data revealed two main clusters (1 and 2) and five outliers (63% similarity level). One of the clusters could again be divided into three clusters; 2A, 2B and 2C (Figure 3). Two clusters within cluster 2 were cut off on a lower similarity level (55-56%) but the pattern of the MDS plot (not shown) allowed to link them to clusters 2A and 2C.



	R	p	dissimilarity (%)	contributing species
Cluster 1- Cluster 2	0.51	0.001	45	*C. crangon, C. allmani, O. albida*
Cluster 2A - Cluster 2B	0.47	0.001	40	*C. crangon, O. albida, A. subulata*
Cluster 2B - Cluster 2C	0.51	0.001	40	*C. crangon, L. vulgaris, A. subulata*
Cluster 2A - Cluster 2C	0.47	0.001	42	*C. crangon, O. albida, P. miliaris*

Figure 3. TOP: Figure based on a fourth root transformed cluster analysis (Resemblance: Bray Curtis similarity; cut-off percentage 63%) of the epibenthic data for the period 2004-2009; BOTTOM: Table comparing R-, p- and dissimilarity values between the different (sub)clusters, and the species responsible for these dissimilarities. The densities and species numbers are average values.

- **Cluster 1** mainly consisted of samples from station 340 and stations on the Gootebank. This cluster was principally characterised by *Crangon crangon, Ophiura albida, Pagurus bernhardus* and *Ophiura ophiura*. The clear separation between clusters 1 and 2 indicated that station 340 should not be considered as reference for the Thorntonbank concession area (cf. section 8.4.3). The average density (170 ind/1000m²) was the highest of all clusters, the average number of species (15 spp.) was also relatively high.
- **Cluster 2A** included samples from station 840 and occasionally displayed an expansion towards the Bligh Bank, especially in spring 2008. The most characteristic species of this cluster were *P. bernhardus, O. albida, O. ophiura* and *Asterias rubens.* This cluster had the lowest average density (13 ind/1000m²) and an average number of species of 12.
- **Cluster 2B** exclusively consisted of autumn samples. Most of the samples in this cluster were taken on the Thorntonbank in 2005, 2008 and 2009, another part of the samples originated from the Bligh Bank (2008 and 2009). Dominant species in this cluster were *O. albida, P. bernhardus, Liocarcinus holsatus* and *O. ophiura.* The average density (28 ind/1000m²) in this cluster was relatively low. The average number of species (16 spp.) was the highest of all clusters.
- **Cluster 2C** mainly consisted of samples from the Thorntonbank, more specifically from autumn 2004, spring 2005, spring 2008 and spring 2009. *Crangon crangon, P. bernhardus, O. albida* and *O. ophiura* were typical species in this cluster. The average density (34 ind/1000m²) and the average number of species (12 spp.) showed intermediate values.

The SIMPER analysis confirmed the high dissimilarity (45%; R=0.51; p=0.001) between cluster 1 and cluster 2. This dissimilarity was mainly caused by the species *C. crangon, Crangon allmani* and *O. albida* which were more abundant in cluster 1 than in cluster 2. Within cluster 2, cluster 2A and 2C differed most significantly (dissimilarity 42%; R=0.47; p=0.001). This was due to *C. crangon, O. albida* (more abundant in 2C than in 2A) and *Psammechinus miliaris* (more abundant in 2A than in 2C).

The results of the ANOSIM analysis of the epibenthos data revealed that season was an important structuring factor (R=0.34; p=0.001). The differences between autumn and spring samples were mainly caused by *C. crangon* (more abundant in spring than in autumn), *Alloteuthis subulata* (more abundant in autumn) and *O. albida* (the most abundant species in autumn). However, the seasonal pattern was not consistent. The Thorntonbank samples from autumn 2004 belonged to a different cluster (2C) than those from autumn 2005, autumn 2008 and autumn 2009, which belonged to cluster 2B. Therefore other factors should be taken into account.

The position in the sandbank system (top *versus* gully) was also a structuring factor (R=0.15; p=0.001) but to a lesser extent than the factor season. In autumn 2008, for example, the samples of the top of the Bligh Bank belonged to cluster 2A, whereas the samples of the gullies of the Bligh Bank resorted under cluster 2B. So, the community on the top of the Bligh Bank significantly differed from the community in the gullies. The dissimilarities between tops and gullies were principally due to the species *C. crangon, O.albida* and *P. bernhardus* which were more abundant in the gullies than on the tops. These differences between tops and gullies were not consistent and occurred only sporadically and locally.

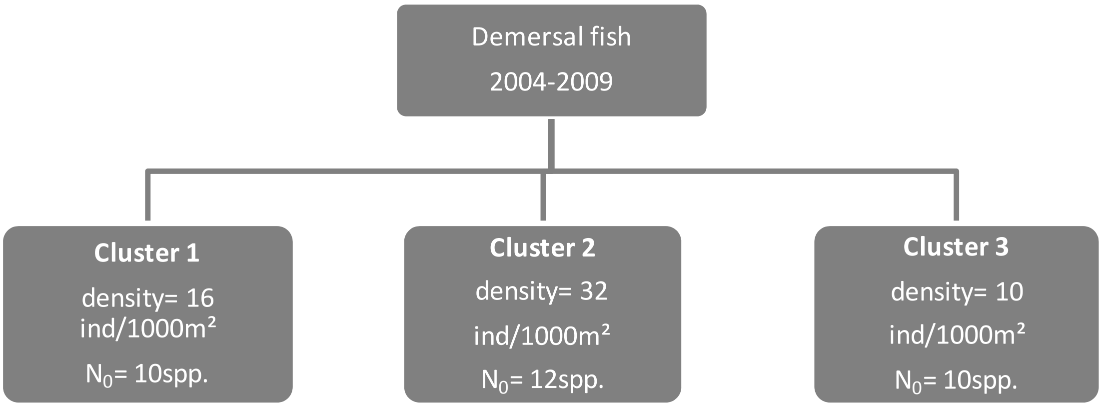
Year was also a significant structuring factor (R=0.11; p=0.001). The differences were situated between 2005 (year before construction of windmills at the Thorntonbank) and 2008 (T1-situation at the Thorntonbank)(R=0.16; p= 0.001) and were mainly caused by *C. crangon, O. albida* and *L. holsatus,* which were all more abundant in 2005.

In the light of the future monitoring of the Bank Zonder Naam in the Eldepasco concession area, the resident communities in the area were listed. In spring 2009, the fish track on the Bank Zonder Naam belonged to the same cluster (2C) as the tracks on the Bligh Bank and the Thorntonbank. In autumn 2009 however, the samples on the Bligh Bank and Thorntonbank made part of cluster 2B, whereas the fish track on the Bank Zonder Naam belonged to cluster 2C.

Station 545 is situated outside the sandbank system of the BPNS. However, it displayed quite some similarities with the Thorntonbank and the Bank Zonder Naam. In spring, the samples of the Thorntonbank, the Bank Zonder Naam and station 545 belonged to the community of cluster 2C and in autumn, they all made part of the community of cluster 2B.

- Demersal fish

Within the demersal fish data, three main clusters (Figure 4) and seven outliers could be distinguished from a cluster analysis at a similarity level of 68%.



	R	p	dissimilarity (%)	contributing species
Cluster 1- Cluster 2	0.47	0.001	32	*C. lyra, E. vipera, B. luteum*
Cluster 2 - Cluster 3	0.70	0.001	37	*E.vipera, C. reticulatus, A. cataphractus*
Cluster 1 - Cluster 3	0.84	0.001	40	*E. vipera, A. cataphractus, S. solea*

Figure 4. TOP: Figure based on a fourth root transformed cluster analysis (Resemblance: Bray Curtis similarity; cut-off percentage 68%) of the demersal fish data for the period 2004-2009; BOTTOM: Table comparing R-, p- and dissimilarity values between the different clusters and the species responsible for these dissimilarities. The densities and species numbers are average values.

- **Cluster 1** mainly included spring samples from the Thorntonbank and the Bligh Bank from 2008. The most dominant species were *Echiichthys vipera, Limanda limanda, Callionymus reticulatus* and *Pleuronectes platessa.* The average density (16 ind/1000m²) showed relatively low values and the average number of species (10 spp.) was the lowest of the three clusters.
- **Cluster 2** was the largest cluster and especially consisted of autumn samples from the Thorntonbank and the Bligh Bank. The characteristic species were *E. vipera, L. limanda, C. reticulatus* and *Callionymus lyra.* This cluster had the highest average density (32 ind/1000m²) and the highest average number of species (12 spp.).
- **Cluster 3** exclusively covered spring samples. The cluster was formed by samples from the Thorntonbank, the Gootebank and samples from station 330 and 340. *L. limanda, C. lyra, Buglossidium luteum* and *P. platessa* were the most characteristic species. The average density (10 ind/1000m²) was the lowest of all clusters. The average number of species (10 spp.) was also relatively low.

The MDS plot (not shown) already gave an indication of the high dissimilarity between cluster 1 and cluster 3. The SIMPER and ANOSIM analyses confirmed this (dissimilarity 40%; R=0.84; p=0.001). The species *E. vipera* (more abundant in cluster 1 than in cluster 3), *Agonus cataphractus* and *Solea solea* (more abundant in cluster 3 than in cluster 1) were responsible for this high dissimilarity. Cluster 1 and cluster 2 were very similar (dissimilarity 32%; R=0.47; p=0.001) since the three most dominant species were the same in both clusters (*E. vipera, L. limanda* and *C. reticulatus*).

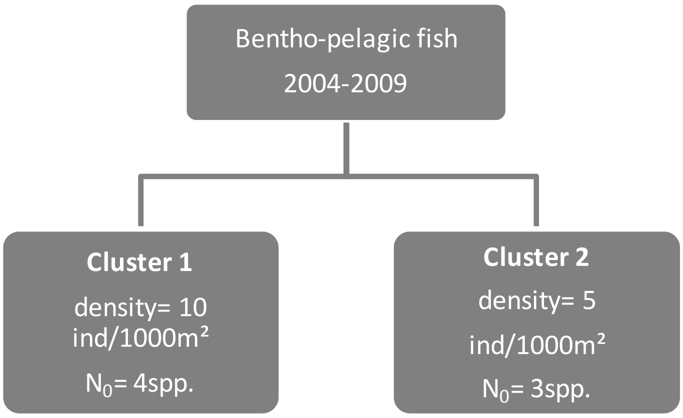
The results of the ANOSIM analysis showed that season was a highly significant (R=0.32; p=0.001) factor structuring the demersal fish dataset. In autumn, the community of cluster 2 was dominant. In spring, the three communities (cluster 1,2 and 3) occurred almost in equal proportions. The seasonal differences were expressed in the occurrence of several species; *E. vipera, Pomatoschistus* sp. and *C. lyra* were all more abundant in autumn than in spring.

There also was a significant difference (R=0.17; p=0.001) in species composition between the tops and the gullies, but this difference occurred only sporadically. In spring 2008, the communities on the top of the Bligh Bank and the Thorntonbank belonged to cluster 1, whereas the communities in the gullies of these banks could be assigned to cluster 2. In autumn 2008, the same pattern was observed on the western part of the Bligh Bank. In general, *E. vipera* was more abundant on the tops of the banks, *C. lyra* and *B. luteum* occurred more in the gullies.

The interannual differences in species composition were significant too (R=0.14; p=0.001), more specific, the differences between 2005 and 2008 (R=0.21; p=0.001). *E. vipera* and *C. lyra* were more abundant in 2008, whereas *B. luteum* and *Pomatoschistus* sp. were more abundant in 2005.

- Bentho-pelagic fish

A cluster analysis of the bentho-pelagic fish data revealed two distinct groups and four outliers at a similarity level of 25 % (Figure 5).



	R	p	dissimilarity (%)	contributing species
Cluster 1- Cluster 2	0.72	0.001	75	*T. trachurus, S. Sprattus, C. harengus*

Figure 5. TOP: Figure based on a fourth root transformed cluster analysis (Resemblance: Bray Curtis similarity; cut-off percentage 25%) of the bentho-pelagic fish data for the period 2004-2009; BOTTOM: Table comparing R-, p- and dissimilarity values between the two clusters and the species responsible for these dissimilarities. The densities and species numbers are average values.

- **Cluster 1** appeared especially in spring but also in autumn 2004, autumn 2006 and in autumn 2007 on the Thorntonbank and the Gootebank. Station 340 also belonged to this cluster -both in spring and in autumn- except for autumn 2005. The main species in this cluster were *Merlangius merlangus, Sprattus sprattus* and *Clupea harengus.* Cluster 1 was characterised by the highest average density (10 ind/1000m²) and the highest number of species (4 spp.).
- **Cluster 2** almost completely consisted of autumn samples. *Trachurus trachurus, M. merlangus* and *Trisopterus minutus* were the dominating species in this cluster. The average density (5 ind/1000m²) and the number of species (3 spp.) in this cluster was lower than in cluster 1.

SIMPER and ANOSIM analyses showed the two cluster to be significantly different (p=0.001), with a high R-value (0.72) and a high dissimilarity percentage (75%). This high dissimilarity was caused by *T. trachurus* (more abundant in cluster 2 than in cluster 1), *S. sprattus* and *C. harengus* (more abundant in cluster 1 than in cluster 2).

Season was a significantly structuring factor (R=0.49; p=0.001). The difference between spring and autumn was mainly caused by *T. trachurus*. This species was the most important species in autumn and was almost absent in spring. *S. sprattus* and *M. merlangus* were more abundant in spring than in autumn. The seasonal pattern was not consistent: in autumn, both clusters occurred across the years.

Differences in species composition between tops and gullies were minimal at the 25% similarity level (R=0.17; p=0.001). Within a cluster however, some variation could be detected. In autumn 2004, the tops of the eastern part of the Thorntonbank were characterised by a slightly different species composition than the gullies. *Trachurus trachurus* was the most responsible species for these differences, with a higher abundance on the tops than in the gullies. *Sprattus sprattus* was also more abundant on the tops than in the gullies. *Merlangius merlangus* showed a higher abundance in the gullies. Again, this difference between tops and gullies was not consistent since it did not occur in the other sandbank systems, seasons or years.

The interannual differences in species composition were not significant (R=0.03; p=0.09).

8.4.2. Impact evaluation of soft substratum epibenthos, demersal and bentho-pelagic fish

8.4.2.1. Thorntonbank

8.4.2.1.1. Density

General

The density data of epifauna, demersal fish and bentho-pelagic fish showed similar patterns across the seasons and the years (2005-2008-2009):

- There were seasonal differences in species composition, with spring characterised by shrimps (Caridea), flatfish (Pleuronectiformes) -mainly *L. Limanda*- and herring and sprat (Clupeiformes), and autumn characterised by echinoderms (Echinodermata) –mainly *O. albida*-, perciforms (Perciformes) -mainly *E. vipera* and *T. trachurus*- and flatfish -mainly *L. limanda*- (Figure 6).
- During the course of 2005-2008, spring densities dropped and partially recovered in 2009. Autumn densities on the other hand increased over the years. This pattern was similar for epibenthos and demersal fish, but was less consistent for bentho-pelagic fish.
- The high densities in the reference areas in 2009 were striking, however densities in reference areas were generally higher than in the impact and fringe areas. In the reference areas, the contribution of the Gadiformes slightly increased in 2009. The Gadiformes were less abundant in the impact areas compared to the other areas, especially in 2008 and 2009.

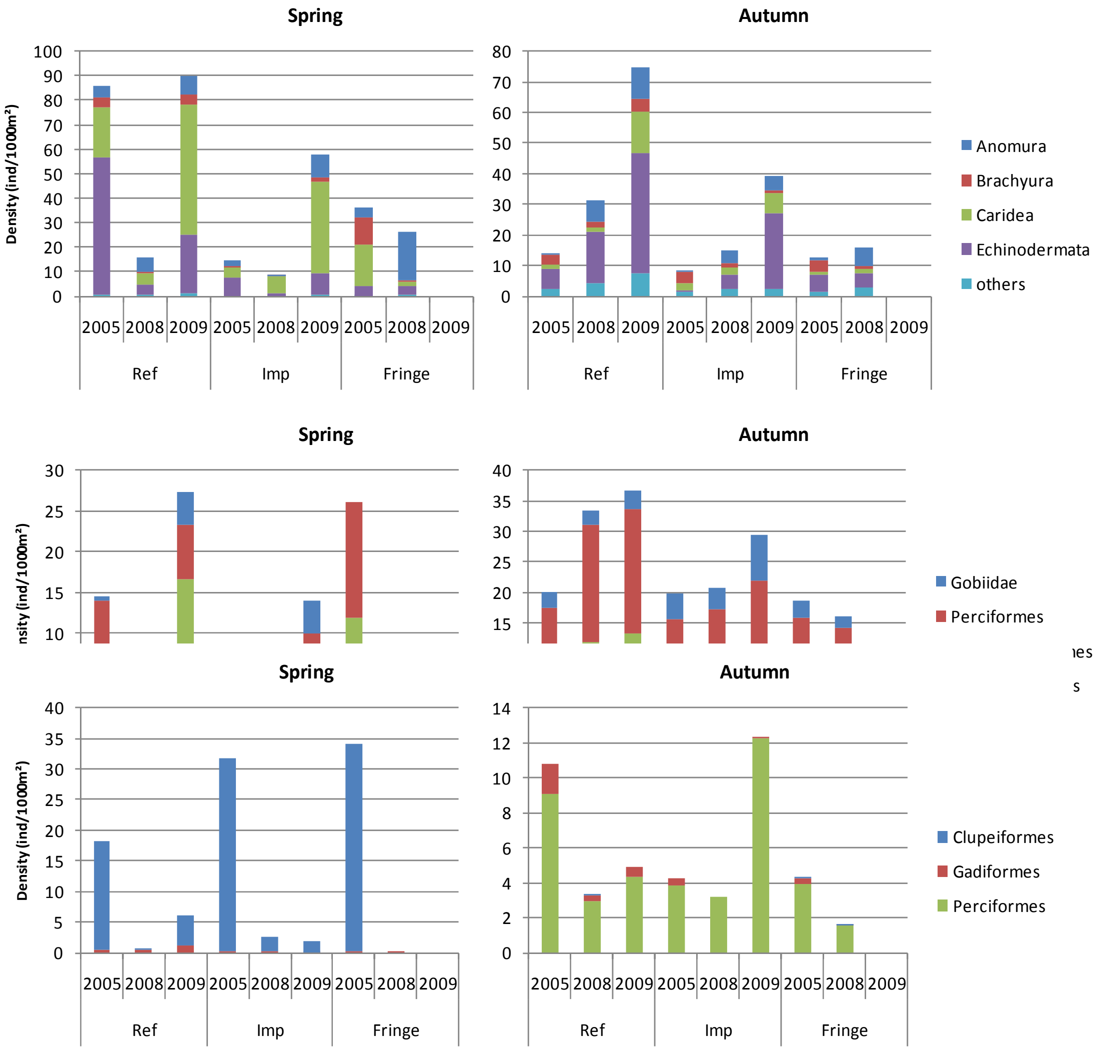


Figure 6. Average densities (ind/1000m²) of the main epibenthic (above), demersal fish (middle) and bentho-pelagic fish (under) groups of the Thorntonbank concession area with indication of the reference areas (Ref), the impact areas (Imp), the fringe areas (Fringe) and the years; no values for the fringe areas in 2009.

Important commercial species

- Brown shrimp (*Crangon crangon*)

The high density values in the reference and impact areas in spring 2009 were striking. In 2005 and 2009, spring densities were higher in the reference areas than in the impact areas and the fringe areas. In 2008, however, the impact areas showed slightly higher values than the reference and fringe areas. Autumn 2009 showed higher densities for the reference areas than the impact areas.

- Plaice (*Pleuronectes platessa*)

In spring 2009, the reference values were higher than the impact values, whereas in 2005 and 2008, the fringe values were higher than the reference and impact values. In autumn 2009 however, the values in the impact areas were higher than in the reference areas and in 2008, the values in the reference areas were higher than in the impact and fringe areas.

- Sole (*Solea solea)*

The reference values in spring 2005 and 2009 were much more elevated than the impact and fringe values. In autumn 2005 and 2009 however, the impact values were higher than the reference and fringe areas.

- Whiting (*Merlangius merlangus*)

Both in spring as in autumn, the reference areas showed higher values than the impact and fringe areas. The highest values were found for the reference areas in spring 2009.

8.4.2.1.2. Biomass (epibenthos only)

During the course of 2005-2008, spring biomass dropped and recovered in 2009. Analogous with the density data, shrimps (Caridea) were responsible for the biomass increase in spring 2009. The fringe areas revealed slightly higher spring values than the reference areas and the impact areas. Autumn showed the same pattern as in spring, except for the reference areas where the biomass values increased across the years. This biomass growth in the reference areas was mainly caused by the Echinodermata. Across the years, higher values were found in the reference areas than in the fringe and impact areas (Figure 7).

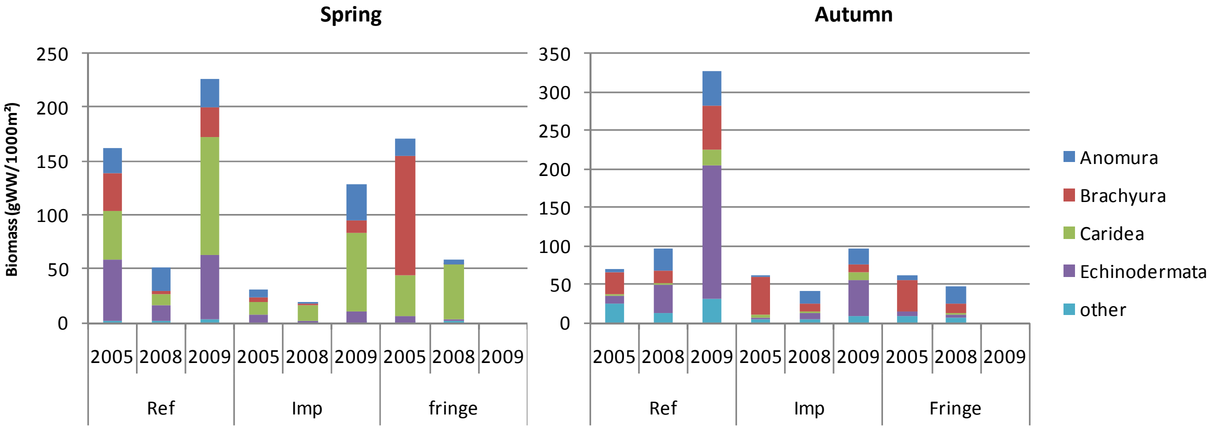


Figure 7. Average biomass (ind/1000m²) of the principal epibenthic species of the Thorntonbank concession area with indication of the reference areas (Ref), the impact areas (Imp), the fringe areas (Fringe) and the years (no values for the fringe areas in 2009).

8.4.2.1.3. Diversity

For epibenthos, the diversity indices N_0 and N_1 were comparable in the reference, impact and fringe areas. Only small interannual and interseasonal differences could be discerned. The average number of species (N_0) varied between 7 and 15 in spring and between 13 and 17 in autumn. The average Hill number N_1 fluctuated between 2.3 and 5.3 in spring and between 5.7 and 7.6 in autumn. Similar patterns were observed for the demersal fish; the average number of species was situated between 6 and 11 in spring and between 10 and 13 in autumn. The average values for N_1 varied between 2.5 and 6.3 in spring and between 5.0 and 7.2 in autumn. The interannual differences between spring samples, however, showed different patterns for the reference area (decrease 2005-2008, increase 2009) than for the impact area (increasing from 2005-2009).

The diversity values of bentho-pelagic fish in the reference areas were comparable with the values in the impact and fringe areas. The average number of species varied between 3 and 5 and N_1 fluctuated between 1.4 and 2.6. Slightly smaller N_1-values could be detected in the impact areas. The average number of species over the three areas ranged from 1 to 5 and the Hill index N_1 varied between 1.0 and 2.5.

8.4.2.1.4. Length-frequency distribution

For all fish species and for all shrimp and crab species, the mean total length was recorded and registered in the database. Additionally, the average length-frequency distribution was determined for four abundant demersal fish species (*Echiichthys vipera*, *Limanda Limanda*, *Solea solea* and *Callionymus reticulatus*), two abundant bentho-pelagic species (*Sprattus sprattus* and *Merlangius merlangus*) and two species of epifauna (*Crangon crangon* and *Liocarcinus holsatus*). No significant shifts in the length-frequency distribution of these species could be detected.

8.4.2.2. Bligh Bank

8.4.2.2.1. Density

General

The density data of epifauna, demersal fish and bentho-pelagic fish showed similar patterns across the seasons and the years (2005-2008-2009) (Figure 8):

- There were seasonal differences in species composition, with spring characterised by shrimps (Caridea), echinoderms (Echinodermata, mainly *Ophiura albida*), perciforms (Perciformes, mainly *Echiichthys vipera*), flatfish (Pleuronectiformes, mainly *Limanda Limanda*) and gadoids (Gadiformes, mainly *Merlangius merlangus*). The densities of herring and sprat were limited, except in the reference areas in 2009. Autumn samples were characterised by echinoderms (mainly *O. albida*), hermit crabs (Anomura) and perciforms (mainly *E. vipera* and *Trachurus trachurus*).
- Densities in reference areas and fringe areas were higher than in the impact areas for epibenthos and benthopelagic fish. For demersal fish, highest densities were consistently found inside the impact area.
- Between 2008 and 2009, densities generally increased, except in the impact area in autumn for epibenthos and demersal fish.

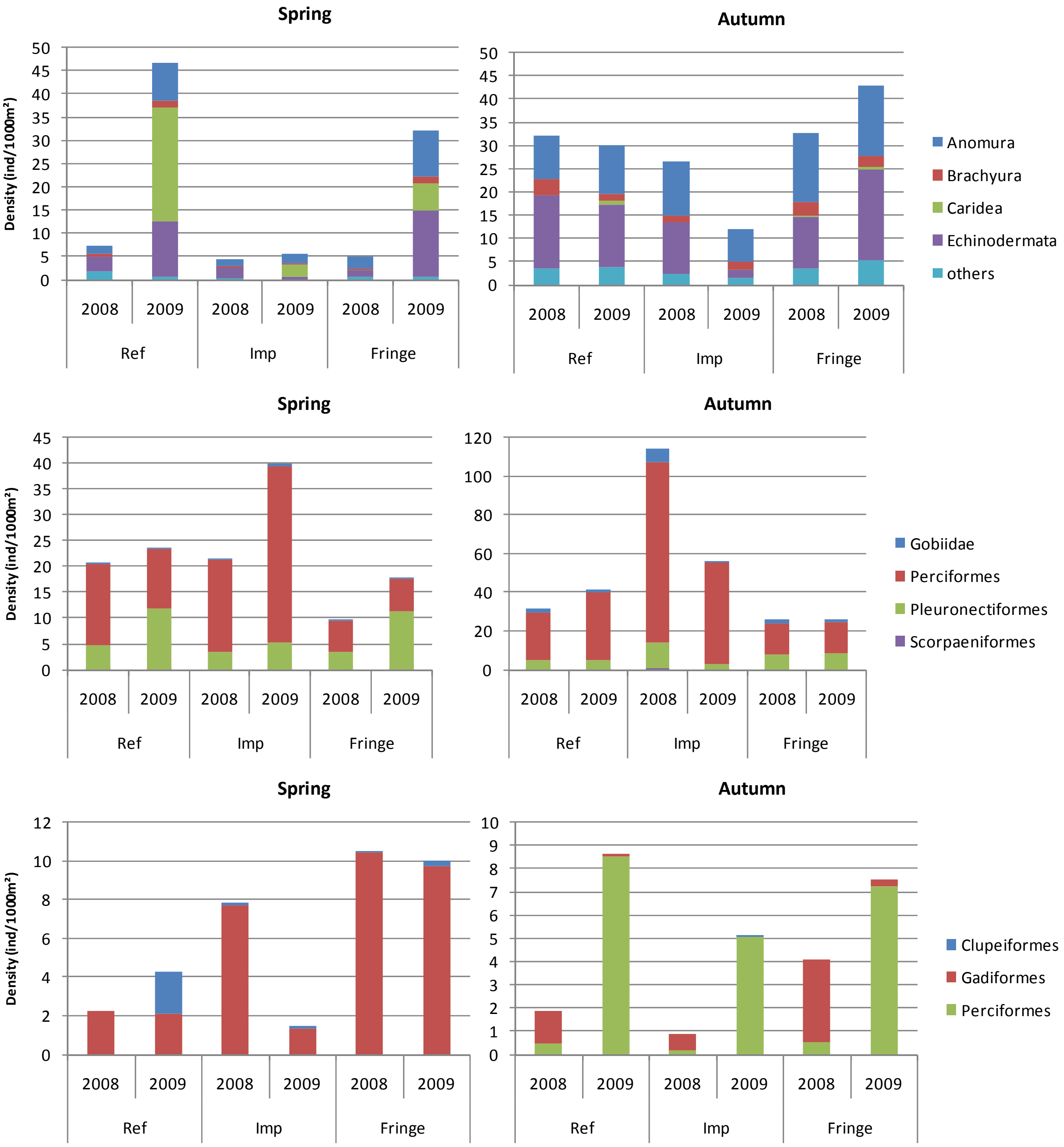


Figure 8. Average densities (ind/1000m²) of the principal epibenthic, demersal fish and bentho-pelagic fish groups of the Bligh Bank concession area with indication of the reference areas (Ref), the impact areas (Imp), the fringe areas (Fringe) and the years.

Important commercial species

- Brown shrimp (*Crangon crangon*)

In spring 2009, the density values in the reference areas were much higher than the values in the fringe and impact areas. The autumn values were rather low.

- Plaice (*Pleuronectes platessa)*

The highest densities were found in the impact area in autumn 2008, followed by the fringe and reference areas. In spring 2008, the density values were slightly higher in the reference areas. In spring 2009, the values were comparable.

- Sole (*Solea solea)*

In 2009, the fringe areas displayed the highest density values. In 2008 however, the values in the impact areas were the highest.

- Whiting (*Merlangius merlangus*)

Almost no whiting was present in autumn. The highest densities in spring were found in the fringe areas. In 2008, the impact areas also showed high values but in 2009, the values dropped to lower values than those in the reference areas.

8.4.2.2.2. Biomass (epibenthos only)

The spring biomass pattern displayed a more incoherent pattern than the density pattern; the values in the reference areas were limited to relatively high values in 2008 which were dominated by Bivalvia. This dominance of Bivalvia could mainly be attributed to the high biomass of *Ensis arcuatus* in station WBB03 (reference Bligh Bank). The impact areas had slightly higher values in 2008 than in 2009 while the fringe areas showed much higher values in 2009 than in 2008. The latter was due to an increase of Caridea, Anomura and Echinodermata. In autumn, the biomass pattern was similar to the density pattern (Figure 9).

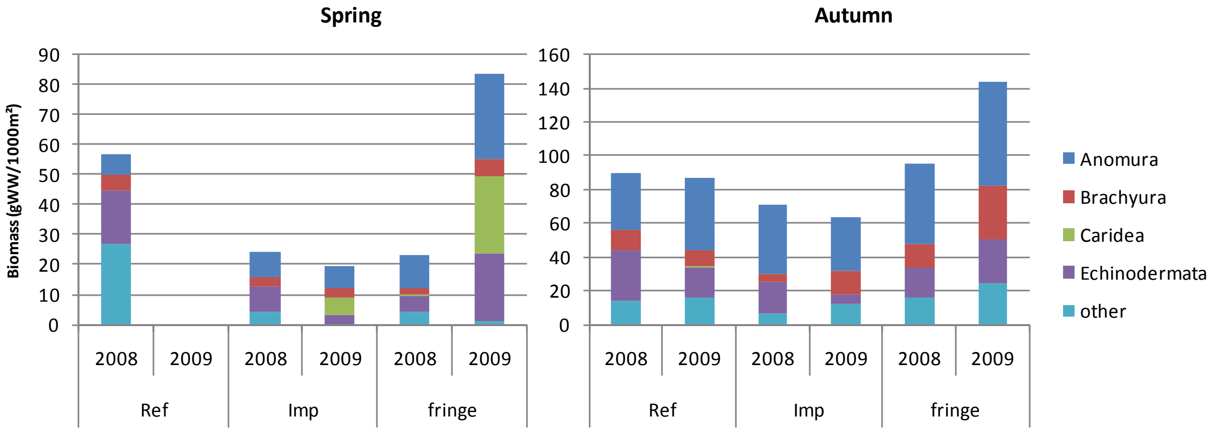


Figure 9. Average biomass (ind/1000m²) of the principal epibenthic species of the Bligh Bank concession area with indication of the reference areas (Ref), the impact areas (Imp), the fringe areas (Fringe) and the years (no values for the reference areas in spring 2009).

8.4.2.2.3. Diversity

There were no significant differences in diversity measures between the reference, impact and fringe areas, both in spring as in autumn for epibenthos. Interannual variation was limited. The number of species N_0 varied between 9 and 17 in spring and between 12 and 20 in autumn. The Hill diversity index N_1 fluctuated between 2.4 and 6.2 in spring and between 4.4 and 9.5 in autumn. The number of demersal fish species was comparable in the reference, impact and fringe areas. N_1 however, showed rather low values in the impact areas, especially in 2009. N_1 varied between 2.2 and 5.8 in spring and between 2.3 and 8.0 in autumn. The number of species ranged from 9 to 13 in spring and from 12 to 16 in autumn.

The diversity values for the bentho-pelagic fish showed no clear pattern or visible differences between the three distinct areas. Again, limited interannual variation was present. For example, 2009 was characterised by the lowest N_1-values, except for the reference and fringe areas in spring. N_1 fluctuated between 1.4 and 3.6 in spring and between 1.0 and 2.5 in autumn. The number of species varied between 2 and 6 in spring and between 2 and 4 in autumn.

8.4.2.2.4. Length-frequency distribution

For all fish species and for all shrimp and crab species, the mean total length was recorded and registered in the database. Additionally, the average length-frequency distribution was determined for four abundant demersal fish species (*Echiichthys vipera, Limanda Limanda, Solea solea* and *Callionymus reticulatus*), two abundant bentho-pelagic species (*Sprattus sprattus* and *Merlangius* *merlangus*) and two species of epifauna (*Crangon crangon* and *Liocarcinus holsatus*). Again, no significant shifts in the length-frequency distribution of these species could be detected.

8.4.3. Evaluating ILVO long term monitoring stations as reference stations

During the 2009 spring campaign, only a limited number of tracks were located in the gullies of the reference areas. However, a number of ILVO long term monitoring stations (sampled for other monitoring assignments by ILVO) was sampled in the vicinity of the wind farm concessions. In the current analysis, the suitability of these tracks as representatives for gullies in the vicinity of the concession zones was examined. It was hypothesized that stations 330 and 340 are similar to stations in the gullies around the Thorntonbank and Goote Bank. Stations 545 and 840 are offshore gully stations possibly resembling gully stations in the vicinity of the Bligh Bank and the Bank Zonder Naam.

The described analysis was based on a database containing data on epibenthos and demersal fish from all gully stations in the wind farm research area in the period 2005-2009. The gully stations WG1 and WG3 at the Goote Bank (sampled in 2005) were omitted since they proved to be unsuitable as references for the Thorntonbank gullies (De Maersschalck *et al*, 2006).

An exploratory analysis showed that samples were primarily separated per season, so the subsequent explorations were done separately for spring samples and autumn samples. Interannual variation was also considerable, especially for the density and biomass values for the epibenthos in spring. We compared seasonally observed values within the Thorntonbank and Bligh Bank gully stations with values observed at stations 330, 340, 545 and 840.

8.4.3.1. Density

The bar charts (Figure 10) clearly indicated that station 340 cannot be considered representative for the gullies at the Thorntonbank, since densities were a lot higher at that station (except in spring 2009, when equally high values were observed in the Thorntonbank gullies). Station 330 corresponded quite well with the Thorntonbank gullies concerning epibenthos and fish densities, but fish densities were low in autumn of 2005 and 2009. Station 545 showed some similarity with Thorntonbank gullies concerning fish densities, but epibenthos densities were significantly lower at this station. Station 840 showed the highest similarity with the Bligh Bank gullies, but densities were consistently lower.

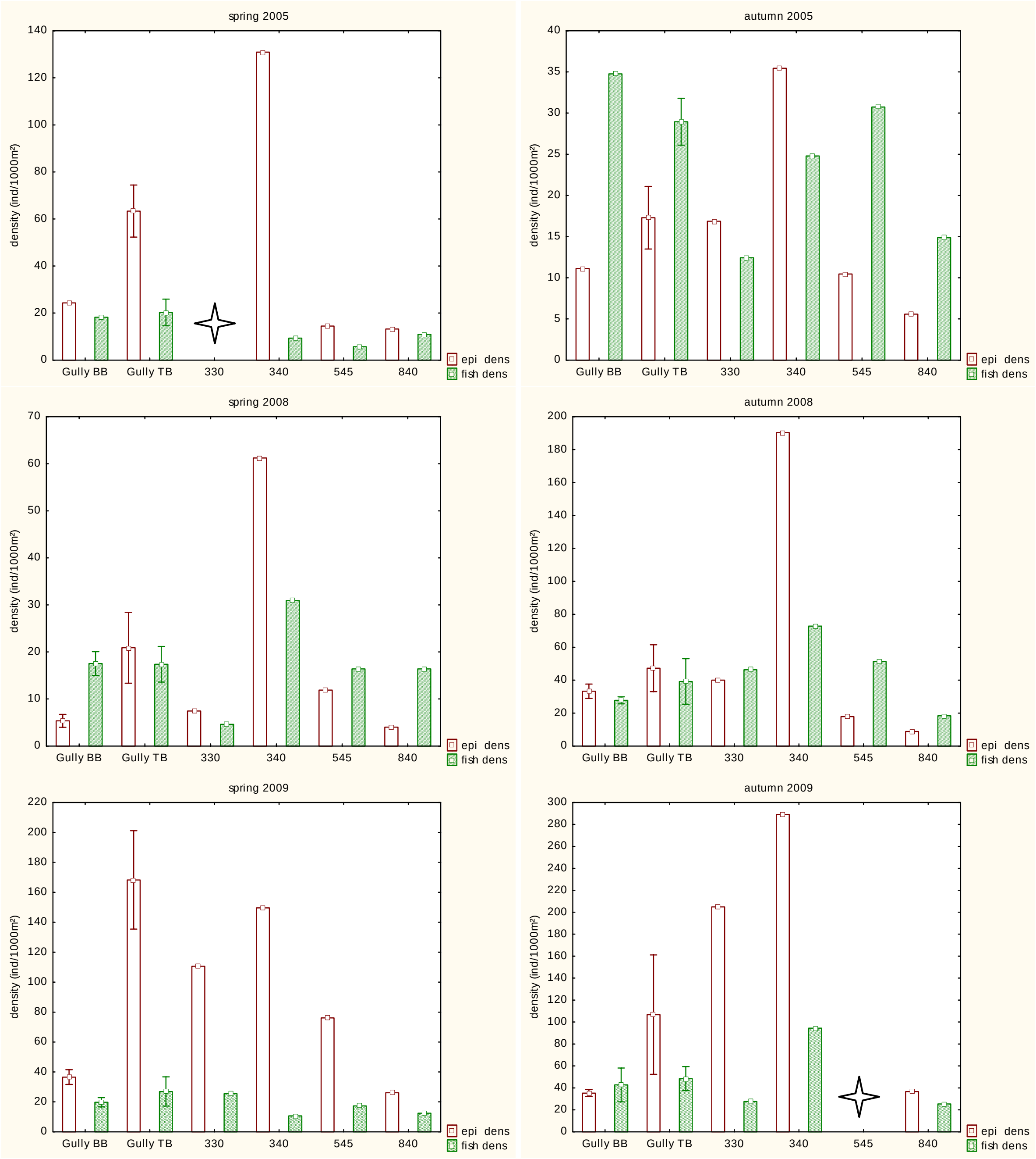


Figure 10 Bar charts of density (ind/1000m²) of epibenthos and demersal fish per season and per year, comparing Bligh Bank gullies and Thorntonbank gullies with ILVO long term monitoring stations 330, 340, 545 and 840 (✧ = no samples).

8.4.3.2. Biomass

The bar charts (Figure 11) based on the biomass data (for epibenthos only), clearly showed that station 340 cannot represent the Thorntonbank gullies since it is characterised by higher biomass values (except in spring 2009 when lower values were observed). There were very few similarities between station 545 and the Thorntonbank gullies but station 330 matched better with the gullies at the Thorntonbank (except in spring 2005, when no data were available and in autumn 2009, when biomass values were much higher). Station 545 and the Bligh Bank gullies also showed some resemblances. Station 840, however, corresponded better with the gullies at the Bligh Bank, especially in spring.

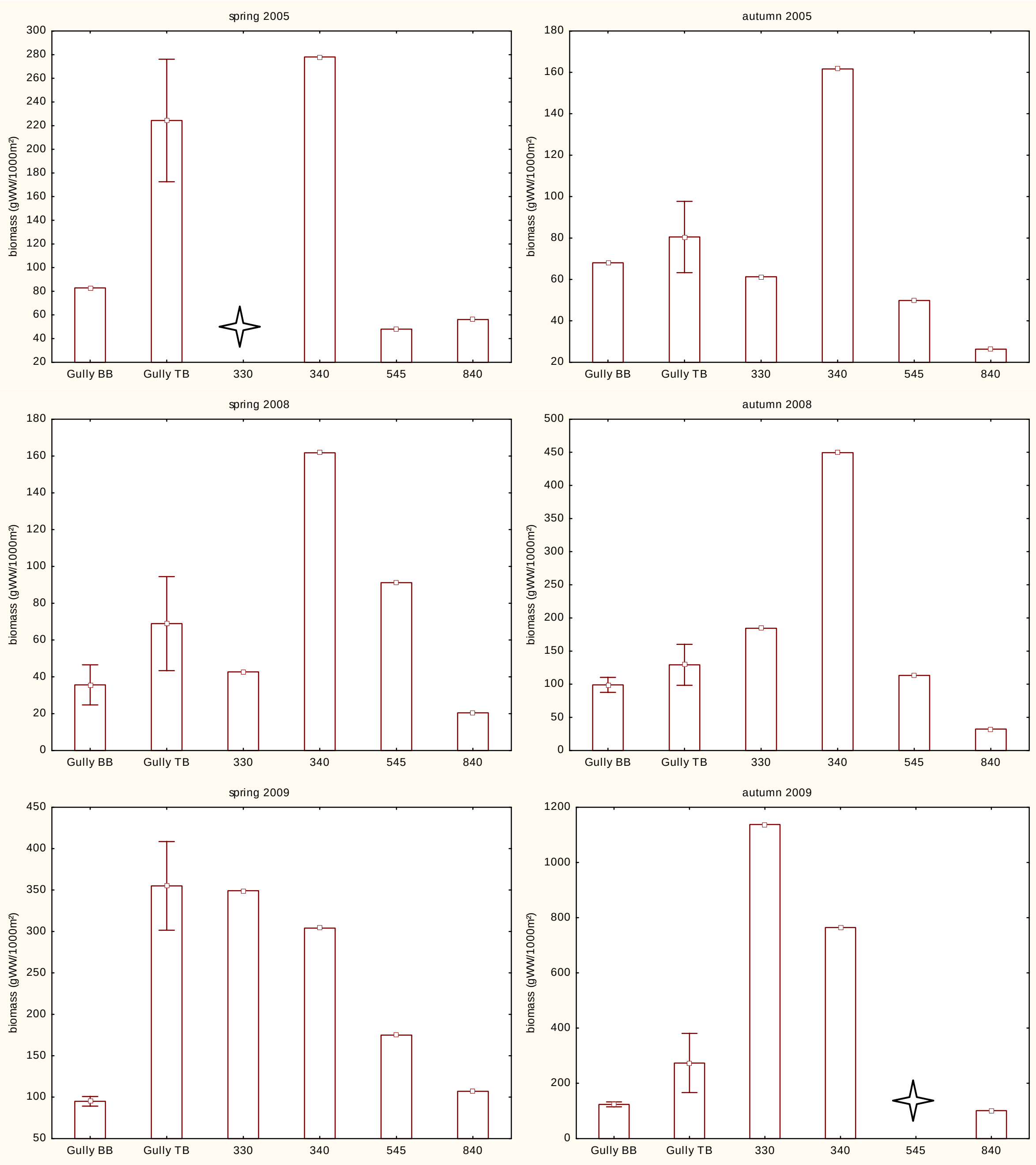


Figure 11. Bar charts of biomass (gWW/1000m²) of epibenthos per season and per year, comparing Bligh Bank gullies and Thorntonbank gullies with general stations 330, 340, 545 and 840 (✧ = no samples).

8.4.3.3. Diversity

The bar charts (Figure 12) based on the diversity indices N_0 and N_1 show that station 330 and station 340 were quite similar with the gullies at the Thorntonbank and that station 545 and the Thorntonbank gullies showed little resemblance. The N_0-values of station 840 corresponded relatively well with the gullies at the Bligh Bank. The similarities between station 545 and the gullies at the Bligh Bank were more limited.

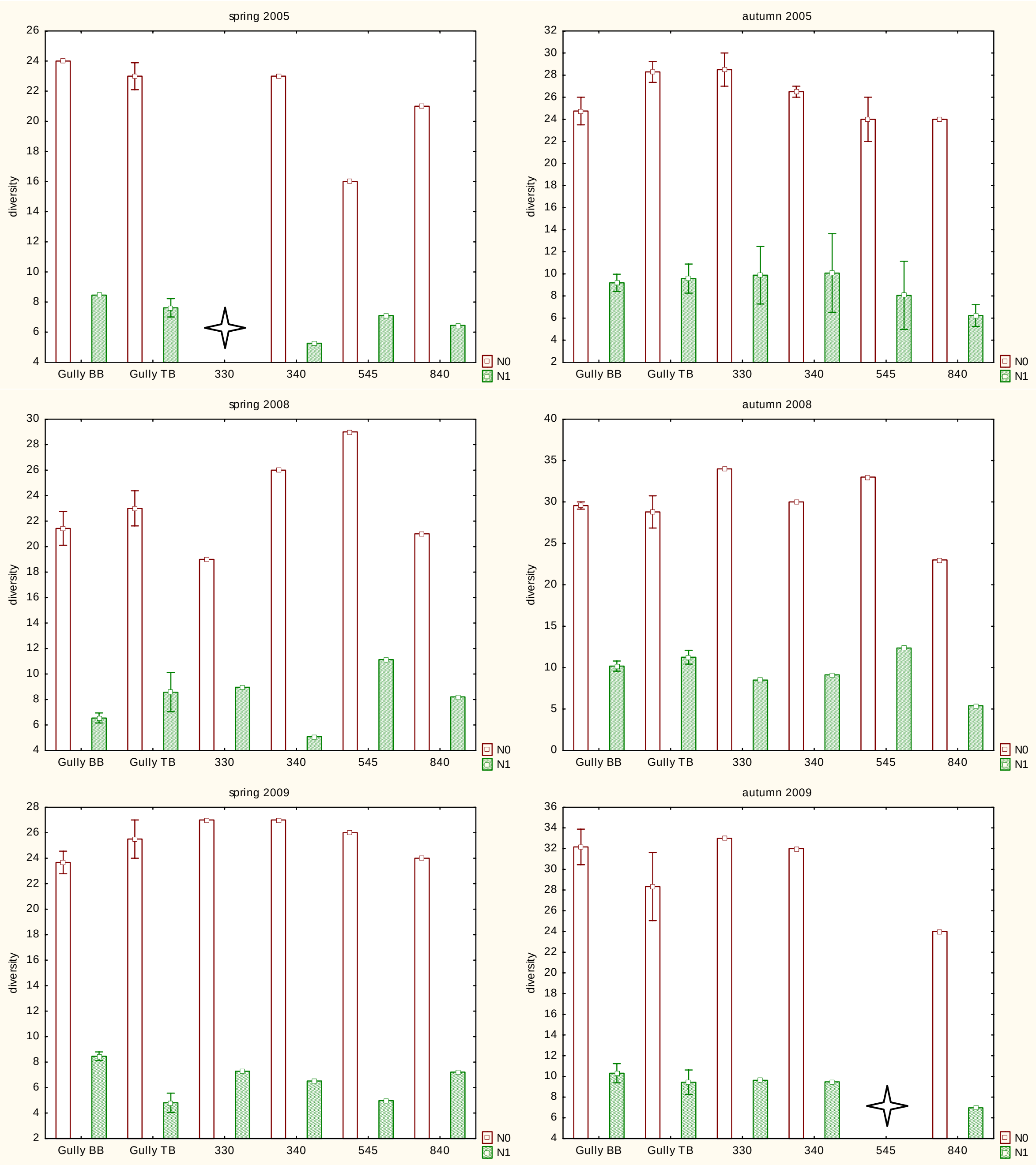


Figure 12. Bar charts of diversity indices N_0 (number of species) and N_1 (bits) per season and per year, comparing Bligh Bank gullies and Thorntonbank gullies with general stations 330, 340, 545 and 840 (✧ = no samples).

8.5. Discussion

8.5.1. Community structure at the wind farm area

Epibenthos and demersal fish have been monitored for decades in the BPNS. A detailed analysis of community structure and natural variability within these ecosystem components revealed the existence of 3 coastal communities and 2 offshore communities (Vandendriessche *et al*, in prep). Fifty-five percent of this biological variation could be explained by the variables depth, salinity, temperature, median grain size of the sand fraction and mud content. In other words, both site specific and temporal conditions were identified as important structuring factors. The sampling stations of the wind farm area are all situated within the offshore area. Within the concession area (200 km²), the composition of epifauna and demersal fish showed a high similarity (≈55%). This is similar to the findings in a 340 km² study area in the German Bight (Hinz *et al,* 2004). The similarity within the bentho-pelagic species assemblage was a lot lower (≈20%), which could be expected based on the aggregation behaviour of the species. The variability of the three ecosystem components was mainly determined by geographical and seasonal patterns on the level of:

- Sandbank system: Stations on and in the vicinity of the Gootebank showed differences with the Thorntonbank and Bligh Bank during both seasons. These differences were more outspoken for epifauna (≈46% dissimilarity with other samples) than for demersal fish (≈38% dissimilarity with other samples). Additionally, the most offshore situated stations showed substantial differences from the rest of the area during several sampling campaigns. Finally, the species assemblages on the Bank Zonder Naam did not always correspond with the assemblages on the Thorntonbank and the Bligh Bank, which is an important result in the light of the future monitoring of this area.
- Sampling season: Seasonality is the most important structuring factor for bentho-pelagic and demersal fish within the wind farm concession area, while this factor is subordinate to spatial differences for epibenthos. The seasonal separation, however, is not consistent over the years, which can be attributed to occasional discrepancies between the timing of the sampling and the onset of spring or autumn conditions.
- Sandbank topography: During several sampling occasions, differences were observed between sandbank top samples and gully samples for all three ecosystem components. These differences, however, were not consistent over the years, seasons and sandbank systems. Based on the available data, it can be hypothesized that the observed differences result from a time lag in seasonal shifts depending on depth.

While seasonality influences the entire wind farm concession area at a similar level, differences in coastal influences, sedimentology and depth cause measurable differences between and within sandbank systems. Although these differences are quite minor on a BPNS scale, they may significantly influence the detection level of impacts at a local scale. The incorporation of this knowledge in the BACI design of the impact analysis, and hence in the selection of impact and reference stations, will underpin a sound interpretation of the detection of any change within the area.

Other than a support tool for the analyses in a BACI design, community analyses (cf. section 8.4.1) can by themselves provide an indication of impact by signalling shifts in species composition (Wilhelmsson *et al*, 2006). Based on the situation in 2009, however, such signals were not observed since all impact stations on the Thorntonbank and Bligh Bank harboured highly similar species assemblages as neighbouring sites for both seasons.

8.5.2. Status of soft substratum epibenthos, demersal and bentho-pelagic fish

Since the dispersion patterns and the extent of the mobility of truly demersal and bentho-pelagic fish differ substantially, it was advised in Vandendriessche *et al* (2009) to adapt the analyses accordingly. Excluding bentho-pelagic fish was not considered since aggregation effects in the vicinity of turbines can be expected (Grift *et al*, 2004). Hence, truly demersal fish and bentho-pelagic fish were treated separately in the analyses. The condition of demersal fish, bentho-pelagic fish and epibenthos was assessed based on the parameters density, diversity, biomass (epibenthos only) and length-frequency for impact stations, reference stations and fringe stations. The distinction between fringe and reference stations was made because an increase in fishery activities is expected just outside the borders of the concession areas. Concerning the Thorntonbank, the situation in 2009 (T2) was compared with the situations in 2008 (T1) and 2005 (T0). For the Bligh Bank, a comparison was made between the situation in 2009 (T1) and 2008 (T0).

The results concerning density, diversity, biomass and length-frequency distributions confirmed the importance of seasonality and small-scale variability, as was indicated by the analysis of the species assemblages (section 8.4.1).

Generally, density and biomass values for the epibenthos were higher in the reference and fringe areas compared to the impact areas on both the Thorntonbank and Bligh Bank. The same pattern was noted for demersal fish on the Thorntonbank, while on the contrary in the Bligh Bank area highest densities of demersal fish were consistently found in the impact area both in spring and autumn 2009. As the above described patterns for epibenthos and demersal fish were also observed in the pre-construction assessments (T0 analyses, 2005 and 2008) for both windmill areas, this cannot be attributed to the construction activities. These patterns should rather be considered as ”background” variability, related to the topographic differences between sandbank tops (impact area) and gullies (fringes and most reference stations). For bentho-pelagic fish species this pattern was less clear, mainly due to the aggregation behaviour of these species.

It should be stated that the current analyses were based on a straightforward and logical subdivision of the samples in impact samples, reference samples and fringe samples. Although this approach corresponds with the aims of the impact assessment, the local variability between and within sandbank systems (sandbank tops and gullies) is hard to incorporate. Consequently, we will again increase the level of detail during future analyses.

Although interannual differences were not a major structuring factor in species composition, density and biomass showed a high variability between the different years. Very low densities and biomass values were observed at most stations on and around the Thorntonbank and Bligh Bank in 2008, especially in spring. In 2009, density and biomass values substantially increased in most stations both in spring and autumn. However, that was not the case in the impact area on the Bligh Bank in autumn 2009, neither for epibenthos or demersal fish. The decrease (autumn 2009 vs. autumn 2008) in the Bligh Bank impact area – in contrast to the increase observed in other areas - might be attributed to the pile driving activities and other construction works which started on the Bligh Bank several weeks prior to the autumn sampling campaign.

In the impact area on the Thorntonbank, some alterations within the epibenthos and fish assemblages could be observed; higher densities of horse mackerel (*T. trachurus*, Perciformes) in autumn 2009 and lower densities of sole (*S. solea,* Pleuronectiformes) in spring 2009, compared to the reference areas around the Thorntonbank, which might be expressions of the attraction effect of man-made constructions on the seabed (=reef-effect) (Petersen & Malm, 2006; Wilhelmsson *et al*, 2006) and of their influence on larger demersal fish species as described by Grove *et al* (1991), respectively. Such attraction effects have already been described for whiting in the North Hoyle wind park (UK) by May (2005). The effects on demersal fish species, such as sole, may result from competition with newly arriving species or from a change in food supply consisting of soft-bottom prey items. This is of course still hypothetical, so the persistence of these observations will be closely watched during future monitoring activities.

For the measures diversity and length-frequency, no signals of impact of the windmill construction and exploitation were observed.

Since only six turbines were present on the Thorntonbank during both 2009 campaigns and since construction activities in the Bligh bank concession zone had only just been initiated at the time of the autumn campaign, a limited number of impact indications was expected either for epibenthos, demersal fish or bentho-pelagic fish. Hence, the 2009 data can be considered as an extended baseline study. By the spring campaign of 2010, the total number of turbines in both wind farms will have increased to 62. This will probably result in measurable changes in the near future compared to the baseline studies of 2005, 2008 and 2009.

8.5.3. Evaluating ILVO monitoring stations as reference stations

During the 2009 spring campaign, the number of tracks in the gullies in the reference areas was very limited. However, several standard monitoring stations (sampled during other monitoring assignments by ILVO) were sampled in the vicinity of the wind farm concessions. In the current analysis, the suitability of these stations as representatives for gullies in the vicinity of the concession zones was examined. It was hypothesized that stations 330 and 340 are similar to stations in the gullies around the Thorntonbank and Goote Bank, and that offshore stations 545 and 840 resemble gully stations in the vicinity of the Bligh Bank and the Bank Zonder Naam. Based on comparisons of the parameters density, biomass, diversity and species composition, the following conclusions were formulated:

1. Station 330 can be used as proxy for the Thorntonbank gullies for all tested parameters
2. Station 340 is rejected as reference since density, biomass and species composition differed substantially from all sampled gully stations in the wind farm concession area. The unsuitability of station 340 was expected since this station is situated in a transitional zone between coastal and offshore conditions with different communities, in contrast to the other stations where offshore conditions were consistent (Vandendriessche *et al*, in prep).
3. Station 545 showed some similarities with gullies in the wind farm concession area, especially concerning fish density, epibenthic biomass and general species composition, but these similarities were insufficient to incorporate the station in the monitoring program of wind farms
4. Station 840 showed most similarity with the Bligh Bank gullies but density values of epibenthos and demersal fish were consistently lower. This should be taken into account when using this station as proxy for the situation in the Bligh Bank gullies.

This analysis illustrates the difficulties we usually observe when comparing different sand bank systems on the BPNS. Again, this shows the urgent need to assign “dedicated” reference areas on every sandbank system where anthropogenic impacts occur. Additionally, the evaluation of suitable reference areas remains an important aspect of impact monitoring since selected reference zones or stations can lose their value during the course of a monitoring program. For example, station WT1 has become less relevant as reference due to increased sand extraction activities in the near vicinity of this station during recent years. In such a case, data of ‘backup’ reference stations such as station 330 can be of high value. In the future, we will focus on the reference stations that are situated on the same sandbank system as the impact stations. The ILVO long term monitoring stations, which are situated on other sandbank systems, are valuable as back-up.

8.6. Conclusions

A detailed community analysis at the wind farm concession area revealed the natural variability within this area, in perspective of the overall variability within the BPNS. The variability of the bentho-pelagic and demersal fish communities was mainly determined by seasonal patterns. The epibenthic community was particularly structured by geographical factors such as sandbank system and topography. In addition to a support tool for the analyses in a BACI design, community analyses can provide an indication of impact by signalling shifts in species composition. Based on the situation in 2009, no such signals were observed.

The condition of demersal fish, bentho-pelagic fish and epibenthos can also give an indication of the impact of the windmills. Density and biomass values for epibenthos were higher in the reference and fringe areas than in the impact areas on the Thorntonbank and Bligh Bank. For demersal fish, the same pattern was visible, except on the Bligh Bank, where higher values were found in the impact areas. Concerning interannual differences, the density and biomass values were higher in 2009 than in 2008, except for the impact area on the Bligh Bank where a decrease was observed. This could be attributed to the pile driving activities and other construction works which started on the Bligh Bank several weeks prior to the autumn sampling campaign. In the impact area of the Thorntonbank, some alterations within the fish assemblages could be noticed, more precisely for sole and horse mackerel. This might be an expression of the attraction effect of the windmills, competition with newly arriving species or a change in food supply. Since only six turbines were present on the Thorntonbank during the both 2009 campaigns and since construction activities on the Bligh Bank had just been initiated at the time of the autumn campaigns, little impact could be noticed. Hence, the 2009 data can be considered as an extended baseline study.

A number of ILVO long term monitoring stations was sampled to examine the suitability of those stations as representatives for the gullies in the vicinity of the concession zones. Station 330 is the only station that can be used as proxy for the Thorntonbank gullies. If reference stations in the windmill area become less relevant, data of station 330 can be of high value as 'backup'.

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Chapter 9. Monitoring seabird displacement effects by offshore wind farms: a modeling approach

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Photo INBO

Abstract

In 2009, we refined the statistical set-up for the assessment of displacement effects on seabirds by wind farms in the Belgian part of the North Sea, more precisely at the Thorntonbank and Bligh Bank. The observed seabird densities were modelled through quasi-likelihood estimation. The resulting models allowed to test for the difference in seabird occurrence between control and impact areas during the reference period.

In case of Northern gannet, Sandwich tern, Common guillemot and Razorbill at the Thorntonbank, as well as for Northern gannet, Black-legged kittiwake and Common guillemot at the Bligh Bank, the delineated control area held highly similar densities compared to the impact area. This of course makes a good base for future BACI-comparison. Moreover, this modelling process is the first crucial step towards a power analysis, which will give insight in the probability of being able to statistically detect specified changes in bird numbers.

In 2008, the first six turbines were installed at the Thorntonbank wind farm site. As expected, we were not yet able to discern any displacement effects. However, there are still about two hundred turbines to be installed at the Thorntonbank (C-Power), Bligh Bank (Belwind) and Bank Zonder naam (Eldepasco), and as such it is too soon to draw any conclusions.

Samenvatting

Het voorbije jaar hebben we de statistische aanpak voor de monitoring van allocatie-effecten door offshore windmolenparken op zeevogels grondig herzien. De waargenomen dichtheden werden gemodelleerd aan de hand van ‘quasi-likelihood estimation’. Deze modellen laten toe om het verschil in waargenomen dichtheden tussen verschillende gebieden (referentie- en impactgebied) en verschillende periodes (voor en na de impact) statistisch te toetsen.

In de eerste plaats werd de geschiktheid van de referentiegebieden geëvalueerd op basis van een vergelijking van de gemodelleerde dichtheden in de referentieperiode. Zo blijkt dat het impact- en referentiegebied op de Thorntonbank sterk gelijkende densiteiten van Jan van Gent, Grote stern, Zeekoet en Alk herbergden. Hetzelfde kan besloten worden voor de dichtheden van Jan van Gent, Drieteenmeeuw en Zeekoet in het referentie- en impactgebied op de Bligh bank. Dit is een stevige basis voor de toekomstige BACI-monitoring, en bovendien is de modellering de eerste stap richting een power-analyse. De resultaten van deze analyse zullen ons inzicht geven in de kans dat vooropgestelde veranderingen in de aanwezigheid van zeevogels statistisch worden opgemerkt.

In 2008 werden de eerste zes turbines gebouwd op de Thorntonbank-site. Zoals verwacht werden voor de onderzochte soorten nog geen verplaatsingseffecten gedetecteerd. Uiteraard dient voor ogen gehouden te worden dat er nog ongeveer 200 turbines moeten gebouwd worden op de Thorntonbank (C-Power), Bligh Bank (Belwind) en de Bank zonder naam (Eldepasco), en het aldus nog veel te vroeg is voor uitspraken.

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: during autumn and spring, an estimated number of no less than 1.0 to 1.3 million seabirds annually migrate through this ‘migration bottleneck’ (Stienen *et al.* 2007).

The near future will see large scale exploitation of offshore wind energy, and a large concession zone comprising almost 10% of the waters under Belgian jurisdiction is reserved for wind farming.

Inevitably, this will affect the local seabird community in a number of ways: 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; …).

The goal of this monitoring study is 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 farm, while others may be attracted to it due to an increase in food availability and roosting possibilities. In April 2008, six wind turbines were installed at the Thorntonbank, and at the Bligh Bank, construction works commenced in September 2009.

9.2. Material & Methods

9.2.1. Reference areas

The study is based on a Before-After Control-Impact comparison. Vanermen *et al.* (2006) and Vanermen & Stienen (2009) delineated control areas for both future wind farms based on the comparability of numbers and seasonality of seabirds occurring. This set-up however was slightly changed, and in case of the Thorntonbank this was based on the following considerations (see Figure 1):

- equal size & shape of control and impact area
- control area fully located within the former control area (Vanermen *et al.* 2006)
- maximum overlap with the monitoring routes sailed during the period 2005-2007 (see Figure 2)
- distance of 0.8 nautical miles between reference and control area, equalling half the mean distance sailed per ten-minute count (the geographical error)

These same considerations were taken into account for the delineation of the control area at the Bligh Bank (see Figure 1). However, since a large part of the impact area is situated on the Dutch part of the North Sea (where no counts of seabirds are available nor planned), the control area there is smaller than the impact area. The surface of the control area does equal that of the part of the impact area lying within the BPNS (see Figure 1).

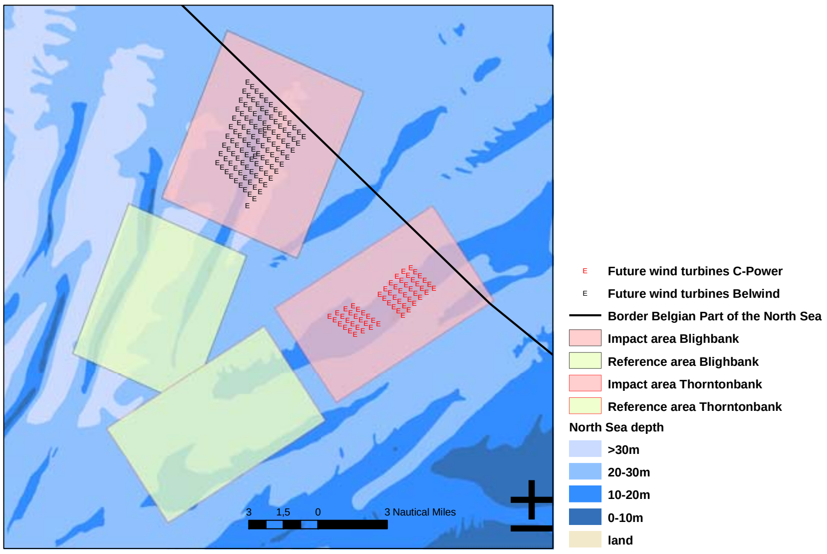

Figure 1. Control and impact areas for both future wind farms at the Thorntonbank and Bligh Bank.

9.2.2. Ship-based seabird counts

From 2005 onwards, intensive monitoring took place through ship-based seabird counts. 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'). The results of these observations are grouped in periods of ten minutes, resulting in so-called 'ten-minute counts', defined by a unique 'position key'. Taking the travelled distance into account, the count results can be transformed to seabird densities with specified X- and Y-coordinates (at the geographical middle point of the track sailed during the ten-minute count).

The resulting database is characterised by huge variation in counted numbers, with far more zero than positive counts, and proportionally very high numbers at few locations. Hence, to increase the statistical power of the data, the variance should be lowered. This can be done by grouping and averaging the measured densities in space or in time, at a scale at which important ecological information does not get lost.

In close dialogue with the team 'Biometrics and Quality Assurance' of the Research Institute for Nature & Forest (INBO), a new approach was worked out, in which our count results were lumped per area (control/impact) and per month per year. Furthermore, only those ten-minute counts performed during days on which both the impact and reference area were visited are included in the analysis. This way, we tried to minimize variations due to short-term temporal changes in seabird abundance and due to strong day-to-day changes in weather and observation conditions.

9.2.3. Monitoring species

For the Thorntonbank study area, six species were selected for future monitoring by Vanermen & Stienen (2009). Northern gannet (*Morus bassanus*), Common guillemot (*Uria aalge*) and Razorbill (*Alca torda*) are widely distributed on the BPNS and occur commonly in the study area. The impact area is not of particular importance to these birds, but their common occurrence does make them rewarding species to monitor. In contrast, Little gull (*Larus minutus*), Sandwich tern (*Sterna sandvicensis*) & Common tern (*Sterna hirundo*) are rather scarce but highly protected species, aggregating in the impact area during at least part of the year. Importantly, all six species show negligible association with fishing vessels, so distribution patterns reflect natural preferences rather than distribution of fishing activity.

An analysis of the bird community at the Bligh Bank revealed that Northern gannet, Lesser black-backed gull (*Larus fuscus*), Black-legged kittiwake (*Rissa tridactyla*) and Common guillemot all occur in relatively high densities (Vanermen & Stienen, 2009). Unfortunately, the Lesser black-backed gull shows strong association with fishing vessels, making this a highly unreliable monitoring species within a BACI-framework. Analogous to the selection procedure of monitoring species for the Thorntonbank wind farm area (see also Vanermen & Stienen, 2009), the Lesser black-backed gull is therefore not included in the analysis. Instead we take Razorbill in consideration, despite its fairly low densities during the reference period.

Apart from these common species, there were indications that the area holds important concentrations of Great skua (*Stercorarius skua*) and Little gull during at least part of the year. High proportions of their relatively small populations migrate annually through the BPNS and therefore receive extra attention.

9.2.4. Monitoring scheme and count effort

Since 1993, the INBO carries out standardised seabird counts at the BPNS. From 2002 onwards, this was performed on a monthly basis 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 a true 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 2).

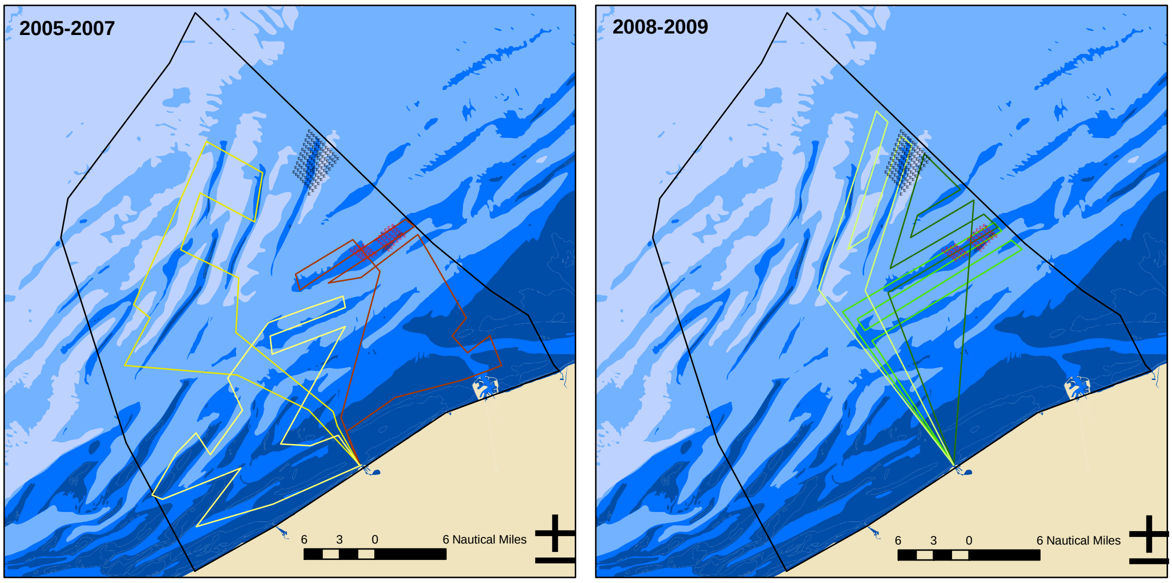

Figure 2. Monitoring routes sailed during the periods 2005-2007 (left) and 2008-2009 (right), with indication of the (future) location of wind turbines of C-Power and Belwind.

Figure 3 and Figure 4 display the count effort per year in the impact and control areas at both wind farm sites. Hereby, count effort is expressed as the number of square kilometres of transect that was counted (number of kilometres sailed multiplied by the width of the transect, equalling 0.3 km).

Only in 2005, the Thorntonbank study area was visited in all 12 months, but monitoring was also very intensive in the impact period 2008-2009. Outside those years, visits were quite irregular. The reference dataset holds 110 count records, and 38 records were collected after installation of the first six turbines.

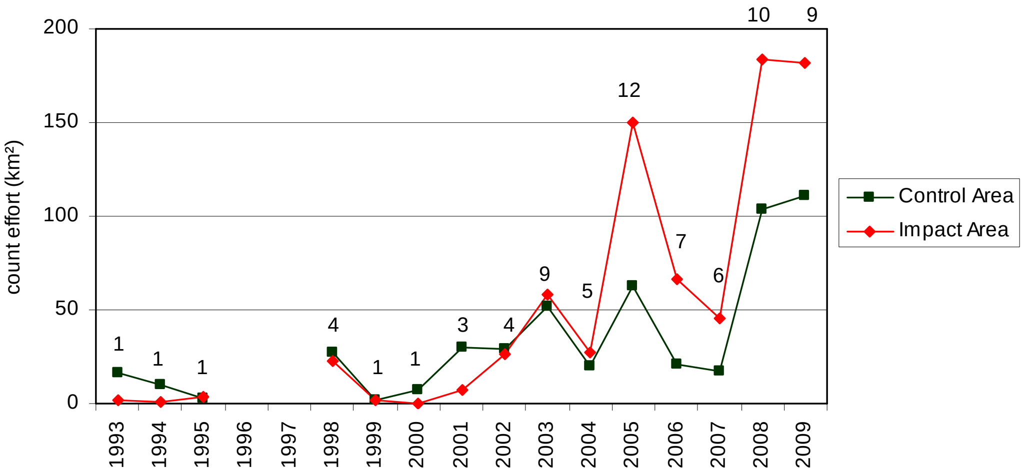

Figure 3. Count effort in the Thorntonbank study area, expressed as the number of km² of transect monitored (the labels refer to the number of months during which monitoring took place).

The Bligh Bank wind farm area was monitored intensively from April 2008 to September 2009, while before that, visits were irregular (Figure 4). The reference dataset holds 116 count records (58 per area), with 4 more counts after the first foundations were installed in September 2009.

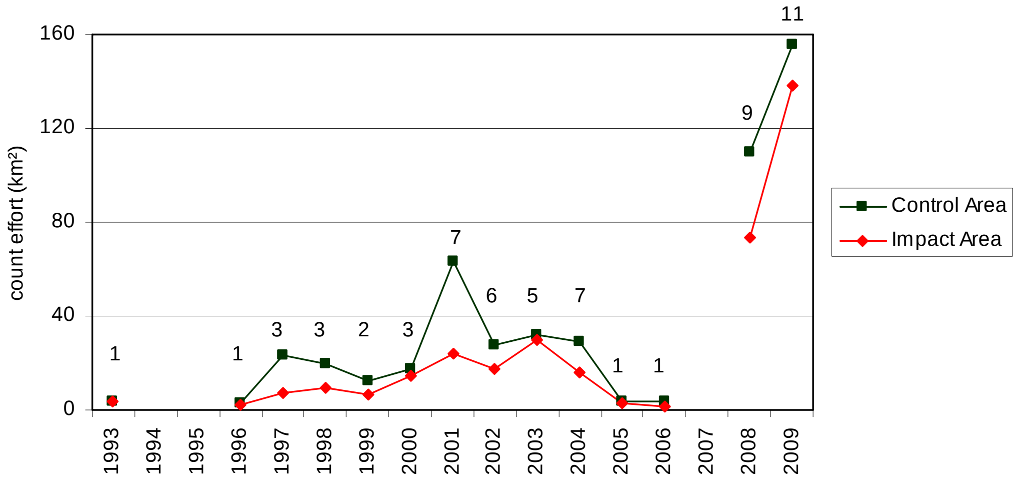

Figure 4. Count effort in the Bligh Bank study area, expressed as the number of km² of transect monitored (the labels refer to the number of months during which monitoring took place).

9.2.5. Data-analysis: modelling

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 (also noted as μ), 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 generally respond to a poisson-distribution. Seabirds however often show aggregated distribution, and we corrected for over-dispersion by applying a quasi-poisson model (quasi-likelihood estimation with a logarithmic link-function) (McCullagh & Nelder 1989, McDonald *et al.* 2000).

Whether counts were performed in the control / impact area or before / after the impact, is defined in the models by the factor variables 'CI' (Control-Impact) & 'BA' (Before-After). Since seabird occurrence is subject to large seasonal fluctuations, we included 'month' as a continuous variable. An elegant method to describe seasonal density patterns with a continuous variable is to use a sinusoidal curve, which can be written as the linear sum of a sine and a cosine term (Onkelinx *et al.* 2008):

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

In the above equation, p is the period of the sinusoidal curve, expressed as the number of months. Coefficients a_1 & a_2 determine the amplitude A and phase shift S of the sinusoidal curve as follows:

$$A = \sqrt{a_1^2 + a_2^2} \qquad S = \arctan \frac{a_1}{a_2}$$

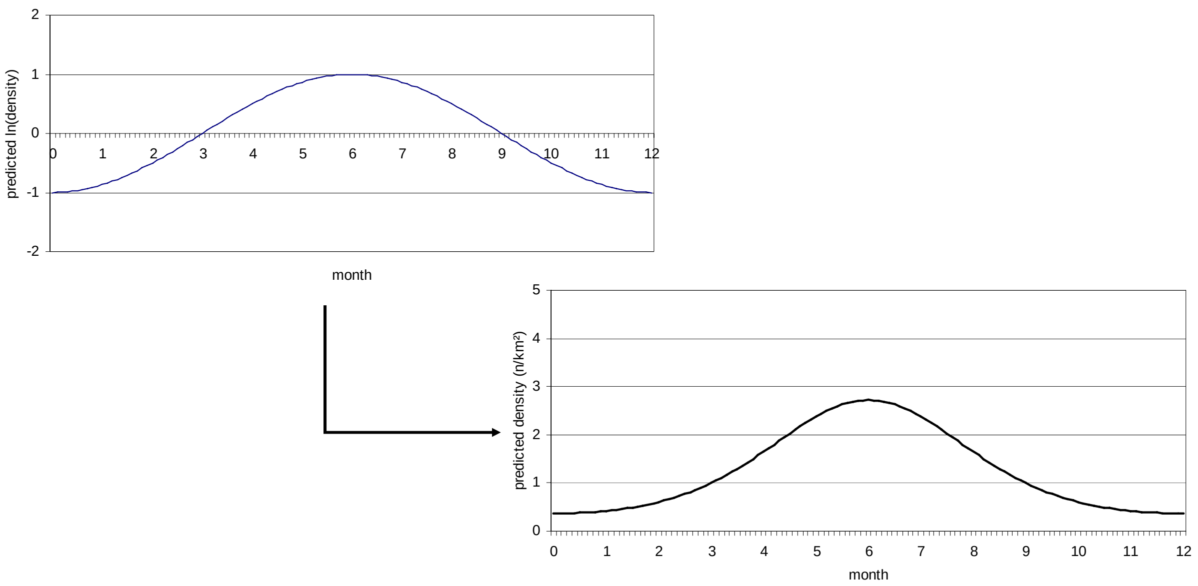

Figure 5. Example of a sine curve in logarithmic scale (left) and the same curve transformed into the linear scale.

Figure 5 presents a fictitious example of a summer visitor, in which the period of the seasonality 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 sine/cosine terms, 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 6).

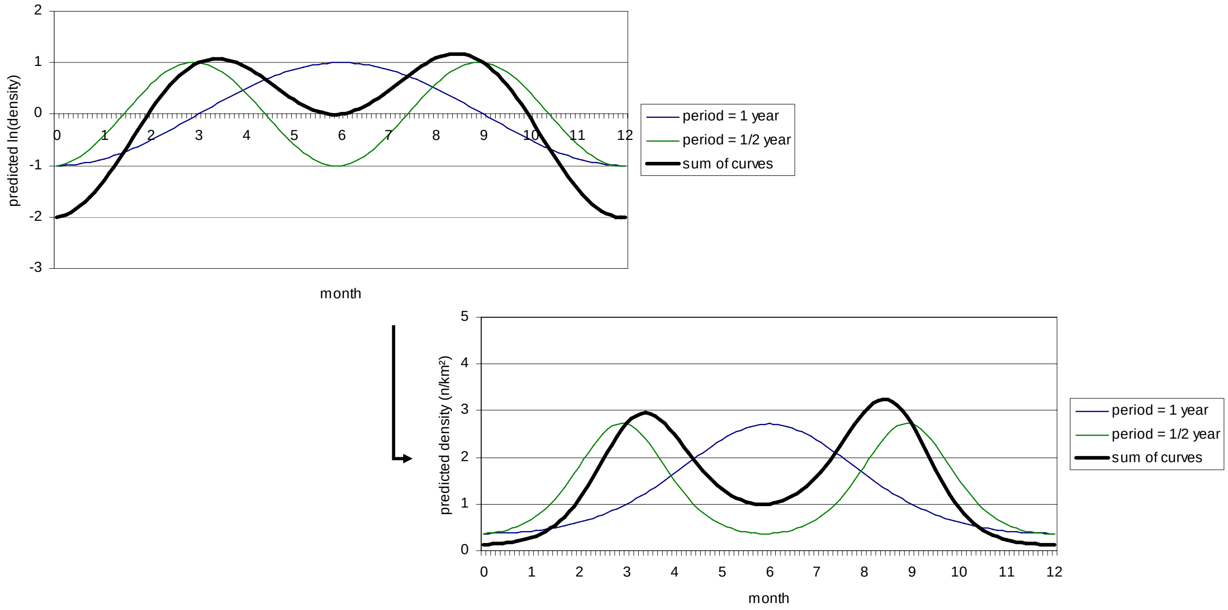

Figure 6. Example of combining two sine curves with different periods, in the logarithmic scale (left) and after transformation into the linear scale (right).

9.2.6. Data-analysis: statistical testing

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

Figure 7 presents the flowchart for the selection of the reference model. When going through the whole flowchart, we end up with one of the following five reference models:

- *reference model 1* “Seasonality+CI+Seasonality:CI”: the full ‘reference model’ including ‘seasonality’ (sum of sine and cosine terms) and the factor variable ‘CI’ (control-impact area), as well as the interaction between both;
- *reference model 2* “Seasonality+CI”: the same model as the previous, but without interaction;
- *reference model 3* “Seasonality”;
- *reference model 4* “CI”;
- *reference model 5* “Intercept”

We start from the most complex model, including an interaction term. By dropping this latter, we may test if there is a difference in seasonality pattern between both areas (*test 1*). Logically, seasonal fluctuations occur on a broader scale that the study area itself, and therefore we do not expect this test to reveal significance. For the same reason, seasonality forms the base of our model and is tested for last. Anyhow, if the p-value of the first test exceeds 0.05, we may drop the interaction and continue with *model 2*. If not, *model 1* is the selected reference model.

Next, we want to know if there is an additive effect of ‘CI’ (*test 2*), which would indicate a difference between the two areas. The resulting p-value of *test 2* will stipulate whether to continue with *test 4*, or alternatively, to drop ‘CI’ and to continue with *test 3*. Eventually we end up with one of the five aforementioned reference models.

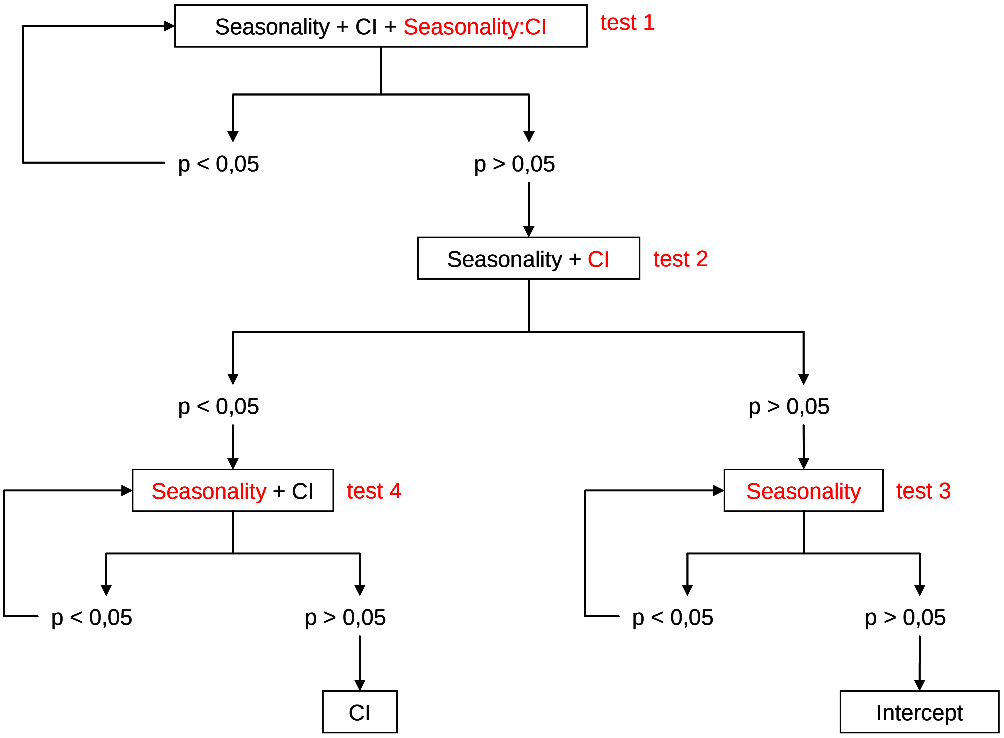

Figure 7. Flowchart of tests performed to select a reference model (the terms indicated in red are successively left out of the model – e.g. test 1 compares a model with the interaction term ‘Seasonality:CI’ included with a model without interaction).

The impact analysis depends on the selected reference model. If we observed an interaction- or area-effect during the reference years, the factor variables ‘BA’ & ‘CI’ are included in the model (4 unique combinations). However, in case we did not observe any difference between impact and control area, we opt to include the factor variable ‘T’ (0=no turbines present; 1=turbines present) instead of ‘CI’, resulting in only 3 unique combinations (Table 1).

Table 1. Overview of the unique combinations of factor variables used in the impact analysis (green=reference period / red=impact period).

‘BA’-‘CI’	Control-Impact	Before-After	Turbine presence	‘BA’-‘T’
0 – 0	Control Area	Before	No turbines	0 – 0
0 – 1	Impact Area	Before	No turbines	
1 – 0	Control Area	After	No turbines	1 – 0
1 – 1	Impact Area	After	Turbines	1 – 1

Depending on the selected reference model, there are five different scenarios (the green terms represent the reference model):

- *reference model 1*: (Seasonality+CI+Seasonality:CI)*BA =
  Seasonality + CI + BA + Seasonality:CI + Seasonality:BA + BA:CI + Seasonality:BA:CI
- *reference model 2*: (Seasonality+CI)*BA =
  Seasonality + CI + BA + Seasonality:BA + BA:CI
- *reference model 3*: (Seasonality)*(BA+T)
  Seasonality + BA + T +Seasonality:BA + Seasonality:T
- *reference model 4*: (CI)*BA =
  CI + BA + BA:CI
- *reference model 5*: (Intercept)*(BA+T) =
  BA + T

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 effects of the ‘BA:CI’- or ‘T’-term (tests 2’ & 2” - Figure 8 & Figure 9). However, when these terms are included in an interaction term of a higher degree, these need to be dropped first (tests 1’ and 1”).

So the first two tests in both flowcharts are crucial, while the following are rather facultative, testing the significance of the terms ‘BA:Seasonality’ and/or ‘BA’. These latter indicate the difference between the periods before and after the impact, due to a change in numbers or seasonality at a broader scale, apart from any turbine effect.

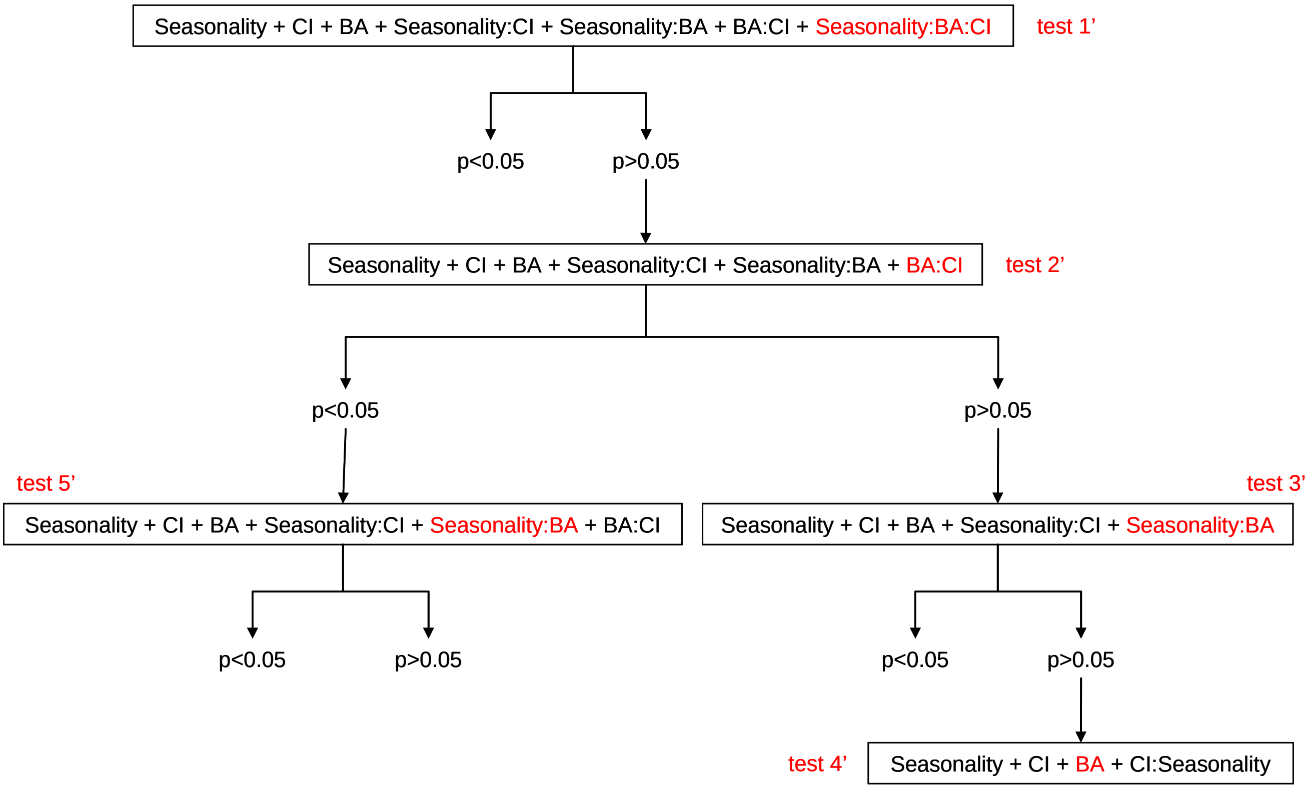

Figure 8. Graphic scheme of models & tests carried out within the framework of the impact study based on reference model 1 (the terms indicated in red are successively left out of the model).

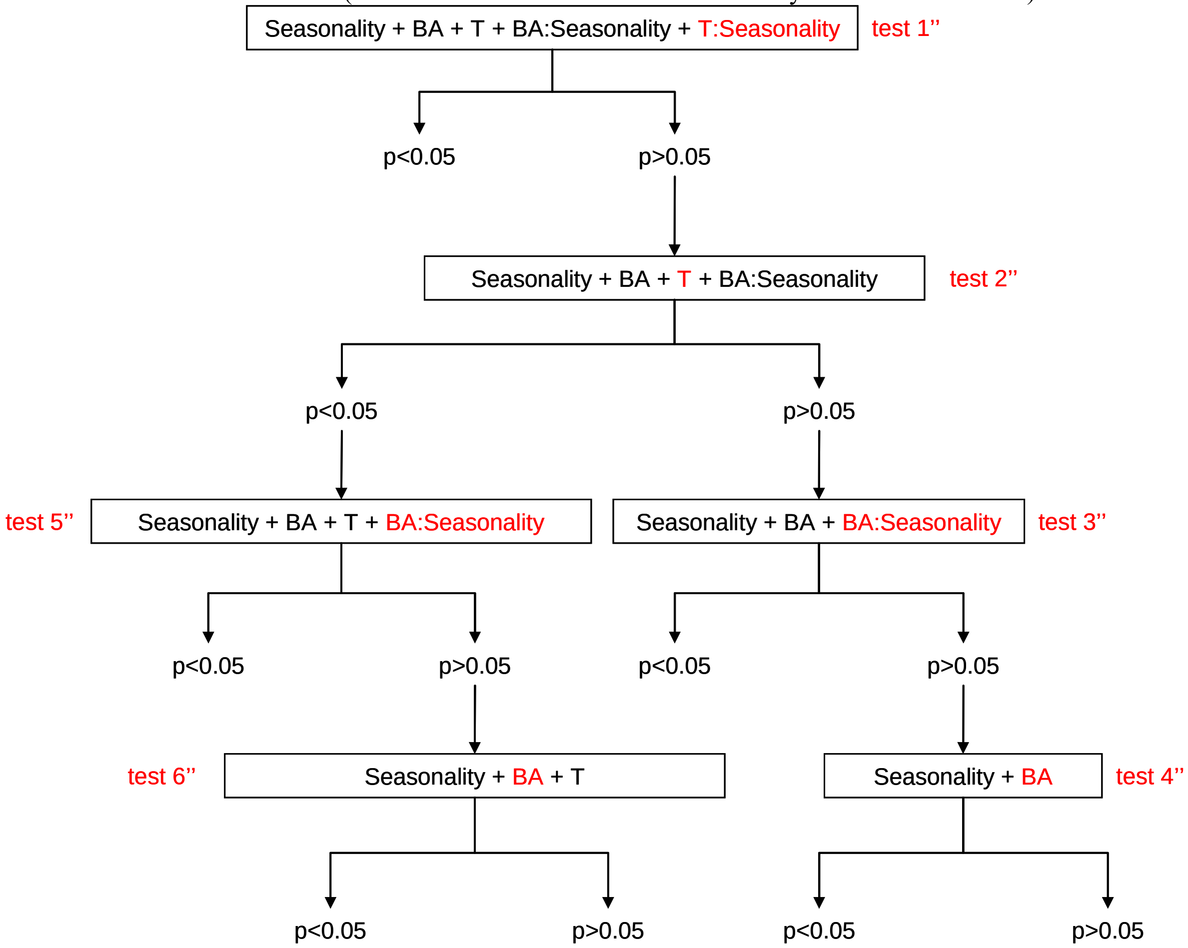

Figure 9. Graphic scheme of models & tests carried out within the framework of the impact study based on reference model 3 (the terms indicated in red are successively left out of the model).

9.3. Results

9.3.1. Seabird presence during the reference period at the Thorntonbank

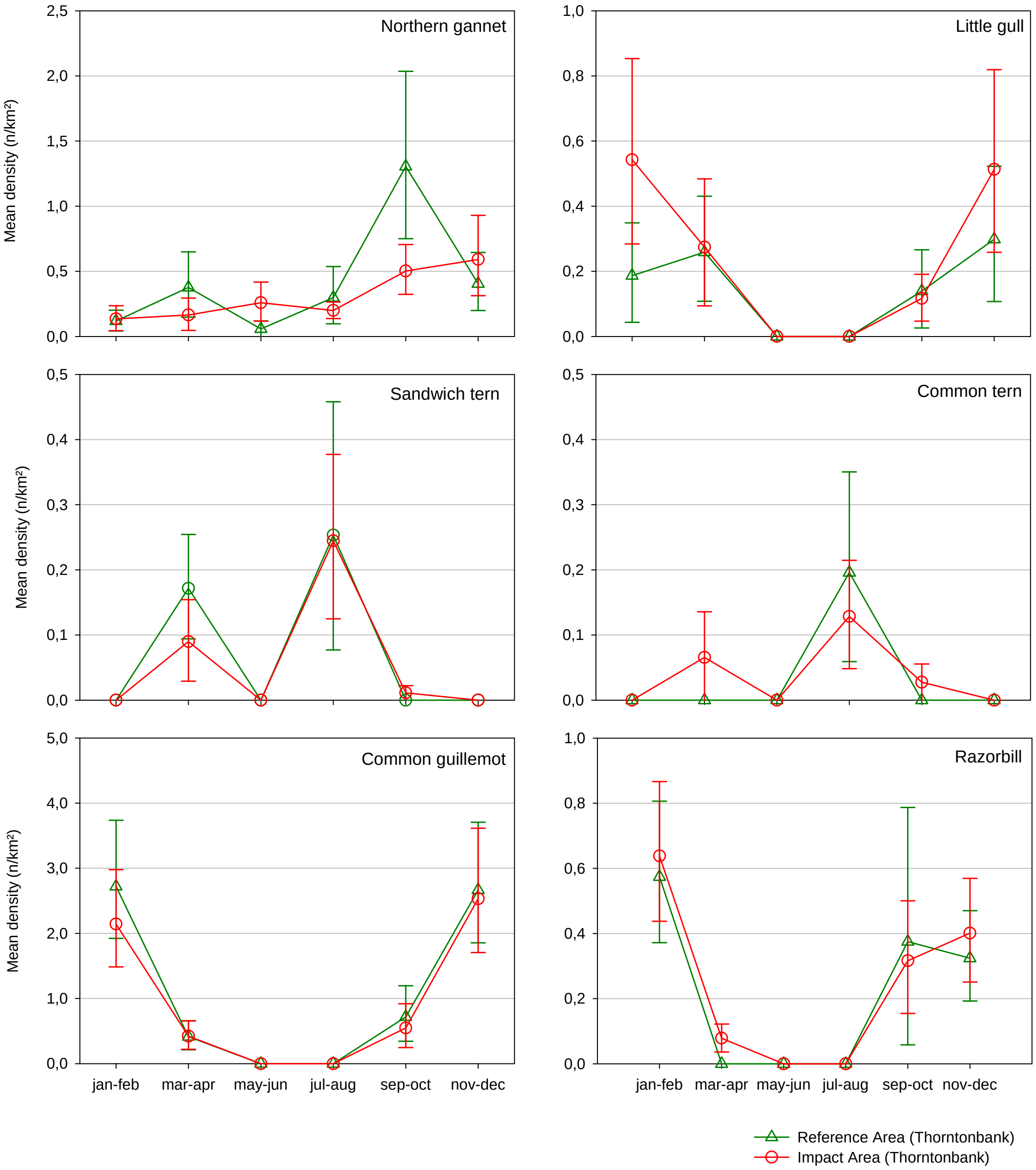

Figure 10. Geometric mean densities (+/-std.error) per two-month period in the Thorntonbank study area during the reference years 1993-2007.

Visual interpretation of mean seabird densities in the Thorntonbank reference and impact area suggests that there are only minor differences in the presence of Sandwich tern, Common guillemot and Razorbill between reference and impact area (Figure 10). Comparability between the two areas is however less for the other species, but except for Northern gannet densities in September-October and Common tern densities in March-April, the ranges of standard errors overlap. In the case of the

Common tern, we are faced with the more worrying fact that the database holds no more than 7 positive (non-zero) counts (2 in the control area & 5 in the impact area).

Modelling the observed densities allows for a statistical analysis of the reference data. Based on the seasonal patterns displayed in Figure 10, we decided to model the tern species with a two-fold seasonality pattern (a curve with period p=12 months added with a curve with p=4 months), while the other species were modelled based on a single sine curve with a period of one year (Table 2). The drop in deviance induced by the resulting reference models varies from 19.4 to 59.4%, for Northern gannet and Common tern respectively.

In the case of Little gull and Common tern, the interaction term contributes significantly to the model (a drop in deviance of 32.6% and 59.4% respectively), proving a different seasonality pattern between both areas. According to the model, peak abundance of Little gull in the reference area occurs in midwinter, while in the impact area, highest numbers are predicted to occur two months later, in early spring. For Little gull, *model 1* was thus the final reference model. This could also be the case for Common tern, however, this species' model is characterised by large standard errors on the predicted densities (Figure 11). It can therefore not be used as a base for impact assessment, let alone for a power analysis.

In the other four seabird species, statistical testing revealed that there are no differences between control and impact area. Only seasonality was able to explain a significant deal of the variance in densities, resulting in *model 3* as a reference model. Peak numbers of both auk species are predicted to occur in midwinter, while Northern gannet is predicted to be most abundant during autumn migration. A different pattern is observed in Sandwich tern. At the BPNS, this species is present from April to September, with numbers peaking in June. At the study area however, Sandwich tern is quite common during migration in April and August, but fully absent during the breeding season (May-June). Some years, high numbers of Sandwich tern breed in the colony of Zeebrugge, but apparently the Thorntonbank is outside the foraging range of these birds (averaging 16km according to Brenninkmeijer & Stienen, 1994).

Concluding, the reference area is well suited for future monitoring of all species except for Common tern. This is mainly due to the very low number of only 7 positive counts in the reference period.

Table 2. P-values resulting from ANOVA-tests (see Figure 7) and drop in deviance based on the selected reference model (* indicates significance).

	Test 1	Test 2	Test 3	Test 4	Model	Δ Deviance
Northern gannet	0.263	0.366	0.003*	-	3	19.4%
Little gull	0.019*	-	-	-	1	32.6%
Sandwich tern	0.688	0.650	0.000*	-	3	55.4%
Common tern	0.048*	-	-	-	1	59.4%
Common guillemot	0.308	0.558	0.000*	-	3	55.1%
Razorbill	0.729	0.481	0.000*	-	3	32.4%

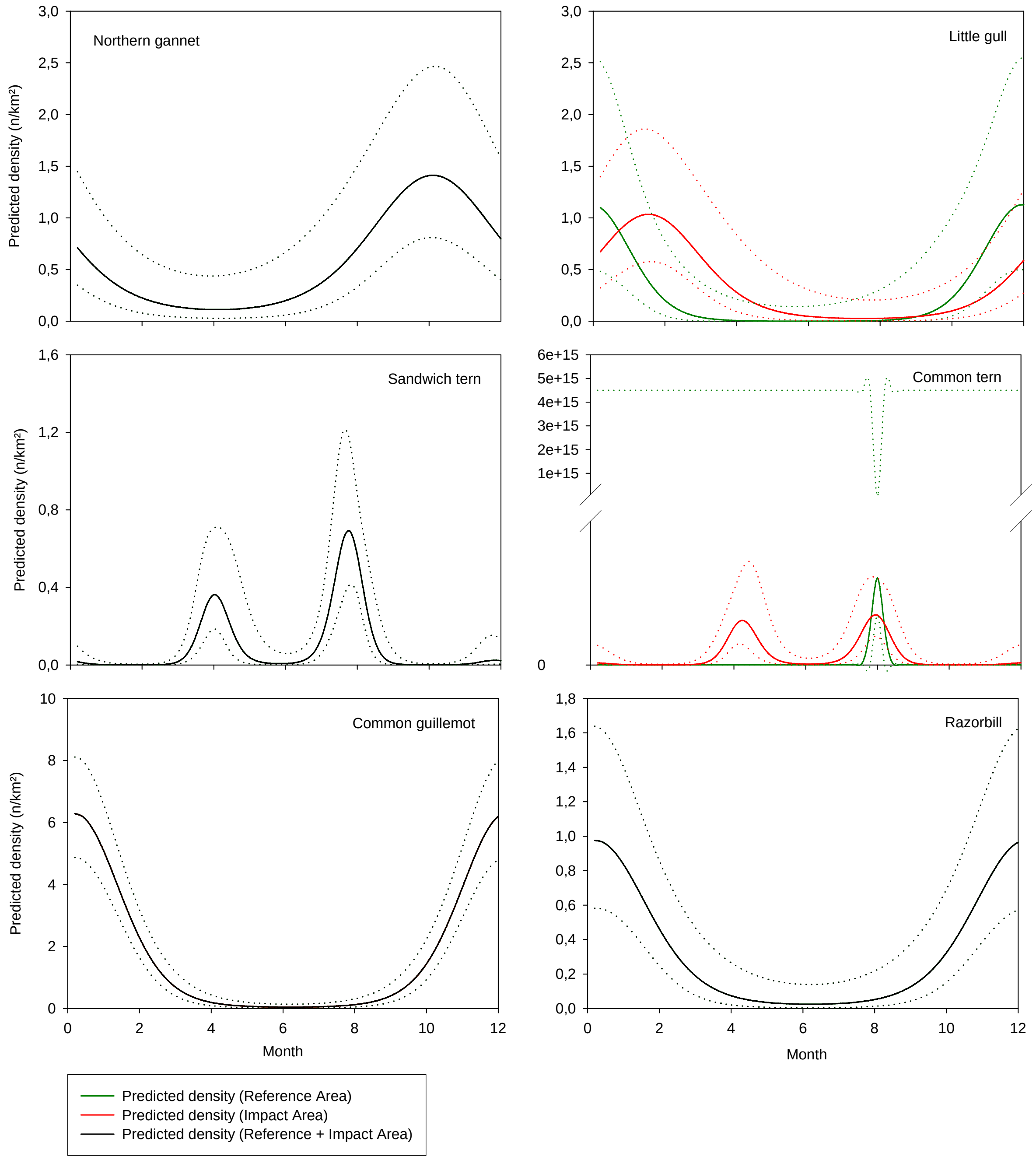

Figure 11. Predicted seabird densities (with 95% point wise confidence intervals) according to the selected reference models for the Thorntonbank wind farm area (the break in the vertical axis in the Common tern graph is at 1 bird/km²).

9.3.2. Seabird presence during the reference period at the Bligh Bank

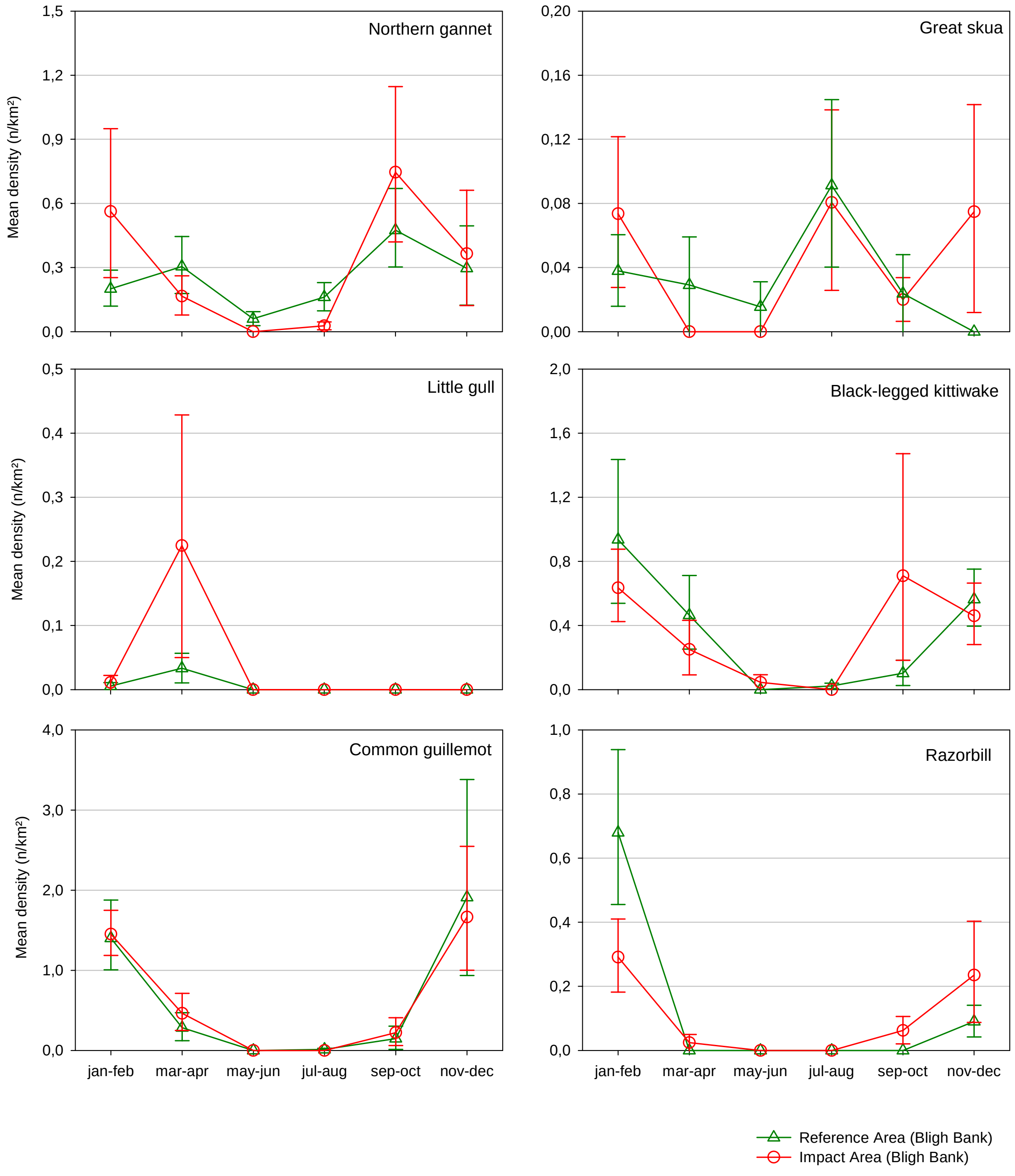

Figure 12. Geometric mean densities (+/-std.error) per two-month period in the Bligh Bank study area during the reference years 1993-2009.

When seabird densities in the impact and reference area at the Bligh Bank are compared, we see that only for Common guillemot, there is very good accordance (Figure 12). In fact, this would also be the case for Black-legged kittiwake if it was not for one record of a very high density observed in October 2008, strongly skewing the seasonal pattern. For the other species, comparability in densities is less striking but due to high variability in the data, differences generally fall within the standard error ranges.

Modelling gives an objective insight in our reference data. Seasonal fluctuations in all six species were modelled using a single sine curve with a period equalling one year (Table 3).

Unfortunately, for Great skua, none of the tested models was able to explain a significant part of the deviance. This species is quite rare and seldomly observed, and even in the BPNS as a whole it does not show a clear seasonal pattern. The resulting model is limited to the intercept.

In the Razorbill and Little gull model, the interaction term appeared to be significant. Razorbill densities in the impact area are predicted to be lower than in the control area, and to peak one month earlier. Unfortunately, the Little gull model is based on very few data (only 5 positive counts), resulting in highly unreliable predicted densities (Figure 13). This is the same scenario as encountered for Common tern at the Thorntonbank. This model too is unuseful and we will therefore not include this species in future monitoring at the Blighbank wind farm.

Lastly, no differences between the two areas could be discerned for the remaining three species, Northern gannet, Black-legged kittiwake and Common guillemot, and seasonality was the only variable contributing significantly to the density models. Predicted densities of these three species all peak during winter months.

Table 3. P-values resulting from ANOVA-tests and drop in deviance based on the selected reference model (* indicates significance).

	Test 1	Test 2	Test 3	Test 4	Model	Δ Deviance
Northern gannet	0.599	0.492	0.020*	-	Model 3	15.4%
Great skua	0.249	0.725	0.186	-	Model 5	0%
Little gull	0.000*	-	-	-	Model 1	71.3%
BL kittiwake	0.360	0.319	0.042*	-	Model 3	20.9%
Common guillemot	0.607	0.187	0.000*	-	Model 3	56.5%
Razorbill	0.018*	-	-	-	Model 1	65.3%

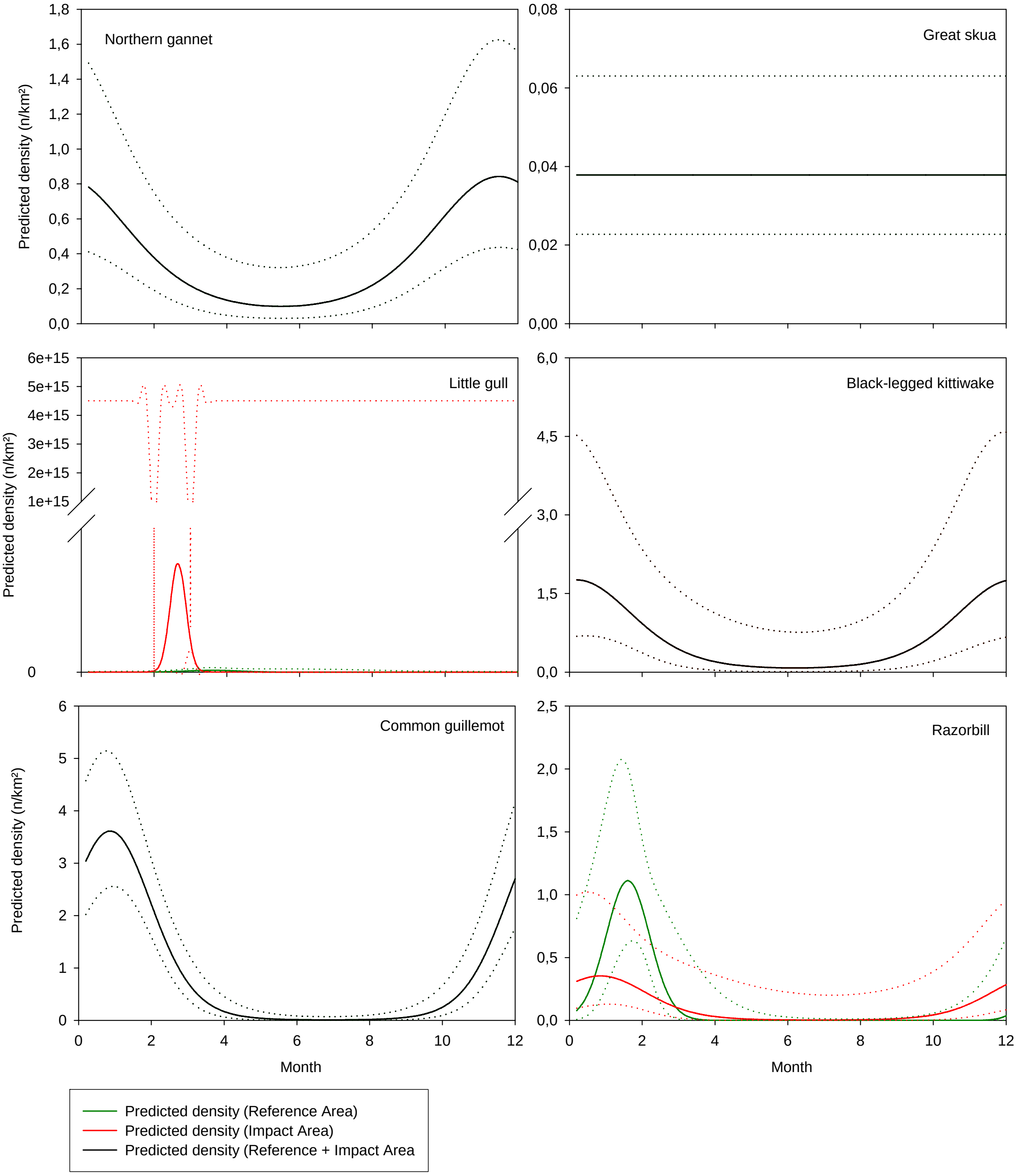

Figure 13. Predicted seabird densities (with 95% point wise confidence intervals) according to the selected reference models for the Bligh Bank wind farm area (the break in the vertical axis in the Little gull graph is at 5 birds/km²).

9.3.3. Impact analysis Thorntonbank

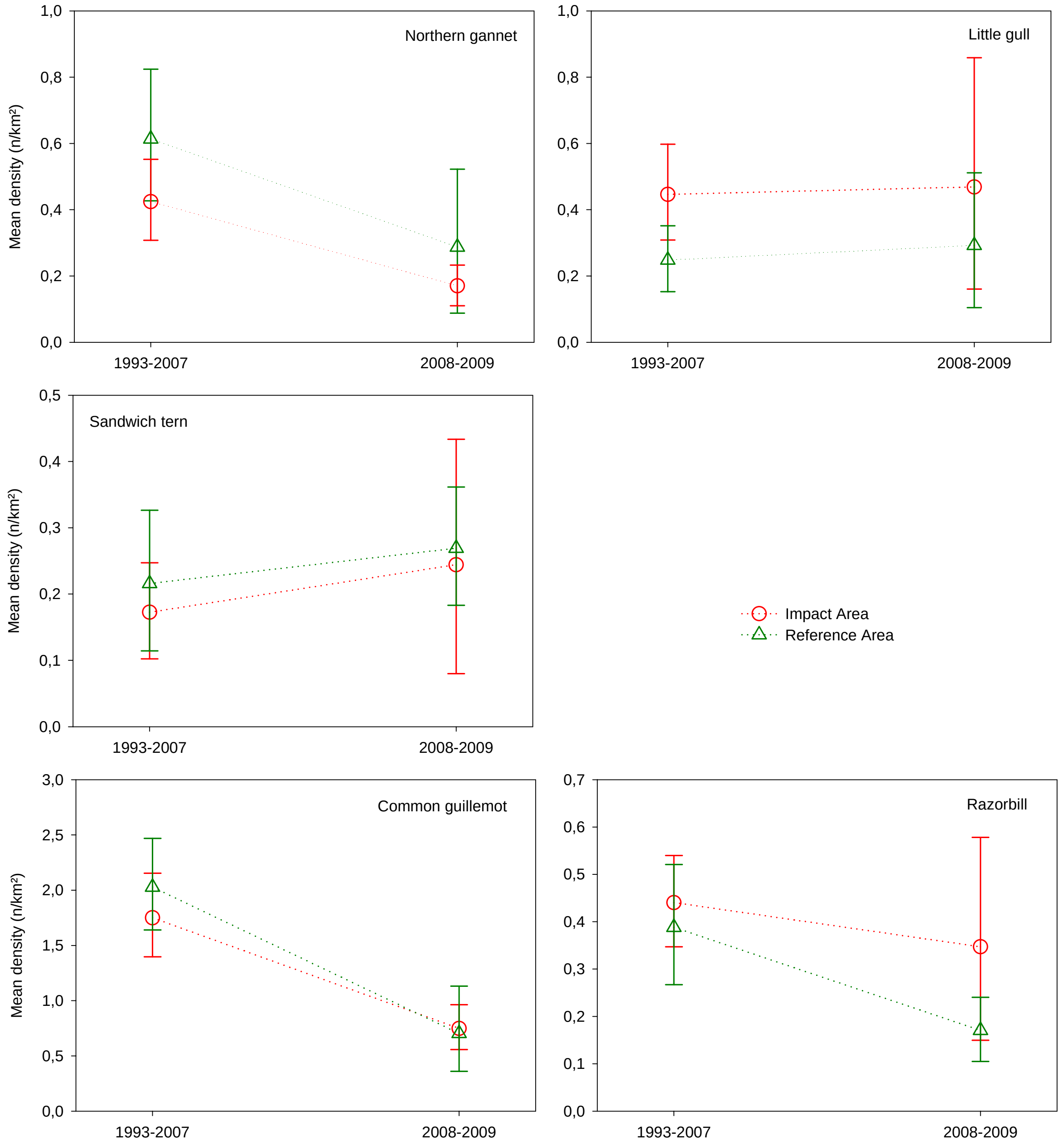

Figure 14. Geometric mean densities (+/-std.error) during periods of peak abundance in the reference and impact area before and after the first turbines were built.

Figure 14 compares geometric mean densities of seabirds before and after the six turbines were built. The means are based on the period of peak occurrence:

• Northern gannet	August-January
• Little gull	November-April
• Sandwich tern	March-April / July-August
• Common guillemot	October-March
• Razorbill	October-March

Little gull densities remained more or less the same in both the impact and the control area. Accordingly, there was no displacement effect indicated by the ‘BA:CI’ term (test 2’). Due to a shift in peak numbers from winter to spring months, there was only a significant effect of the interaction between 'BA' and seasonality (test 3').

A clear drop in densities of Northern gannet and Common guillemot occurred in the impact area, and a strikingly parallel decrease took place in the reference area. Accordingly, tests 1" & 2" did not reveal any turbine effect ('T:Seasonality' & 'T'), while the drop in densities after 2007 indicated by 'BA' was significant. This is most probably due to a general decrease in numbers rather than a displacement effect of the turbines.

Razorbill densities slightly decreased in the impact area, with a more pronounced decrease in the control area. This difference however did not appear to be significant. In both areas, densities of Sandwich tern slightly increased, but again, no turbine effects could be detected.

Table 4. P-values resulting from ANOVA-tests for the impact analysis based on reference model 1 (see also Figure 8) (* indicates significance).

	Test 1'	Test 2'	Test 3'	Test 4'	Test 5'
Little gull	0.184	0.302	0.002*	-	-

Table 5. P-values resulting from ANOVA-tests for the impact analysis based on reference model 3 (see also Figure 9) (* indicates significance).

	Test 1''	Test 2''	Test 3''	Test 4''	Test 5"	Test 6"
Northern gannet	0.183	0.635	0.580	0.045*	-	-
Sandwich tern	0.057	0.340	0.258	0.782	-	-
Common guillemot	0.566	0.528	0.624	0.000*	-	-
Razorbill	0.874	0.394	0.705	0.114	-	-

9.4. Discussion

Compared to the previous monitoring report (Vanermen & Sitenen, 2009), we introduced two new developments in our approach. Instead of using the ten-minute count results as the traditional base for seabird data processing, we now grouped these count data per area and per month per year, in order to decrease variability. Secondly, we modelled our data using quasi-likelihood estimation, and comparability of impact area and control area could be tested based on the resulting models.

When analysing the reference data, it appeared to be impossible to perform reliable statistical processing in case of Common tern at the Thorntonbank and Little gull at the Bligh Bank, due to a very low number of positive count records. For Great skua the proposed modelling set-up failed to explain a significant deal of the deviance due to an unclear seasonal pattern in the species' occurrence at the Bligh Bank study site.

On the other hand, control and impact areas held highly comparable densities of most other studied species, as in Northern gannet and Common guillemot at both sites, as well as Razorbill and Sandwich tern at the Thorntonbank site and Black-legged kittiwake at the Bligh Bank site.

We did observe a significantly different seasonality pattern in Little gull at the Thorntonbank, and in Razorbill at the Bligh Bank. We regard seasonal occurrence of seabirds as a broad scale phenomenon, and therefore we do not expect differences in seasonal patterns to occur at such a small scale. This might suggest that observed densities of these species do not reflect a truthful situation, and we should be careful towards conclusions in future impact assessments concerning these species.

The selected reference models will be used as a base for a power analysis. This will make it possible to determine the survey effort necessary to detect specified changes in bird numbers with a certain significance level (for example a 25% change in bird numbers with a 5% significance level) (McLean *et al.*, 2006).

Finally, we presented our approach for future impact assessments. We already tested for displacement effects by the six turbines at the Thorntonbank, and none could be detected. Clearly, it is far too soon to draw any conclusions because of two reasons. First of all, this assessment is based on the numbers within the full impact area (future wind farm location plus buffer zone), where presently only 6 out of 54 turbines are present. Furthermore, until the year 2010, seabird counts were restricted to the buffer zone, since it was prohibited for the research vessel to enter the area in between the turbines.

9.5. Acknowledgements

We first want to thank n.v. C-Power, n.v. Belwind and the Management Unit of the North Sea Mathematical Models (MUMM) for their financial input and assigning this research to us. MUMM staff members Robin Brabant, Steven Degraer, Bob Rumes & Thierry Jacques are thanked for their guidance and critical comments on this report, and the same accounts for my colleagues Dirk Bauwens and Paul Quataert of the "Biometrics and Quality Assurance" team. We would also like to thank all volunteers who assisted during the seabird counts (especially Walter Wackenier & Kevin Lambeets), as well as the crew of the research vessel 'Zeeleeuw', and not in the least the Flanders Marine Institute (VLIZ), without who's logistic support this research would not be possible.

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Chapter 10. Spatio-temporal patterns of the harbour porpoise *Phocoena phocoena* in the Belgian part of the North Sea

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Abstract

The placement of offshore wind farms can have consequences for the ecosystem; one of the ecosystem components for which concerns exist is marine mammals. As the most common marine mammal in the Belgian part of the North Sea (BPNS) is the harbour porpoise, the focus of impact assessment lies on this species. Aerial surveys yielded actual population size estimates of low hundreds of animals up to 4000 individuals, which constitutes approximately 1.6 % of the total North Sea population. Therefore the harbour porpoise should be considered a significant top of the food chain constituent of the BPNS. Passive acoustic monitoring using Porpoise Detectors (PoDs) demonstrated its potential to add to the information obtained through aerial surveys. Strandings data over four decades indicate a recent increase of the species in the southern North Sea, due to a southward shift in the population. The combined data from aerial surveys, passive acoustic monitoring and strandings monitoring revealed a clear seasonal pattern, with harbour porpoises being typically abundant in late winter and early spring (min. on average 0.68 ind./km²), while lower numbers (max. on average 0.31 ind./km²) tend to stay in more offshore and northerly waters from late spring to autumn. Erratic invasions of harbour porpoises in the BPNS might however blur the general seasonal spatio-temporal pattern, which complicates our understanding of its spatial distribution and migration behaviour. The combination of results obtained from different monitoring methods allows for a general assessment of the reference situation of this species, before the major development of offshore wind farms in Belgian waters.

Samenvatting

Het plaatsen van offshore windparken in de Noordzee kan gevolgen hebben voor het ecosysteem. Zeezoogdieren vormen één van de ecosysteem componenten waarover bezorgdheid bestaat. Het inschatten van effecten concentreert zich op de bruinvis, gezien dit het meest algemeen voorkomende zeezoogdier is in Belgische wateren. Luchtsurveys toonden aan dat tussen enkele honderden en 4000 bruinvissen voorkomen in het Belgische deel van de Noordzee, of tot ongeveer 1.6% van de Noordzeepopulatie. Vandaar dat deze soort beschouwd wordt als een belangrijke toppredator in deze wateren. Naast luchtsurveys hebben ook andere technieken zoals passieve akoestische monitoring met Porpoise Detectors (PoDs) hun potentieel bewezen voor het aanleveren van extra informatie. Strandingsgegevens tonen aan dat in het laatste decennium een sterke stijging is opgetreden in het aantal bruinvissen in de zuidelijke Noordzee, als gevolg van een verschuiving van de populatie. De combinatie van luchtsurveys, passieve akoestische monitoring en de analyse van strandinggegevens toont een duidelijk seizoenaal beeld, met een algemeen voorkomen van bruinvissen in de late winter en vroege lente (min. gemiddeld 0.68 ind/km²), en een lager aantal (max. gemiddeld 0.31 ind./km²), verder van de kust, van de late lente tot de herfst. Een onregelmatig voorkomende influx van dieren uit meer noordelijke wateren kan dit algemeen patroon vertroebelen. De combinatie van de resultaten van verschillende onderzoeksmethoden laat toe een algemene inschatting te voorzien voor de referentiesituatie m.b.t. bruinvissen in Belgische wateren, vóór de belangrijke ontwikkeling van offshore windparken.

10.1. General introduction

Recently, initiatives were taken to construct offshore wind farms in Belgian waters. Concern exists about the ecological impact of the construction and exploitation of offshore wind farms. For instance, in cetaceans the exposure to excessive noise can lead to damage, in the form of a temporary or permanent hearing threshold shift (Southall et al., 2007; Thompson, 2000; Verboom & Kastelein, 2005). Pile driving activities can disturb porpoises over tens of kilometres (Brandt et al., 2009; Diederichs et al., 2009; Lucke, 2010; Tougaard et al., 2006; 2009). As such, the monitoring of marine mammals is of vital importance for an adequate assessment of actual and possible effects of human activities at sea, such as offshore wind farms. On the basis of these assessments, measures can be proposed to avoid and/or mitigate impacts on the population of these protected species. Therefore, marine mammals comprise one of the focal ecosystem components of the monitoring programme of the offshore wind farm developments in Belgian waters (Anonymus, 2004; 2008).

As the harbour porpoise Phocoena phocoena is by far the most common marine mammal in Belgian waters (Haelters, 2009) and very sensitive to disturbance (Bain & Williams, 2006; Cox et al., 2001; Lucke et al., 2009; Thompson, 2000; Verboom & Kastelein, 2005), the monitoring of the impact of wind farms on marine mammals focuses on this species.

As (1) most marine mammals are wide-ranging and highly mobile animals and (2) important geographic distribution shifts of harbour porpoises in the southern North Sea have been observed (SCANS II, 2008), it is a challenging task to discern natural from human induced changes. Up to now, the migration patterns of porpoises in the North Sea remain unclear, as are the driving forces behind these migrations, as well as behind the shifts in distribution that have occurred throughout the years (Haelters & Camphuysen, 2009; SCANS II, 2008). Hence, a good knowledge of the baseline situation is a prerequisite for being able to quantify the effects of offshore wind farm on harbour porpoises. This paper therefore investigates patterns in population size, as well as spatial and temporal distribution of the harbour porpoise in Belgian waters.

10.2. Material and methods

For investigating the baseline situation (population size, spatial and temporal occurrence) of the harbour porpoise in the Belgian part of the North Sea (BPNS), a combination of methods was used:

- aerial line transect sampling to assess population size and spatial distribution;
- passive acoustic monitoring (PAM) to investigate short- to medium-term variability (weeks to months) in (relative) abundance of harbour porpoises;
- strandings data analysis to extract information on medium- to long-term variability (months to years) in occurrence.

The multi-method monitoring approach allows for a combination of the results of the different monitoring activities, which leads to a total scientific value higher than the mere sum of the individual approaches. Such combined approach is needed given the difficulties in elucidating the population dynamics of the most common marine mammal in one of the best studied marine areas in the world.

10.2.1. Aerial line transect sampling

The use of aerial surveys is considered a highly efficient way to assess the population size and distribution of marine mammals, especially in coastal waters with an airfield nearby. The advantage over ship based surveys is that predefined track lines can be covered easily, without having to take account of shipping lanes, anchorage areas and shallows. Also, a large area can be covered in a short period of time. The survey methodology used during 2008 and 2009 is line transect sampling (Buckland *et al*., 2001), in which a number of tracks are flown and observations are recorded together with their perpendicular distance to the observation platform.

The aircraft used was a high wing two-engine Norman Britten Islander, owned by the Royal Belgian Institute of Natural Sciences (RBINS). This aircraft was originally equipped with only one bubble window, allowing for only the observations of the observer at the bubble window to be used for analysis. From spring 2009 onwards, after the installation of a second bubble window, the observations of two observers could be used. The survey altitude was 600 ft (183 m), and the groundspeed was kept at 100 knots (185 km/h). Flights were only performed during good to moderate observation conditions (sea states of 1 to 2). The surveys covered parallel track lines, 5 km apart and perpendicular to the coastline to follow an onshore – offshore gradient. For practical and flight-technical reasons, survey tracks only started 5 km from the shore.

Observations of marine mammals were recorded, together with the angle perpendicular to the aircraft at which the animals were seen. A hand-held SUUNTO PM-5/360PC clinometer was used to measure the angle, from which the perpendicular distance to the aircraft was calculated. The track and position of observations were recorded by GPS. The observations, together with the distances from the aircraft, allow for modelling a detection probability: the probability to observe an animal at a certain distance from the aircraft (Buckland *et al*., 2001). For analysing the collected data, the programme DISTANCE was used (Thomas *et al*., 2009). With this software, the most suitable detection model can be chosen for the data collected, and density, average group size and number of animals in the survey area are estimated. Also the Effective (half) Strip Width (ESW) is estimated: it indicates the theoretical width of the track for which the probability to miss animals within this width is equal to the probability to detect animals outside this width.

During 2008 and 2009, in total five successful surveys were performed: 8-9 April 2008, 5 May 2008, 18-19 February 2009, 14-20 May 2009 and 4-5 August 2009. The BPNS, with a surface of approximately 3.600 km², was only partly covered during the survey of 5 May 2008. The distances covered on track for the other four surveys ranged from 242 to 357 nautical miles (nm) (10 to 13 tracks), while the 5 May 2008 survey only covered 143 nm (6 tracks). The individual tracks varied in length between 20 and 34 nm.

The parameters applied, and the assumptions made for the data analysis, were:

- The detection probability of a group of animals is similar to the detection probability of a solitary animal.
- The detection probability remains constant over habitat type, season, time of the day, observer and density of animals. All data were pooled in order to establish a detection model: a half normal cosine adjusted distribution was selected as the detection function, on the basis of the Akaike Information Criterion (AIC) (Buckland *et al*., 2001).
- As not all animals are observed on the track (perception bias), and some are not visible because they are too deep to be observed (availability bias), a correction factor for g(0) needs to be applied. This factor indicates the probablility to see an animal or group of animals at distance 0. For g(0) 0.45 was used, as estimated by Hiby (2008) for similar surveys; it was not possible to calculate this correction factor for the surveys undertaken. No confidence values were applied to g(0).

The detection model was based on 89 observations of a total of 105 porpoises. The resulting estimate of the ESW was 134 m (90% CI: 116 m – 154 m).

10.2.2. Passive acoustic monitoring

PAM devices are increasingly popular for short- to medium-term (i.e. weeks to months) monitoring of cetaceans, both for basic ecological research and for impact assessment of human activities. The PAM devices used during 2009 were C-PoDs (Porpoise Detectors, manufactured by Chelonia Ltd). PoDs consist of a hydrophone, a processor, batteries and a digital timing and logging system (www.chelonia.co.uk). They are anchored under water at selected locations, and have autonomy of up to four months. A PoD does not record sound itself: it generates a raw file with for each sound event characteristics, such as its time of occurrence, duration, dominant frequency and sound pressure level. The raw file can be analysed with dedicated software that applies a filter to only retain those clicks identified as being in trains. The program identifies trains that originate from cetaceans (within a certain probability), and trains that originate from other sources (such as boat SONARs). It can distinguish, using typical frequencies, between harbour porpoises and dolphins. The data thus obtained give an indication of the (relative) abundance around the device, up to a distance of approximately 300 m.

The advantage of using PoDs for monitoring cetaceans, is that they provide continuous information over a short- to medium-term period, independent of weather conditions, and in between aerial surveys. A difficulty in using PoDs is the mooring system, which should be cost-efficient. PoDs, even with robust mooring systems, are regularly lost (eg. Diederichs *et al*., 2009; Brasseur *et al*., 2004). Also, PoDs do not provide for an estimate of the absolute abundance of cetaceans.

During 2009, two C-PoDs were moored in autumn, a period when no aerial surveys were undertaken. For the mooring of both PoDs, a tripod (Van den Eynde *et al.*, 2010) was used: the PoD was attached to the central column of the tripod, at 1.5 m above the seafloor. A first PoD was moored from 19 October 2009 to 9 December 2009 at the Gootebank (51°26.9'N, 002°52.6'E; 21.4 km offshore; depth of 22 m below mean low low water spring (MLLWS)). The second PoD was moored from 6 November 2009 to 19 May 2010, with short interruptions for servicing (51°21.4’'N, 003°07.0'E; 4.5 km offshore; depth of 6.5 m below MLLWS).

The data were analysed using CPOD.exe software version 1.054. The measure for harbour porpoise presence is detection positive minutes per day (dpm), which is the number of minutes per day in which the presence of harbour porpoises was detected. Only high and moderate train quality data (high and moderate detection probability) were used, and the species filter was set to harbour porpoises.

10.2.3. The collection of additional data

Many other sources of information on marine mammals can be used to shed some light on their occurrence, ecology and health status in the BPNS. They include strandings data and the results of the necropsy on stranded animals. Yearly trends in strandings can reflect trends in the number of harbour porpoises at sea, and seasonal migrations can be revealed. Investigations of stranded animals can point at problems that the population is facing, such as bycatch, disease, or previous exposure to excessive noise (Jauniaux *et al*., 2002).

Being legally protected, stranded and accidentally caught marine mammals must be reported to the authorities, represented by the RBINS; to all possible extent, carcasses are collected and made available for scientific research purposes. As a consequence of the legal requirements, in combination with the easy public access to the shoreline, the dense human presence of the shore and the fact that coastal authorities and members of the public are well informed, the marine mammals strandings database managed by the RBINS can be considered as fairly complete from 1990 onwards.

For this paper, general trends in monthly and yearly (i.e. medium- to long-term variability) strandings data are presented. The data include a very small number of animals found dead at sea, and animals accidentally caught and brought into port by fishermen. They also include accidentally caught animals that were discarded and subsequently washed ashore. A more detailed analysis of the strandings data of harbour porpoises in Belgium and the Netherlands up to 2007 was reported in Haelters & Camphuysen (2009).

10.3. Results

10.3.1. Aerial surveys

Three to 43 harbour porpoises were detected by observers on task during each of the aerial surveys, which renders a population size estimate for the BPNS ranging from 201 to 3,994 individuals (Table 1). The average group size varied between 1.00 and 1.35 individuals. The May 2008, May 2009 and August 2009 surveys (i.e. late spring and summer) indicated the lowest density of harbour porpoises (max. 0.31 ind./km^2), while the aerial surveys of April 2008 and February 2009 (i.e. late winter and early spring) indicated a much higher density (min. 0.68 ind./km^2).

Table 1. Overview of the number of observed animals by on task observers and the estimate of the average group size, density and abundance within a surface area equivalent to the Belgian part of the North Sea, i.e. 3600 km² (CI, confidence interval). No estimate of the number of animals was made for the survey of 5 May 2008, given the incomplete coverage of the study area.

Survey	Number of observations (number of animals)	Group size (ind.) (90% CI)	Density (ind./km²) (90% CI)	No of animals per 3600 km² (90% CI)
8-9 April 2008	40 (43)	1.11 (1.02-1.22)	1.11 (0.75-1.64)	3994 (2707-5892)
5 May 2008	5 (5)	1 (-)	0.31 (0.08-1.31)	-
18-19 February 2009	20 (27)	1.35 (1.09-1.67)	0.68 (0.46-1.01)	2448 (1652-3627)
14-20 May 2009	12 (13)	1.08 (1.00-1.24)	0.17 (0.09-0.31)	600 (321-1122)
4-5 August 2009	3 (3)	1 (-)	0.06 (0.02-0.14)	201 (83-488)

In April 2008 and February 2009 harbour porpoises were present both in inshore and more offshore waters, whereas May 2008, May 2009 and August 2009 only yielded observations further offshore, in the northern half of the BPNS (Figure 1).

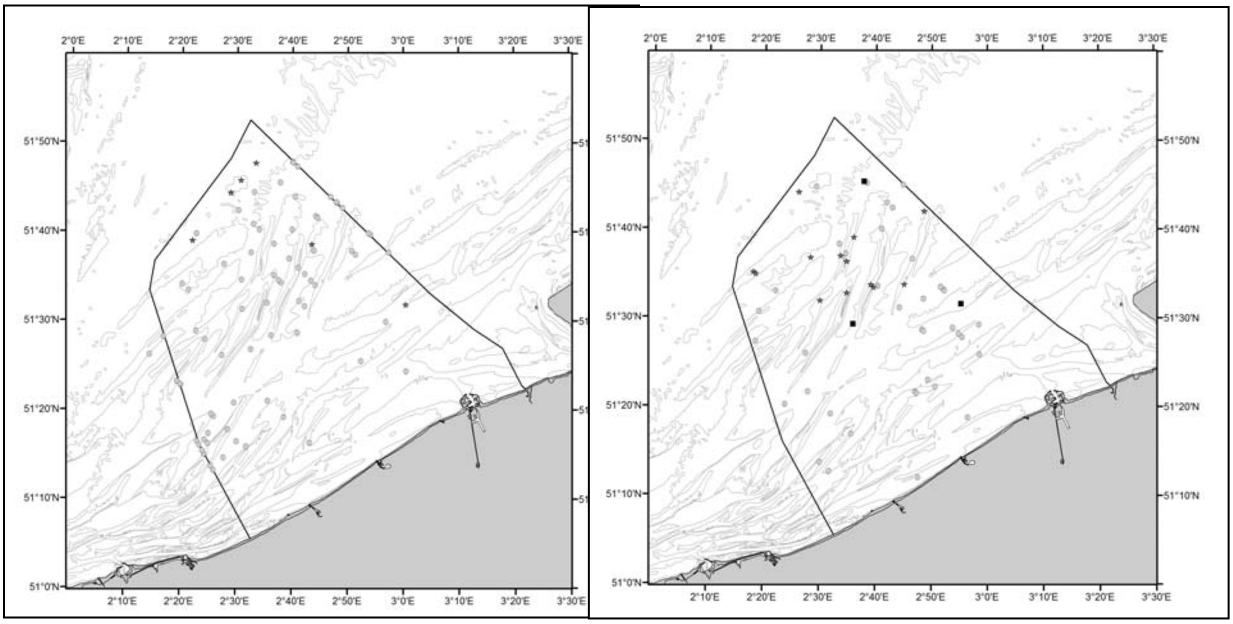

Figure 1. Left panel: Detections of harbour porpoises during the 2008 surveys: 8-9 April (grey circles) and 5 May (dark grey stars). Right panel: Detections of harbour porpoises during the 2009 surveys: 18-19 February (grey circles), 14-20 May (dark grey stars) and 4-5 August (black squares). Observations made off track, as well as those made by the observer at the side of the aircraft without bubble window, are included.

10.3.2. Passive acoustic monitoring

PoD moorings in November and early December 2009 showed a more frequent detection of harbour porpoises further offshore compared to nearshore waters (Wilcoxon signed rank test: $p < 0.001$), suggesting that in autumn harbour porpoises were more common further offshore than inshore (Figure 2). Furthermore, an increase in the number of detection positive minutes per day (dpm/d) was observed from October to December in offshore waters (mid October to mid November 2009: average 17 dpm/d; mid November to early December 2009: average 32 dpm/d). Nearshore, the number of detection positive minutes per day was generally low, with on average 9 dpm/d between early December 2009 and the end of May 2010. Short periods of a higher number of detections were found between mid December and early January (on average 13 dpm/day), between the end of January and early February (20 dpm/d), and from the end of March into the first fortnight of April (21 dpm/d).

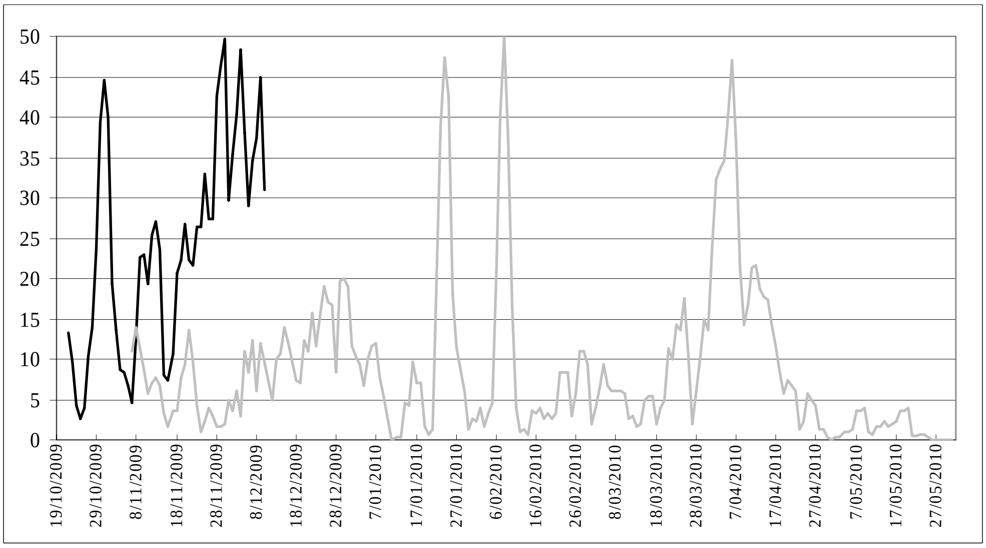

Figure 2. Detection positive harbour porpoise minutes per day (Y-axis) – or the number of minutes per day in which porpoises were present around the PoD (floating average over 3 days) - at the offshore Gootebank site (20 October to 8 December 2009: black line) and at the nearshore MOW1 site (7 November to 30 May 2010, with short interruptions for servicing the PoD: grey line). The data obtained during the day of the mooring and the day of retrieval of the PoD are excluded.

10.3.3. Strandings data

Based on the strandings data, an increase in the number of stranded animals from the late 1990s onwards was found: while only a few animals (max. 6 ind./y) washed ashore between 1970 and 1997; this number increased to more than 85 ind./y in the period 2005-2007 (Figure 3). In 2008 and 2009, the increase was interrupted, with respectively 62 and 66 ind./y.

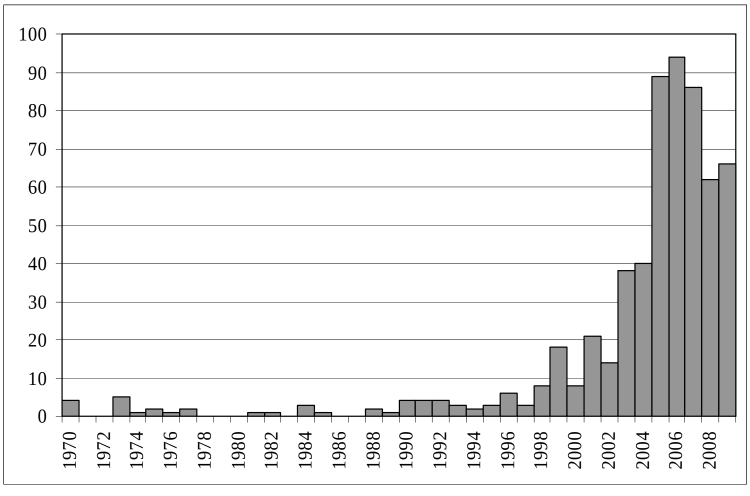

Figure 3. Total number of stranded harbour porpoises in Belgium from 1970 to 2009.

The monthly numbers of stranded animals peaked from March to May (in total 43% of all stranded animals) and in August (13%) (Figure 4). Only few animals washed ashore in July (6%) and between October and January (in total 16%). Grouping of strandings data in different periods (figure 3) indicates that the seasonality has not changed since the 1970ies.

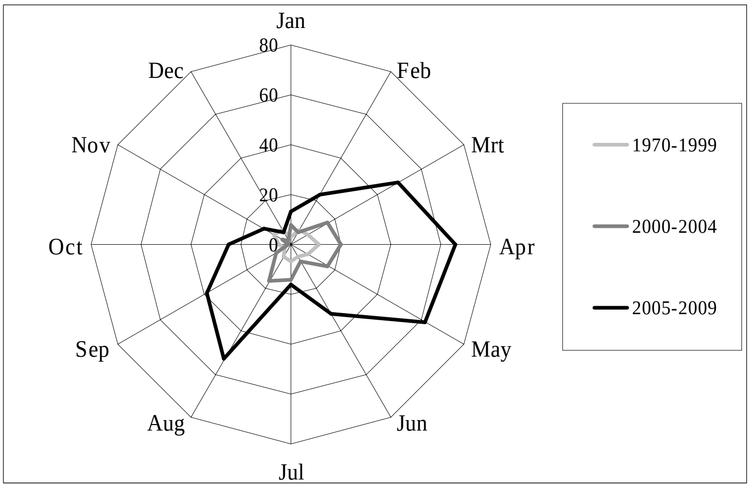

Figure 4. Total number of harbour porpoises stranded in Belgium per month between 1970 and 1999, 2000 and 2004 and 2005 and 2009.

10.4. Discussion

10.4.1. Importance of Belgian waters for harbour porpoises

Since aerial surveys yielded actual population size estimates of up to about 4,000 individuals (spring 2008), harbour porpoises should be considered a significant top of the food chain constituent of the marine ecosystem in the BPNS, as was expected by the environmental impact report prepared for licensing the environmental permits (MUMM, 2004; 2008). This number, which is the first absolute estimate of the number of porpoises in the BPNS, means that up to 1.6 % of the total North Sea population of harbour porpoises, estimated at a quarter of a million individuals (SCANS II, 2008), can at least occasionally be found in the BPNS. Given its significant presence and its protection status, at the Belgian as well as at the European level (Habitats Directive 92/43/EEC, Annex 2), it is clear that the harbour porpoise legitimately takes an important position when it comes to the evaluation of the ecological effects of the construction and exploitation of offshore wind farms, as well as other human activities in the marine environment, such as trammel net fisheries.

The harbour porpoise has however not always been abundantly present in Belgian waters, as illustrated by the tenfold increase in yearly numbers of stranded animals from 1970 to 2009. One should however take into account that strandings data may be slightly biased by meteorological conditions and incidental catches. Between 2003 and 2007, for example, 19% to 63% of stranded animals for which a cause of death could be identified, had drowned in fishing gear (Haelters & Camphuysen, 2009). The increase has also been observed in Dutch waters (Camphuysen & Peet, 2006), and it can be interpreted as a return of the harbour porpoise to the southern North Sea due to a shift in the population, rather than a population increase. The redistribution of harbour porpoises in the North Sea may have been caused by local reductions in prey availability, especially in the northern part of the North Sea (Camphuysen 2004, SCANS II, 2008). These reductions are probably caused by changes in environmental conditions.

10.4.2. Short- to medium-term spatio-temporal patterns

The spatio-temporal distribution of the harbour porpoises in Belgian waters indicates that harbour porpoises are abundant in the BPNS in late winter and early spring, while lower numbers tend to stay in the more offshore and more northerly waters in late spring and summer. Although aerial surveys are lacking in autumn, PoD measurements indicated (1) a more offshore distribution in that period and (2) increasing harbour porpoise densities from autumn to late winter.

Next to the aerial surveys, the same spatio-temporal pattern was also picked up by the strandings data analysis, showing a peak of stranded animals in March to May, which should be linked to the high nearshore densities of harbour porpoises. The relatively late peak of strandings in May can partly be explained by the washing ashore of decomposed animals, many of which probably already died in April (Haelters *et al.*, 2006). The second peak of strandings in August also mainly concerned decomposed carcasses of juvenile organisms that drifted in from more offshore waters (MUMM, unpublished data).

The yearly seasonal population size and geographic distribution cycle, as described above, however also seems to be blurred by more erratic events, complicating our understanding of the harbour porpoise’s spatial distribution and migration behaviour. Two examples of such erratic events were detected during the present study. First, a dip in number of strandings (decrease: ± 30 %) was observed in 2008 and 2009. This dip coincided with a more offshore distribution of harbour porpoises in late winter and spring 2008 and 2009, as shown by incidental sightings reported to MUMM (MUMM, unpublished data; Haelters & Camphuysen, 2009; Haelters, 2009). It should hence not be interpreted as a decrease in population size. Secondly, the high number of strandings in September-October 2009 suggests a short intrusion into Belgian waters

10.4.3. Recommendations

In the framework of the monitoring of effects of the construction and exploitation of offshore wind farms, it is advised to perform aerial surveys on a more regular basis and to extend its seasonal coverage to periods of the year, in which estimates of density are currently lacking. Aerial surveys covering the BPNS should be performed immediately prior to, during and after pile driving activities (cfr. Lucke, 2010).

The results of the PoD moorings demonstrate the potential of this PAM device. Even a low number of PoDs provides continuous information on the spatio-temporal patterns of harbour porpoises in the BPNS, in addition to discrete data obtained through aerial surveys. It is hence advised to further the exploitation of PoDs in Belgian waters. Such information is important, for instance in the planning stages of construction activities for offshore wind farms. PAM can also provide information about effects on harbour porpoises of construction and exploitation of offshore wind farms.

A continuation of the long-term data series on marine mammal strandings is advised, given its added scientific value, complementary to both aerial and PAM surveys.

10.5. Conclusions

Given the actual high density of harbour porpoises in the BPNS, the BPNS should be considered seasonally of international importance to this protected marine mammal. Harbour porpoises however do not show a random spatio-temporal distribution in the BPNS: they are found abundantly throughout the whole BPNS in late winter and spring, whereas lower numbers tend to occur in more offshore waters in late spring to early winter. In some years, this general seasonal spatio-temporal cycle might be blurred by erratic shifts in density or spatial distribution. Whereas we now start having a proper view on the harbour porpoise’s spatio-temporal distribution, it still remains, for instance, impossible to disentangle the cause-effect relationships behind these patterns. The data however allow for a first good visualization of the spatio-temporal patterns of harbour porpoises in Belgian waters prior to the major development of offshore wind farms (i.e. reference condition).

10.6. Acknowledgements

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Chapter 11. Seascape and socio-economic study: final results

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Simulation Grontmij NL

Abstract

This socio-landscape study into the perception of far-shore wind farms in the Belgian part of the North Sea is part of the monitoring of the environmental effects of several licensed wind farms and their cumulative effects.

Similar to a study of 2002, the methodology includes a public inquiry of 1000 persons, particularly coastal inhabitants, tourists, second residents, sailors and coastal workers. A combination of photo simulations and views of the real windmills are used. With regard to the results of the research of 2002, we can determine certain tendencies in the attitude towards wind energy and wind farms at sea and in the perception of these farms. The results are similar to those written in the international literature regarding the perception of wind farms.

In 2009, respondents are globally seen as a little more positive towards wind energy and wind farms at sea. The number of persons with a positive attitude has risen by 10% in comparison with 2002. Generally, people still find the quality of the seascape very important: the wide sea view and the openness, naturalness and the tranquillity of the sea. The perception value of the sea is influenced by the windmills at sea. In addition, the degree of visibility is qualifying: the distance offshore, the orientation as seen from the coastal towns and the number of visible windmills. When the windmills are placed at a sufficiently large distance and/or are limited in number, a fundamental change in this perception is prevented, which will add to the acceptance. Aside from these visual factors, ecological and economic factors also play a role in the degree of acceptance.

Based on these results, it seems not necessary to adjust the licensed far-shore projects (C-Power, Belwind and Eldepasco). However, further monitoring of the perception, with the steady expansion of the farms, is necessary. With the further filling-in of the legally foreseen area (especially regarding the area south of the C-Power project) attention has to be paid to the aspects of orientation, height and spacing of the visible windmills. This can be linked with a follow-up perception inquiry. Particularly the views of the communities Blankenberge and De Haan, with the most oblique viewing angle in regard to this area and also the highest possible visibility, have to be sought. Finally, some recommendations are formulated with respect to the layout of the wind farms and the usage of simulations in the perception inquiry.

Samenvatting

Dit socio-landschappelijk onderzoek polste naar de beleving van een offshore windparken in het Belgische deel van de Noordzee en maakt deel uit van het monitoringsprogramma naar de milieu effecten van de verschillende vergunde windparken en hun cumulatieve effecten.

De methode, analoog als deze van het onderzoek in 2002, omvat een enquête bij 1000 personen meer bepaald kustbewoners, toeristen, tweede verblijvers, zeilers and mensen die werken aan de kust. Voor de enquête werd gebruikt gemaakt van fotosimulaties en het reële zicht op de windmills. Vergeleken met de resultaten van 2002 kunnen bepaalde tendensen worden afgeleid met betrekking tot de houding t.o.v. windenergie en offshore windparken en tot de beleving van deze parken. De waarnemingen komen overeen met de bevindingen in internationale literatuur betreffende de beleving van windparken.

In 2009 staan de ondervraagden iets positiever t.o.v. windenergie en offshore windparken. Het aantal mensen met een positieve houding steeg met 10% vergeleken met 2002. Algemeen vinden de mensen de kwaliteit van het zeelandschap zeer belangrijk: het open zeezicht en de weidsheid, de natuur en de rust van de zee. De beleving van de waarde van de zee wordt beïnvloed door de windturbines in zee. Bijkomend is de zichtbaarheidsgraad determinerend: de offshore afstand, de oriëntatie zoals gezien vanuit de verschillende kustgemeenten en het aantal zichtbare windturbines. Indien de windturbines voldoende ver geplaatst worden en/of gelimiteerd zijn in aantal voorkomt het een fundamentele verandering van de beleving en zal het alzo de aanvaardbaarheid verhogen. Naast deze visuele factoren, spelen ook ecologische en economische factoren een rol in de graad van aanvaardbaarheid.

Gebaseerd op de resultaten van het onderzoek is het niet nodig om de vergunningsvoorwaarden van de vergunde windparken te wijzigen (C-Power, Belwind, Eldepasco). Een verdere monitoring van

de beleving bij de geleidelijke uitbreiding van de windparken is nodig. Bij de verdere invulling van de windparkzone (en vooral de zone ten zuiden van het huidige C-Power project) dient aandacht te worden besteed aan de oriëntatie aspecten zoals hoogte en tussenruimte van de windturbines. Dit kan gekoppeld worden aan een follow-up belevingsonderzoek. Meer bepaald dient het zicht vanuit Blankenberge en De Haan, vanwaar met de meest schuine stand naar het windpark wordt gekeken en dus ook de grootste zichtbaarheid waargenomen wordt, onderzocht te worden. Besluitend worden enkele aanbevelingen geformuleerd met betrekking tot de ruimtelijke inplanting van de windmolenparken en het gebruik van simulaties bij belevingsonderzoek.

11.1. Introduction

Currently three projects for offshore wind farms have been granted an environmental permit in the Belgian part of the North Sea. Three other projects are currently applying for an environmental permit (Figure 1). When this research took place six wind mills were already placed at sea on the Thorntonbank at 27 km distance to the coastline.

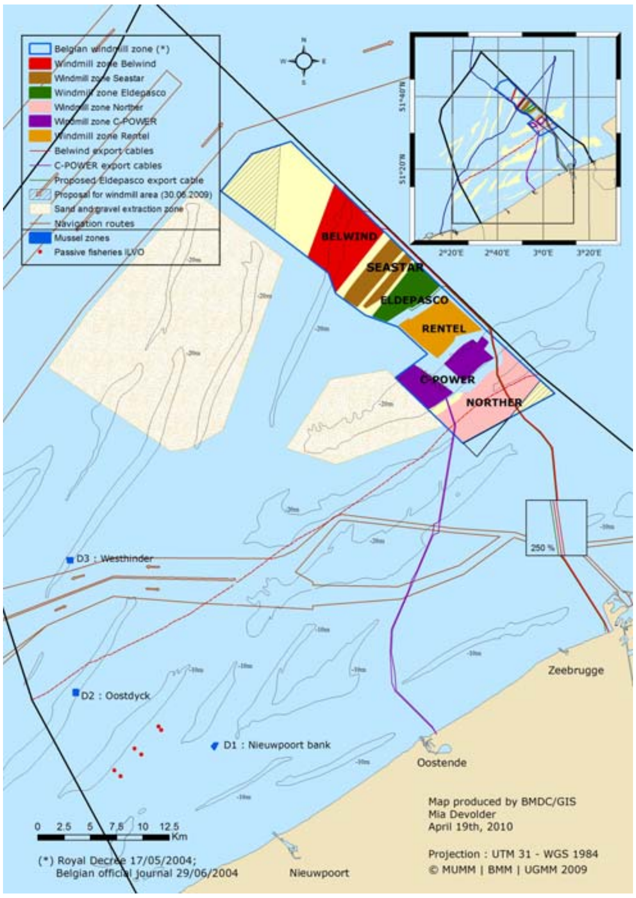

Figure 1. Overview of the Belgian offshore wind farm area and licenced projects.

Although Belgium has little experience with sociological landscape studies, the used research methodology is very well known in other countries where a long experience exists of measuring perceptive effects of infrastructural works within a certain landscape. A sociological survey focuses on visual experience and according "total experience" of the perception of the surroundings and landscape. This kind of survey mostly has a wider scope and other effects are measured simultaneously. Typically such a sociological survey will investigate into the quality of the life from the respondents.

In 2002 a first sociological seascape survey took place in Belgium to sound for the acceptation and assessment of renewable energy and more specifically of offshore wind farms in Belgium. For this purpose 405 persons were interviewed on two possible wind farms situated 6 and 12 km out of the coast. In 2003 a limited follow-up was organised on the subject (different groups of people were simultaneously interviewed. At that time no wind farm had been built at sea yet. When the environmental permits of C-Power, Belwind and Eldepasco were issued a monitoring of the seascape based on photosimulations and a sociological landscape survey was foreseen.

During the summer of 2009 a public inquiry was held to see if people's general opinion had changed since 2002. Researchers wanted to know if eventually acceptance grows as wind farms are constructed (integration of perception/acceptance).

The public enquiry also tried:

- to estimate the eventually cumulative effects and the saturation of observation;
- see if there's a need for people to be more involved;
- comparison of reaction on real situation versus simulated situations.

11.2. Material and methods

11.2.1. Sociological landscape study

11.2.1.1. General information

The primary goal of the sociological landscape study was to investigate people's opinion on the existing wind farm with 6 windmills. The second goal was to determine how people feel about the impact of the planned extension of the wind farm and the completion of other wind farms in the wind farm area.

The sociological landscape study was set up based on the following four steps:

- definition of the research population,
- the choice of sample survey,
- selection of the enquiry method,
- selection of the questions to be asked during survey.

People were interviewed face-to-face. The used formulary was made with a teleformprogram. This program allows for automatical scanning of the answer on the forms and avoids mistakes in the dataset.

11.2.1.2. Design of the enquiry

Questions used in the survey were based on the previous study of 2002. The questionnaire had different parts:

- to find out with which frequency the person is in contact with the view of wind farms at sea, the first part of the questionnaire focused on the relation of the persons with the coast side;
- the second part examined the social relevance of the durable development by proposing assumptions on wind farms and wind energy in general; this to know the peoples opinion in this matter and see if the peoples' opinion has changed according to the previous survey in 2002;
- the third part sounded the experience of the actual wind farm, how the visual impact is judged from the dike, what the impact was of the turned wings, what the impact of lights in bad weather conditions or at night are;
- the fourth part of the questionnaire looked into the effects the wind farm has on the behaviour of people (perception, acceptance,…);
- the fifth part focused on the cumulative impact of the second and third wind farm in the wind farm area; photo simulations were used for this part;

- the last part focused on socio demographic information of the people (age, education level,etc.).

11.2.1.3. Survey conditions

The public enquiry was held from June 30th till September 9th 2009. That summer was very sunny with few rainfall and general good weather conditions. From all surveys, 63% were held in sunny conditions with few or no clouds or rain, 21% of the surveys were without any rain, but under a cloudy sky with few to no sun. Only 3% of the surveys were in rainy conditions.

For more than half of the surveys (55%) a good seaward visibility was registered, meaning a good contrast and theoretically visible C-Power project (6 windmills). Hazy conditions were registered in about 40% of the surveys. Bad visibility was registered for 6% of the surveys.

11.2.1.4. Response and respondents

The survey was held amongst 1000 people over 18 years old. Following target groups were chosen:

- Local inhabitants: 235 people, 24 %
- Second residential people: 222 people, 22%
- Day tourists (no overnight stay)[1]: 257 people, 26%
- Long stay tourists (at least one overnight) [2]: 244 people, 24%
- People not living, but working at the coast side: 42 people, 4%

A specific group of respondents being sailors[3] were identified (45 persons) as being 11 local inhabitants, 9 second residentials, 8 long stay tourist and 17 day tourist. Sailors are people having actually sailed at least once in the past 12 months.

Surveys were held in Knokke-Heist-Duinbergen, Zeebrugge, Blankenberge, Oostende, Nieuwpoort and De Haan. The surveys were equally divided over the different communities (16.7% of the respondents each community). 55 (5.5%) of the people had a non Belgian nationality. From the total of 1000 surveys, 77 were held in French. Interviewed persons were living in coastal communities (25%), Flanders (87.6 %), Brussels (3.3%), Walloonia (5.5%) and outside Belgium (3.6%).

Slightly more than half of the interviewed (53%) were women. Age categories were evenly spread. Both not differing from these from Belgian population indexes (http://statbel.fgov.be/nl/statistieken/cijfers/index.jsp). More than half of the people interviewed followed a higher education (bachelor or master). Additional another 37% finished high school. Only 13,1% of the respondents is lower educated. Compared to the average Belgian adult population (+ 15y), where 40% is lower educated, 20% finished junior high and 20% finished high school,, the medium and highly educated peoples are over represented in this survey.

11.2.1.5. Comparison with the 2002 survey.

Compared to the 2002 survey double the number of people was interviewed. In 2009 a little less local habitants were questioned, a little more tourists and second residents. The number of people working at the coast side but not living there was slightly higher than 2002. The survey was more evenly spread over the different communities. In 2009 more women than men were questioned, in 2002 this was vice versa. More higher educated people were questioned in 2009 compared to 2002. The category of sailers was only introduced during the 2009 survey.

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[1] Day tourists are those tourists that visit the coast without having an overnight

[2] Long stay tourists have at least one overnight.

[3] Sailors are defined as people that recently sailed on the Northsea, once the past 12 months.

11.2.2. Photo simulations and photo montages

To investigate the impact of the already built windmills at sea simulations and photomontages of the offshore wind farms were used, besides the real view at sea.

11.2.2.1. Photosimulations

For the photosimulation a base layer of a neutral sea picture was used. On this base layer a simulation of the windmills was added digitally to give an impression on how the situation would look like with real windmills. The created picture is called a “simulation picture”. Using this technique many different viewpoints and angles can be simulated. The use of neutral base layer is important because the simulations are used in the inquiries for the sociological landscape study and the evaluations made by the interviewed people may not be influenced by casualties on the photo like e.g. ships, objects on the beach, etc.

The following picture arrangements were used: the first 6 windmills (WT) of C-Power (CP), the total CP project, CP + Belwind (BW), CP + BW + Eldepascp (EDP), CP + BW + EDP + total wind farms area (cfr Fig. 1). Details of the different projects are given in the table 1.

Table 1. Detailed overview wind farm project

	C-Power (CP)	Belwind (BW)	Eldepasco (EDP)	Total wind farm area (cfr. Fig.1)
Nr of windmills	60 WT	110 WT	36 WT	206 WT
Minimum Distance to coastline	27 km	42 km	38 km	

Three different viewpoints were taken at the coastside: Zeebrugge (location with the shortest distance to the wind farm), Ostend (most western location where windmills are still visible), Knokke (location at the eastern end of the coast) and Nieuwpoort at the westcoast (longest distance to the wind farm). To have a good insight in the difference of experience between people on the dike and people in their apartment the visualizations were made at two different view elevations. A viewpoint from the seaside was also taken into account. A night view simulating the effects of the wind farms lights was also used. For practical reasons only six simulation pictures were used during the survey:

1. Sea scape without windmills,
2. Simulation of the first six real windmills of the C-Power, viewpoint from dike in Blankenberge,
3. Simulation of the three permitted wind farm projects seen from the dike in Blankenberge,
4. Simulation of the fully occupied wind farm area seen from the dike in Blankenberge, simulation of the fully occupied area (“worst case”),
5. nigh view with safety lights on, viewpoint from dike of Blankenberge,
6. Simulation of the worst-case scenario seen from sea.

For the picture simulations the 3D visualization program WindPRO was used. The coordinates of the windmills, the coordinates of the viewpoints and the view angles are the input for the program. The diminishing visibility with distance and perspective issues were taken into account. Photos were taken with a digital camera, a Nikon 20D with 10 megapixel resolution. No artificial light was used. The quality of the pictures had to be excellent as to be able to use them for poster printing.

11.2.2.2. Photomontage

Pictures of the first 6 windmills were used to evaluate the real effects of these 6 first windmills. On top of the simulations made with the neutral base layer, also photomontages using the real windmills at sea as the base layer were made. This photomontage was then compared to the real situation at sea and to pictures of that real situation. This methodology allowed us to determine whether the photomontage gives a good impression of the real situation that is seen by people at the coast side. Pictures were taken at the same viewpoints as for the photosimulations.

11.3. Results and discussion

11.3.1. Socio demografic information

From all people asked for (> 1000), 64% was willing to participate. The response rate of 64 % is a good score for a face-to-face survey. The response rate for a similar survey in the Netherlands varied from 4 to 72% (Intomart GFK, 2009).

11.3.2. General perception and appreciation of the coast

11.3.2.1. General appreciation of the coast and the seaside

In a closed questionnaire respondents could indicate maximum three aspects that they appreciated the most at the coast side. Of the 13 offered possibilities these were the 6 most appreciated aspects[4]:

1. The beach, sun and sea (tanning and swimming): 49,3%
2. Walking along the seaside, in dunes or on the dike, get some fresh air: 43,0%
3. The cosiness and holiday atmosphere: 35,8%
4. Nature, clean and fresh air (dunes, birds and nature reserves): 33,9%
5. The repose and quietude: 28,8%
6. The grandiose landscape and views, the sea view: 25,8%

These answers were given by half to quarter of the respondents. Striking is the fact that the last one (grandiose landscape and views, the sea view) was selected by more than 25% of the people.

11.3.2.2. Elements of disturbance in the actual seascape

To the question if something disturbed the respondent in the current seascape, 12% gave a positive answer. Pollution of the sea was mentioned the most as was the bustle of tourism (cars, people,…). Third were the Zeebruges harbor activities. The wind farm at the Zeebruges harbor was mentioned by six persons, the wind farms at sea were mentioned by three.

11.3.2.3. Appreciation of the “empty” seascape

The respondents were asked to watch photo 1 and to describe and assess the seascape using predefined answers. The seascape was clearly very positively assessed. Words as ‘freedom’, ‘attractive’ and beautiful were very often used (40%). Additionally people also mentioned ‘clean’, ‘undisturbed and ‘unique’. Negatively inspired adjectives that were predefined were significantly less used, but still 4% of the respondents found the seascape gloomy.

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[4] The other possibilities in the questionnaire were restaurants and café’s, shops, sport and recreation possibility, events, cultural and historical visits, work possibilities and others

Photo 1. Sea scape without windmills (Photo: Grontmij)

11.3.2.4. Comparison with the 2002 survey.

The survey of 2002 was held in spring, whereas the 2009 survey was held in summer during mostly shiny weather. This is probably reflected in the fact that in 2009 significantly more people indicated beach, sun and sea as most appreciated followed by nature, clean and fresh air. The 2009 survey confirmed the importance of age and education, also indicated by the 2002 survey. The fact that male were more interested by ‘sea view’ could not be concluded in 2002, but was in 2009. When asked about disturbance factors people in 2002 put the Zeebruges harbor activities in first place whereas this was send down to the third place in 2009 as pollution of the sea was first mentioned. In 2002 only one person mentioned the wind farm at sea. Even thought that in 2002 a different picture was used for the appreciation of the “empty” seascape, most adjectives mentioned (calm, naturally, infinite, open…) were the same as in 2009.

11.3.3. Ideas about wind energy

This chapter looks at people's opinion about wind energy in general and offshore wind energy in particular. Theretofore statements on the subject are used. Additionally people were asked their preference or not for offshore wind and people were asked for their ideal place to put wind farms.

11.3.3.1. Wind energy in general

Following statements on general wind energy subjects were proposed to the people.

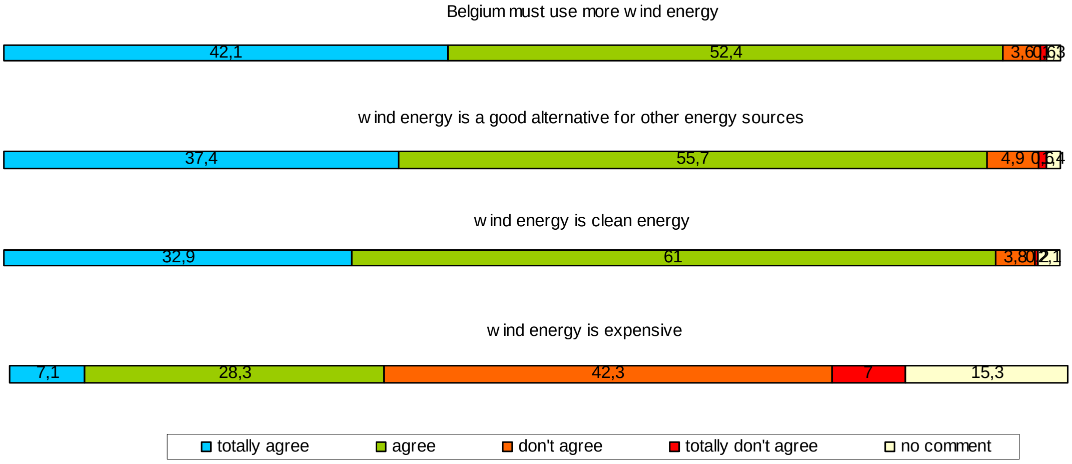

Figure 2. Agreement / disagreement with the statements on wind energy in general, survey 2009 (in %)

Almost everyone (95 % of the respondents) is convinced that Belgium should use more wind energy, almost 94% agrees that wind energy is a clean energy. Both statements are not agreed with by 4% of the people. Almost everyone (93%) also agrees that wind energy is a good alternative for other energy sources; about 6% doesn't agree (totally), 1% has no opinion. It's striking how much people agree with these statements on wind energy in general.

11.3.3.2. Applicability of wind energy

This statement gathers information on the persuasion of applicability of wind energy. It is notable that on this statement more different opinions are noted than on the general wind energy statement. More than one out of three agrees that wind energy is expensive. Quite a lot of people (15%) do not have an opinion on this subject, half of the respondents (49%) does not agree (totally) and thus does not think that wind energy is expensive.

It's obvious that respondents doubt more on the applicability of offshore wind energy than on wind energy in general. The answers on these questions give a clear view on proponents and opponents of wind energy.

11.3.3.3. Offshore wind energy (wind energy at sea)

Three statements sound people’s opinion on the advantages of an offshore wind farm.

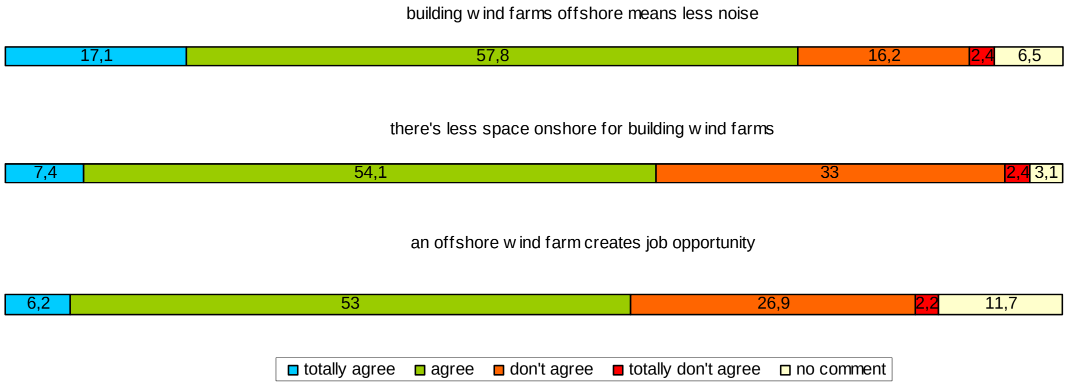

Figure 3. Agreement / disagreement with the statement about advantages of an offshore wind farm, survey 2009 (in %)

Globally a fairly positive image of the sea is set forward. Almost ¾ of the respondents is (totally) convinced that at sea there’s no burden of noise from a wind farm and more than 61% thinks moreover that less space is available on shore for a wind farm. Still one out of three does not agree with this statement. Almost 60% of the respondents think that an offshore wind farm will bring more work to the region whereas less than 30% is not (totally) convinced. On this advantage statement respondents hesitate the most (almost 12% ‘no opinion’).

Two statements sound people’s opinion on the **disadvantages** of an offshore wind farm.

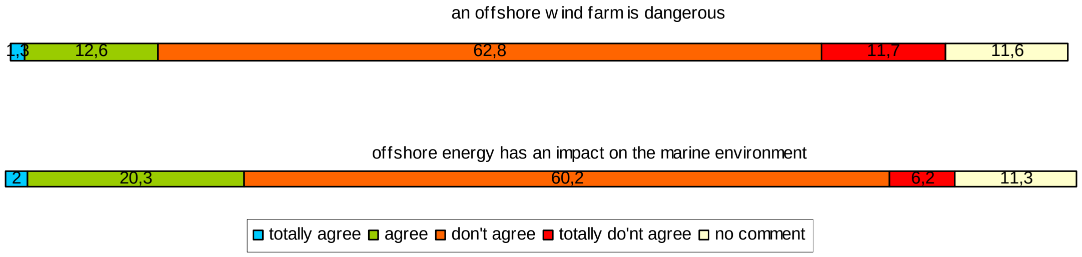

Figure 4. Agreement / disagreement with the statement about the disadvantages of an offshore wind farm, survey 2009 (in %)

Almost ¾ of the respondents doesn’t believe (at all) that an offshore wind farm could be dangerous, although almost 12% has no opinion. Comparable opinions are seen when formulating that a wind farm doesn’t affect nature at sea; 2 out of 3 respondents (totally) don’t agree, a few more than 11% of the respondents has no opinion. Nevertheless almost 25% of the respondents think that a wind farm affects nature.

Assessing people’s **opinion on the view** of an offshore wind farm was done by using following statements:

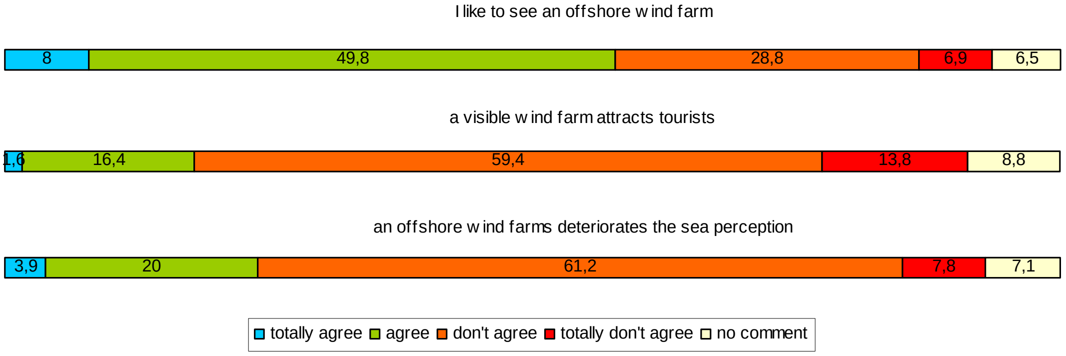

Figure 5. People’s opinion on the view of an offshore wind farm, survey 2009 (in %)

More than half of the respondents (57.8%) (totally) agree with the first statement and more than 1/3 of the respondents (totally) don’t agree to look at a wind farm at sea. A comparable, more generally formulated statement generates more positively results: almost 70% (totally) don’t agree with the statement that a wind farm at sea will affect the ‘sea perception’, and only 24% agree. A majority of the respondents don’t think that a visible offshore wind farm will attract more tourists, only 18% agrees (totally) with his statement.

Finally a statement sound for people’s opinion on the **possibility to buying shares** of wind farms.

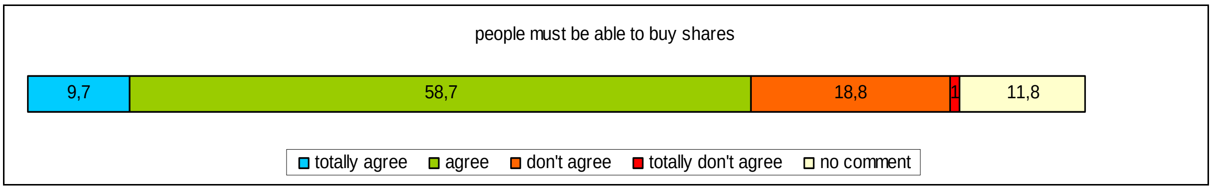

Figure 6. People’s opinion on the possibility to buy shares of an offshore wind farm, survey 2009 (in %)

More than 60% of the respondents agree (totally) that citizens should be able to buy shares of an wind farm. About 12% has no opinion about this and almost 1 out of 5 doesn’t (totally) agree with this statement.

11.3.3.4. Opinion on the construction of an offshore wind farm

Respondents were asked their opinion on the construction of offshore wind farms and the results are put next to the results of 2002.

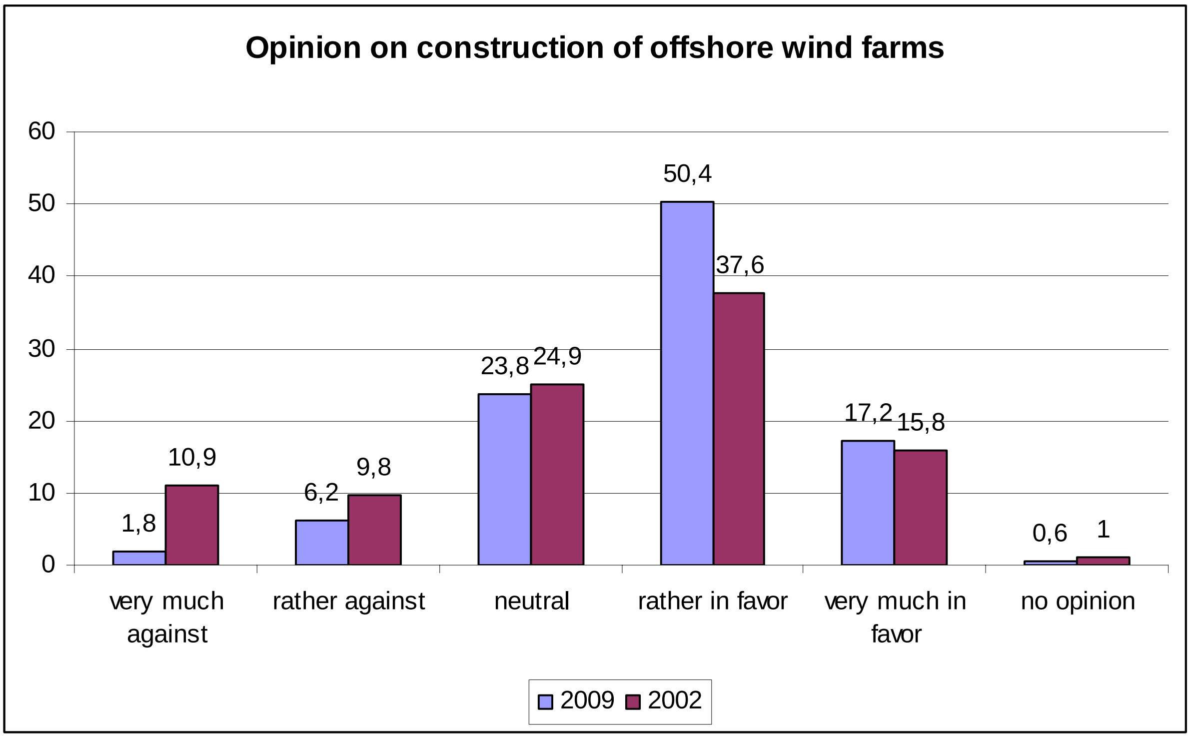

Figure 7. Opinion of Construction of offshore wind farms, survey 2009 compared to survey 2002 (in %)

More than half of the respondents (50.4%) said to be rather in favor of the construction of offshore wind farms and 17% is even very much in favor thereof. A small minority of 8% is (rather) against offshore wind farms. When looking into detail people living at the coast and sailors are less in favor of construction of offshore wind farms than people living further, but still predominantly positive. Age does not seem to matter but gender does seem to matter: men are slightly more positive than women and more people are in favor when they had a higher education. As the higher educated people are more represented in the respondents group this opinion on the construction of offshore wind farm is globally too positively presented.

11.3.3.5. The best place to construct a wind farm

All respondents were asked where they would prefer to have wind farms built. This was an open question so all locations were possible. More than 64% of the respondents think that the sea is a suitable site and this makes the sea most mentioned. For 28% to 39% of the respondents wind farms are also acceptable to be built in industrial zones, harbor areas and along highways. For 7% of the respondents it doesn’t matter where the wind farms are built: for this group every location is good. Less than 9% thinks that wind farms should be built in agricultural areas and a bit more than 1% said that wind farms shouldn’t be built anywhere.

11.3.3.6. Comparison results 2002

It has to be mentioned that not all statement were repeated in 2009, so obviously comparison is only possible for those statements that were proposed in both years. In general respondents in 2009 were as positive towards wind energy as in 2002.

Looking at respondents’ answers about the advantages of offshore wind energy it is seen that proportions between different groups (positive, neutral, negative) didn’t vary much when asked about space onshore to built wind farms, but that there is an important number of respondents in 2009 who are of the opinion that an offshore wind farm wouldn’t raise noise nuisance.

Disadvantages of offshore wind farms are estimated to be less. For both statements (see fig. 3) the number of positive opinions increased, while the number of negative opinions declined when compared to 2002.

When comparing proponents and opponents for both years it can be seen that there is a significant decline of the opponents and at the same time a significant rise of proponents.

Table 2. P values of two samples test for equity of proportion (two sided) tested with the program R 2.9.2. (Agresti, 2002). A P-value lower than 0.05 means a statistical significant trend. Test on question ‘ wat is your opinion on the construction of offshore wind farms.

	2002 (%)	2009 (%)	P value*
Very much against	10.9	1.8	0.375
Rather against	9.8	6.2	0.022
Neurtal	24.9	23.8	0.702
Rather in favor	37.6	50.4	0.000
Very much in favor	15.8	17.2	0.578
No opinion	1.0	0.6	0.665

Analysing the answers for both years for age, gender, education and groups the following can be concluded:

- Age doesn’t matter;
- In both years men are more positive than women;
- In both years the positivity rises with education level, the higher educated people are, the more they are positive;
- In both years local habitants are more negatively than others, with respect to the construction of offshore wind farms.

Additionally a significant change in opinion was noted for the most suitable place to build a wind farm. While in 2002 a bit less than half the respondents were in favor of offshore wind, in 2009 this rose to 2/3 of the respondents in favor. Significantly less respondents find the countryside a good place for wind farms (from nearly 18% to nearly 9%).

11.3.4. Experience, effects and acceptation of the view on offshore wind farm

11.3.4.1. Experiences of the first six windmills of the C-Power project on the Thorntonbank

Firstly, the respondents were asked whether they had knowledge of the C-Power project. At the moment of enquiry six windmills on the Thorntonbank had been built. A majority of 88% answered positively when asked if they were aware of wind farms being built offshore. Men are more aware than women, elderly more than youth and the more educated the more aware respondents were. Results also show that local habitants, sailors and people working at the coastside are more aware of the projects than tourists. It can be clearly concluded that the stronger the bond with the coast/sea the more people are aware of the C-Power project.

Respondents were then asked if they’d seen building activities of the wind farm. About half of the persons questioned answered positively. Again it was clear that the stronger the bond with the coast/sea the more people saw the building activity. From the group of respondents that did see the building activity, 81% indicated that they saw the windmills at sea. A minority of this group (25%) also saw construction activity on land. Construction activity took place in Ostend. From all people questioned in Ostend almost 1/3rd (32%) saw the construction activity on land.

When looking at the communities where enquiries were done, the conditions in which this happened and the visibility in the direction of the sea, it can be concluded that the community where the enquiries are done is important: the windmills seem to be more visible in Blankenberge en De Haan. These two locations look oblique onto the six already built windmills, meaning that a bigger part of the horizon is ‘taken’ by the windmills when compared to the communities of Zeebrugge, Heist or Knokke. In the latter communities the distance to the six windmills is shorter, but the view angle also sharper. It could also be concluded that the windmills are as visible in sunny as in cloudy weather and that the visibility seaward is found to be of minor importance.

When the respondents were asked if they could see the windmills at the moment of questioning, only 12.6% answered positively. Those respondents who answered positively were also asked how acceptable the view on the six windmills was. For a majority (93.7%) the view was acceptable, 4% thought the view was unacceptable and a single person (0.8%) found it totally unacceptable.

All respondents were also shown photo 2 (excellent visibility) of the six windmills already built with viewpoint Blankenberge. The respondents were again asked how acceptable this view was. The results are much comparable to the previous question with the real view; meaning that the acceptability of the real view on the six windmills is very comparable to the acceptability of the simulated view on the six windmills.

Photo 2. Simulation of the first six real windmills of the C-Power, viewpoint from dike in Blankenberge (Simulation and montage: Grontmij)

11.3.4.2. Experiences, effects and acceptance of potential future scenarios

Respondents were asked to look at four different simulations: a first one showing windmills of the three permitted projects being C-Power, Belwind and Eldepasco, followed by a simulation of the Belgian wind farm area fully occupied with windmills (worst cases scenario). Also a simulation of night view and a simulation taken at sea were shown.

Three permitted projects

Respondents were shown photo 3 and asked to assess the seascape using the same set of words as for the picture without windmills (see 11.3.2.3). It was clear that the answers given when seascape pictures with windmills were used, were less uniform than answers given when using the seascape pictures without windmills. For the latter the respondents mostly agreed on positive adjectives whereas the opinion for the simulation with windmills still uses positively adjective but also more negatively loaded adjectives. Still most used adjectives describing picture 4 were positive being beautiful, unique, attractive, freedom and nice and given by 17.8 to 27.5 % of the respondents. These were followed by negative words like disturbed, unpleasant and unattractive (11.4 to 15.1%). Age, gender and education were not determine for this question. When asked how acceptable this view was, 78% answered (totally) acceptable. For the six windmills already built 95.6% answered positively meaning that nearly 18% has no problems with the six windmills but doesn't accept this view (with three projects). A total of 22% of the respondents find the view on the three projects (totally) unacceptable.

Photo 3. Simulation of the three permitted wind farm projects seen from the dike in Blankenberge (Simulation and montage: Grontmij)

Most respondents (85%) don't think these three project will influence the number of visitors at the seaside. Most (90%) of the tourists indicate they will probably or certainly return to the seaside as a day tourist, and 77% will return as a long stay tourist.

Worst case: Belgian wind farm area completely built

Viewing photo 4 respondents were asked if the distance from the windmills to the beach is acceptable. More than 62% thinks this distance is acceptable, but still 20% finds this distance not to be acceptable, 13% finding it a bit acceptable and 5% having no opinion. People indicating finding the distance unacceptable were asked under which conditions this fully built area would become acceptable. The different opinions are shown in figure 7.

Photo 4. Simulation of the fully occupied wind farm area seen from the dike in Blankenberge (Simulation and montage: Grontmij)

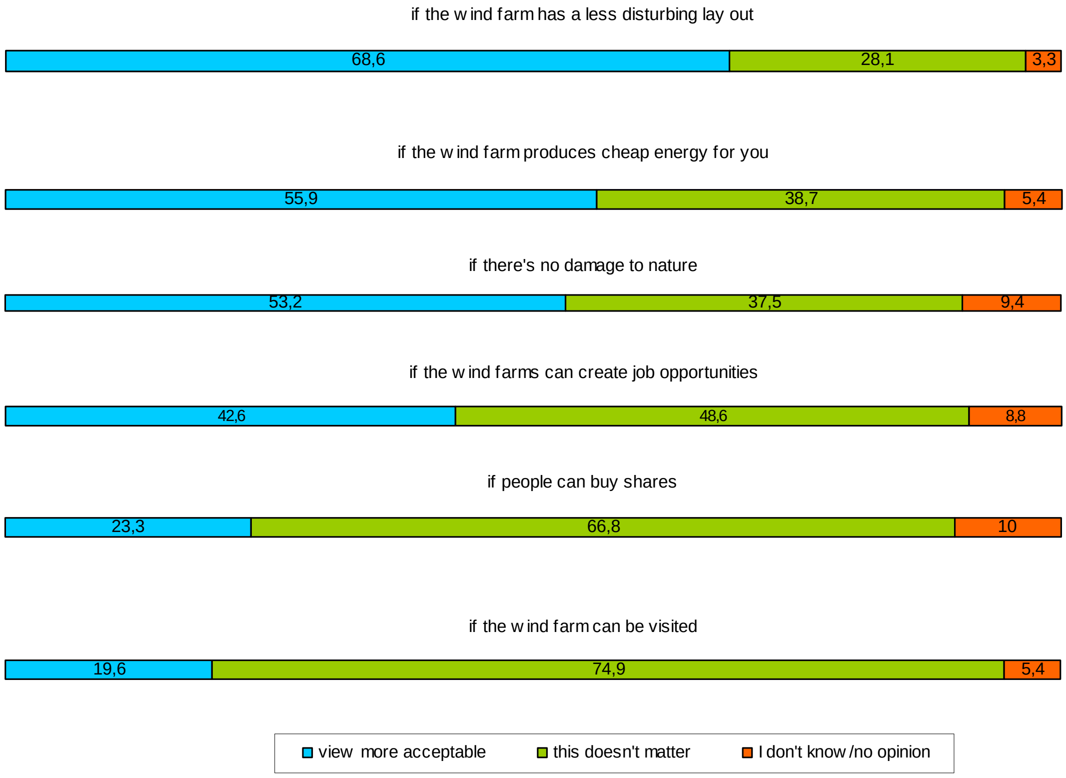

Figure 8. Conditions which could make the view on the fully accupied wind farm area (‘worst case’ simulation) more acceptable, survey 2009 (in % of the Total people that originally thought the view was not or partly acceptable, n=331)

For 84% of those respondents it would become more acceptable if the wind farms were less visible, 68.6% wants the wind farm to have another orientation, 55.9% would find it more acceptable if the wind farms would provide them with cheap energy, 53.2% if there’s no harm for nature, 42.6% if the wind farms would raise work opportunity, 23.3% if people could buy shares and finally 19.6% if the park could be visited.

Night view

The simulation of the night view showed the worst case scenario with all windmills having safety lights on. Asked for the acceptability of this view 90% of the respondents answered having no problem with this view, a minority of 10% finding it (totally) unacceptable.

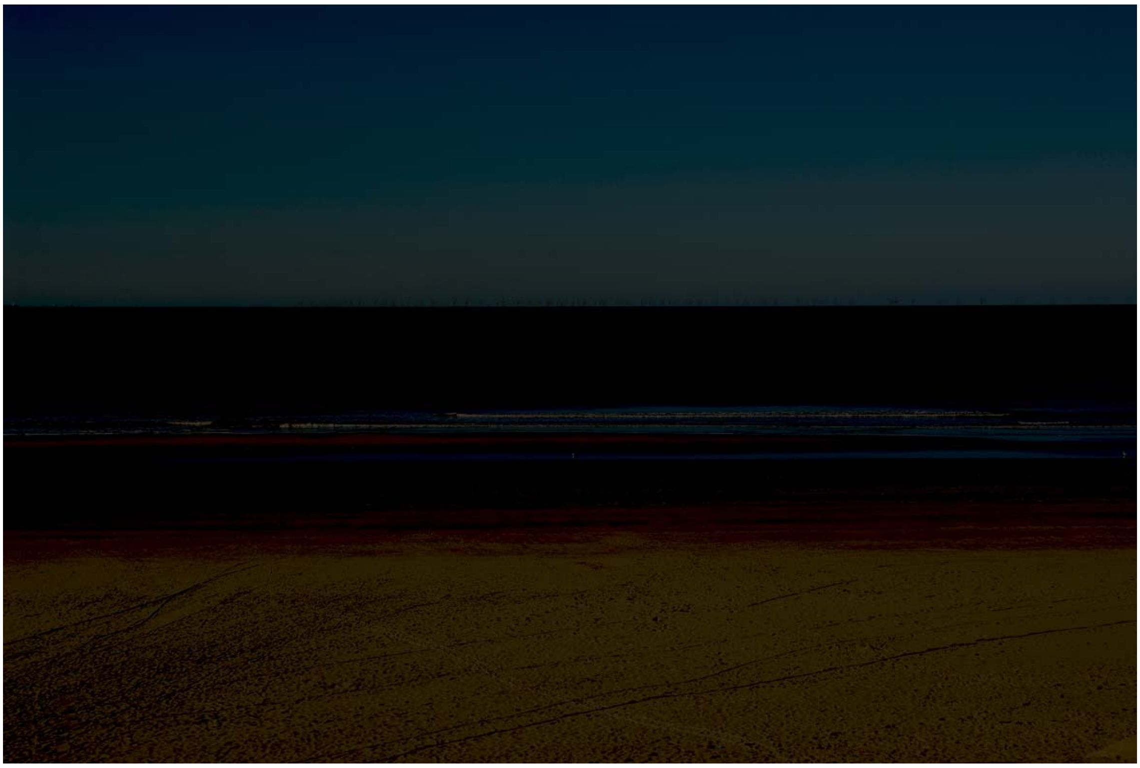

Photo 5. simulation of the fully occupied area (“worst case”), nigh view with safety lights on, viewpoint from dike of Blankenberge (simulation and montage, Grontmij)

At sea view

The worst case situation was also used for the simulation at sea (photo 5). The nearest distance to the windmills is 700 m, viewing direction is seawards to the northwest. Again respondents were asked how acceptable this view was. Still a majority of 55% finds this view acceptable but it is clear that this simulation is the less accepted by the respondents: almost one out of three finds this view unacceptable adding another 10.7% of the people finding it totally unacceptable. This shows again that the distance to the windmills and the proportion of the horizon being taken by the windmills is of utmost importance for the acceptability of the view on wind farms.

Photo 6. Simulation of the worst-case scenario seen from sea, survey 2009 (simulation and montage, Grontmij)

For this simulations the sailors group were specifically asked if they thought this wind farm would restrict their sailing activity. The majority 77.8%) doesn’t think the wind farm will restrict their sailing activity whereas 22.2% thinks it might. When asked if they would alter their sailing route to go and see the wind farms, 71.1% said they would do so.

11.3.4.3. Comparisons results 2002

In 2009 a series of new questions on the already built six windmills of the C-Power project were asked. In both years simulations were shown to the respondents but on the 2009 simulations the windmills are farther away from the coast. In 2002 plans existed to construct windmills at 6 and 12 km out of the coast. Picture 5 gives an example of the used simulations in 2002 and 2009.

Photo 7. Simulation of the picture used in 2009 (left) and 2002 (right) (simulation and montage, Grontmij)

The question on acceptability in 2002 was only asked for the simulations at 6 km. At that time 62.2% of the respondents did think this simulation was (very) acceptable and 36% (very) unacceptable. Compared to the 2009 situation the latter scored significantly better: 95.6% (very) acceptable for the simulations of the six windmills, 77.8% (very) acceptable for the simulations of the three permitted wind farms and 90.3% (very) acceptable for the night view. The 2009 simulations are at a greater distance offshore which leads to a more positive attitude and a bigger acceptability (which was also seen with the at sea view simulation in 11.4.3.2).

The 2009 simulations were clearly more positively received than the 2002 ones, which can be seen when compared people's opinion on the simulations of the seascape without and with wind farms. In 2002 the seascape with windmills at 6 km offshore was mainly negatively assessed using adjectives as affected, ugly, disturbed followed by clean, whereas in 2009 for the simulation with the three permitted project people assessed the simulations with positive adjective like beautiful, unique, attractive, freedom and clean, only then followed by affected, disturbed an unattractive. But still in 2009 more negative adjectives were used when compared to the simulations without windmills.

11.3.5. Information wish of respondents

As a last question respondents were asked on which aspects they would like to be informed. The most common answers given are shown in figure 9.

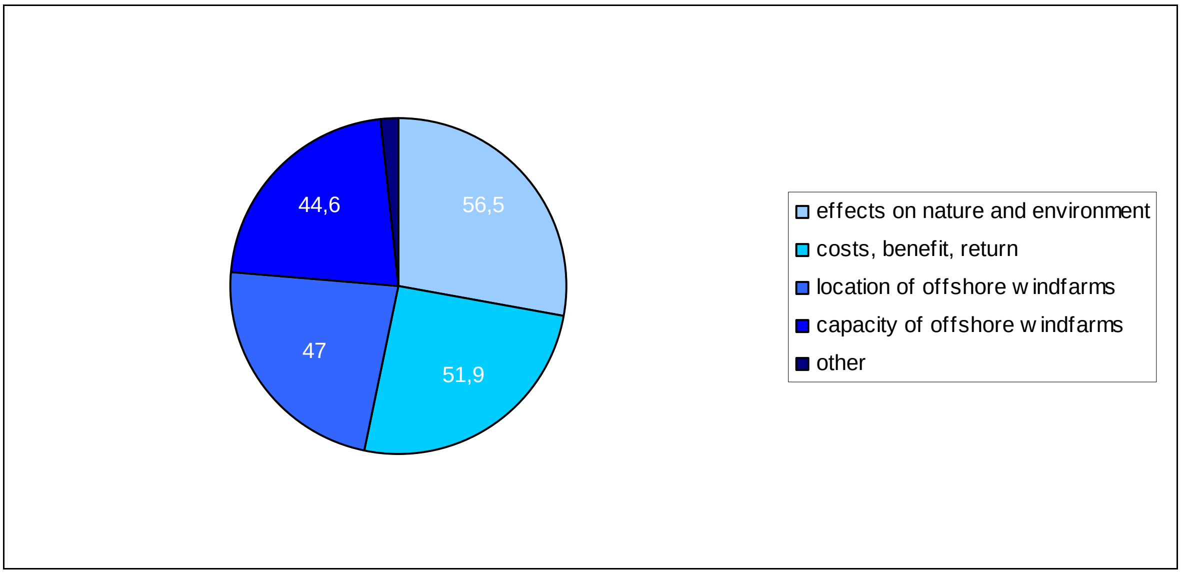

Figure 9. Information whishes of respondents on different aspects of offshore wind farms, survey 2009 (in %)

11.3.6. Efficacy of the use of simulations in inquiries

The simulation of the six windmills were compared to the pictures taken of the real situation in November 2009. Pictures were taken from two viewpoints (dike and a higher location e.g. top of building) in Blankenberge, Ostend en Nieuwpoort. Results are given in 11.3.4.1. It can be concluded that the simulations provide a fairly good approximation of the real situation. It can thus be assumed that the simulations of the future developments are a good approach of the expected real situation. The simulations show the windmills in excellent visibility (optimal contrast) which makes the simulated windmills more visible than they mostly really will be as with rainy weather and less contrast conditions more windmills will become less visible.

- From the experiences of 2002 and 2009 the following recommendations follow:
- To be relevant the simulations have to be made in optimal visibility with high contrast
- To choose a higher viewpoint than the beach (e.g. dike)
- For simulations at sea or from a closer viewpoint attention has to be paid in using the right colors, shaping and lights for the windmills.

11.4. Conclusions and recommendations

In general it can be concluded that respondents in 2009 have a similar positive opinion towards wind energy as respondents in 2002. It is striking that the number of undecided respondents decreased in 2009, resulting in **a 10% increase** for the group of respondents that have a positive opinion on the view of offshore wind farms.

From the 2009 results it is clear that distance and the number of windmills (and thus the proportion of the horizon 'occupied') are very important when it comes to acceptance of offshore wind farms. The 2009 survey also confirmed the underlying factors in public opinion on off shore wind farms, such as seascape and visibility. This has also been concluded from similar research in other countries and from the answers of the respondents to the question of what would make the windmills more acceptable: 84% of the respondents who found the proposed worst case scenario (totally) unacceptable answered that this would become acceptable if the wind farm was less visible. Nevertheless this group of people who were opposed to the worst case scenario, in which the total Belgian off shore wind farm area is filled up with, is only 33 % (of which 20% not accepting and 13% more or less accepting). A large number of these respondents also stated that a less disturbing layout would make the view more acceptable. Besides the visual aspects other factors play a role: if the wind farm would produce cheap energy, if there was no damage for nature, or if the park would give rise to more work opportunities. The possibilities to buy shares or visit the park are of less importance.

It is also concluded that the used simulations are a fairly good approximation of the real situation. It can thus be assumed that the simulations of the future situation adequately reproduce the expected future reality. From the experiences of 2002 and 2009 it can be recommended, in order to increase relevance, to make the simulations in optimal visibility with high contrast, to choose a higher viewpoint than the beach (e.g. dike), and for the simulations at sea or from a closer viewpoint to pay attention to using the right colors, shaping and lights for the windmills when producing the simulations.

For future projects (especially the one on the sandbank in front of C-Power and at a shorter distance from the coastline) to be developed in the Belgian offshore wind farm area it is recommended to take into account the conclusions of this study regarding the visibility of wind farms (number, distance, layout,…) as factors of public acceptance. This is especially the case for the viewpoints from the area Ostend - De Haan - Blankenberge that have the highest proportion of their horizon 'occupied' by windmills. Aspects of orientation, height and spatial layout of the windmills (cumulative with the existing projects) are of utmost importance in response to indentify potential visual effect of the proposed developments A comparative survey can be made of the alternative design proposals with different patterns and height of the windmills. Future monitoring could evaluate the effect of the planned project to be built in front of C-Power so that eventually negative effects can be mitigated during the construction of this wind farm. The proposed layout and choice of the windmills (height,…) is generally a compromise between capturing the most wind and taking into account technical, functional and ecological constraints. The research question is if the aim of creating a harmonious and positive visual effect can also play a significant role in the layout of off shore wind farms.

For that simulation different layouts en windmills can be used. Especially the perception in the viewpoints Ostend, Blankenberge and De Haan need to be integrated in this evaluation. For all wind farm projects a repeated inquiry on a regularly basis (eg 5 years) is proposed.

11.5. Literature

Houthaeve, R. & Vanhulle, A. (2010) Monitoring van de effecten van far-shore windmolenparken op het landschap – deel socio-landschappelijk onderzoek, studieopdracht BMM, 108 pp.

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Schöne, M (2004) in Senternovem, Matton office, Dans der turbines, studie naar windturbines en landschappen, Duurzame Energie.

WES (2002) Landschappelijke beleving van windmolenparken in zee, rapport in opdracht van BMM, 74pp + bijlagen.

WES (2003) Landschappelijke beleving van far-shore windmolenparken, beoordeling gebaseerd op groepsdiscussies uitgevoerd in opdracht van C-Power, 25 pp + bijlagen.

Annexes

Annex 1: Systematic species list of hard substratum epifauna

2008-2009 zonder soorten < 1 mm		
	2008	2009
PROTOZOA		
CILIOPHORA (Ciliata)		
Polyhymenophora		
Folliculinidae	x	
PLANTAE		
CHLOROPHYTA		
Ulvophyceae		
Ulva intestinalis or *U. Compressa*	x	x
Blidingia minima (Nägeli ex Kützing) Kylin, 1947	x	x
Ulothrix flacca (Dillwyn) Thuret in Le Jolis, 1863	x	x
RHODOPHYTA		
Bangiophyceae		
Bangia fuscopurpurea (Dillwyn) Lyngbye, 1819	x	
Porphyra umbilicalis (Linnaeus) Kützing 1843		x^F
Acrochaetium secundatum (Lyngbye) Nägeli 1858		x^F
CHROMISTA		
HETEROKONTOPHYTA		
Phaeophyceae		
Fucus vesiculosus Linnaeus 1753		x^F
Petalonia fascia (O.F.Müller) Kuntze 1898		x
Scytosiphon lomentaria (Lyngbye) Link, 1833		x^F
ANIMALIA		
CNIDARIA		
Hydrozoa		
Clytia hemisphaerica (Linnaeus, 1767)		x

Hydractinia echinata (Fleming, 1828)		x
Leuckartiara octona (Fleming, 1823)	x	
Obelia cfr. dichotoma (Linnaeus, 1758)		x
Obelia longissima (Pallas, 1766)	x	
Tubularia indivisa Linnaeus, 1758		x
Tubularia (Ectopleura) larynx Ellis & Solander, 1786		x (10)
Anthozoa		
Metridium senile (Linnaeus, 1767)		x
Sagartia troglodytes (Price in Johnston, 1847)	x	x
Urticina felina (Linnaeus, 1761)		x
NEMERTINA		
Lineidae		x
Oerstedia dorsalis (Abildgaard, 1806)		x
PLATYHELMINTHES		
Leptoplana tremellaris (Müller, 1774) Örsted 1843		x
ANNELIDA		
Chaetopterus variopedatus Cuvier 1827		x
Eulalia viridis (Johnston, 1829)		x
Gattyana cirrhosa (Pallas, 1766)	x	x
Harmothoe pachenstegeri Michaelsen, 1896		x
Harmothoe extenuata (Grube, 1840)	x	x
Lanice conchilega (Pallas, 1766)	x	x
Lepidonotus squamatus (Linnaeus, 1758)	x	x
Myrianida (Autolytus) sp. (prolifera-edwardsi-brachycephalus complex*)*	x	x
Nereis (Eunereis) longissima Johnston, 1840		x
Nereis pelagica Linnaeus, 1758		x
Pectinaria koreni (Malmgren, 1866)		x
Pholoe synophthalmica Claparède, 1868		x
Phyllodoce mucosa (Örsted, 1843)		x
Phyllodoce longipes Kinberg, 1866		x
Pomatoceros triqueter (Linneaus, 1758)	x	x
Sabellaria spinulosa Leuckart, 1849		x
MOLLUSCA		
Bivalvia		
Aequipecten opercularis (Linneaus, 1758)	x	x
Abra alba (Wood W., 1802)		x

Heteranomia squamula (Linneaus, 1758)	x	x
Mytilus edulis (Linneaus, 1758)	x	x
Parvicardium spec.	x	
Spisula solida (Linneaus, 1758)	x	
Venerupis senegalensis (Gmelin, 1791)	x	x
Gastropoda		
Aeolidia papillosa (Linnaeus, 1761)		x
Crepidula fornicata (Linneaus, 1758)	x	x
Cuthona gymnota (Couthouy, 1838)		x
Epitonium clathratulum (Kanmacher, 1798)	x	x
Facelina bostoniensis (Couthouy, 1838)	x	x
Nassarius incrassatus (Ström, 1768)	x	x
Odostomia turrita Hanley, 1844		x
Onchidoris bilamellata (Linnaeus, 1767).		x
Onchidoris muricata (Müller, 1776)		x
Pusillina inconspicua (Alder, 1844)	x	x
ARTHROPODA - CRUSTACEA		
Cirripedia		
Elminius modestus Darwin, 1854	x	x
Balanus crenatus Bruguiére, 1789		x
Balanus perforatus Bruguiére, 1789	x	x
Megabalanus coccopoma (Darwin, 1854)	x	
Semibalanus balanoides (Linnaeus, 1758)		x
Amphipoda		
Amphilochus neapolitanus Della Valle, 1893	x	
Aora gracilis (Bate, 1857)	x	
Atylus swammerdami (Milne-Edwards, 1830)	x	
Corophium (Monocorophium) sextonae (Crawford, 1937)	x	
Corophium (Monocorophium) acherusicum (Costa, 1851)		x
Iphimedia nexa Myers & McGrath, 1987	x	
Jassa herdmani (Walker, 1893)	x	x
Jassa marmorata (Holmes, 1903)	x	x
Phtisica marina Slabber, 1769	x	x
Stenothoe valida Dana 1852		x (10)
Stenothoe spec.	x	
Decapoda		
Cancer pagurus Linnaeus, 1758		x
Galathea intermedia Liljeborg, 1851	x	
Hippolyte varians Leach, 1814	x	

Liocarcinus depurator (Linnaeus, 1758)	x	
Liocarcinus holsatus (Fabricius, 1775)	x	x©
Maja squinado (Herbst, 1788)		x©
Macropodia linaresi Forest & Zariquiey-Alvarez, 1964	x	x
Necora puber (Linnaeus, 1767)	x	x©
Pagurus bernhardus (Linnaeus, 1758)	x	x©
Pilumnus hirtellus (Linnaeus, 1761)	x	x
Pisidia longicornis (Linnaeus, 1767)	x	x
Thoralus cranchii (Leach, 1817)	x	
ARTHROPODA - HEXAPODA		
Diptera		
Telmatogeton japonicus Tokunaga, 1933	x	x
ENTOPROCTA		
Pedicellina nutans Dalyell 1848		x (10)
BRYOZOA		
Cyclostomatida		
Cheilostomatida		
Electra pilosa (Linnaeus, 1767)	x	x
Conopeum reticulum (Linnaeus, 1767)		x
Callopora dumerilii (Audouin, 1826)		x (10)
ECHINODERMATA		
Asteroidea		
Asterias rubens Linnaeus, 1758		x
Echinoidea		
Psammechinus miliaris (Gmelin, 1778)	x	x
Ophiuroidea		
Ophiura spec. juv.		x

Benthic species - not typical fouling

Intertidal species

x (10) only in February 2010

x© identified on video

x^{F} not in intertidal scrape samples

Annex 2: Systematic species list soft substratum macrobenthos

Phylum	Class	Order	Family	Species	shortname
Annelida	Clitellata	/	/	Oligochaeta sp.	Oligsp.
	Polychaeta	/	Orbiniidae	*Orbinia* sp.	Orbisp.
		Capitellida	Capitellidae	*Capitella capitata*	Capicapi
				Capitellidae sp.	Capisp.
				Heteromastus filiformis	Hetefili
				Notomastus latericeus	Notolate
		Cirratulida	Cirratulidae	Cirratulidae sp.	Cirrsp.
				Cirratulus filiformis	Cirrfili
			Paraonidae	*Aricidea minuta*	Aricminu
				Paraonis fulgens	Parafulg
		Eunicida	Dorvilleidae	*Parougia eliasoni*	Paroelia
			Lumbrineridae	*Lumbrineris* sp.	Lumbsp.
		Magelonida	Magelonidae	*Magelona filiformis*	Magefili
				Magelona mirabilis	Magemira
		Opheliida	Opheliidae	*Euzonus flabelligerus*	Euzoflab
				Ophelia limacina	Ophelima
				Travisia forbesii	Travforb
		Phyllodocida	Glyceridae	*Glycera alba*	Glycalba
				Glycera lapidum	Glyclapi
				Glycera sp.	Glycsp.
			Hesionidae	*Microphthalmus similis*	Micrsimi
			Nephtyidae	*Nephtys caeca*	Nephcaec
				Nephtys cirrosa	Nephcirr
				Nephtys hombergii	Nephhomb
				Nephtys longosetosa	Nephlong
				Nephtys sp.	Nephsp.
			Nereididae	*Eunereis longissima*	Eunelong
				Nereididae sp.	Neresp.
			Phyllodocidae	*Eteone longa*	Eteolong
				Hesionura elongata	Hesielon
				Phyllodoce lineata	Phylline
				Phyllodoce maculata	Phylmacu
				Phyllodoce rosea	Phylrose
			Poecilochaetidae	*Poecilichaetus serpens*	Poecserp
			Polynoidae	*Harmothoe extenuata*	Harmexte
				Malmgreniella glabra	Malmglab
			Syllidae	*Myrianida prolifera*	Myriprol
				Sphaerosyllis hystrix	Sphahyst
				Syllis armillaris	Syllarmi
		Spionida	Spionidae	*Aonides oxycephala*	Aonioxyc
				Aonides paucibranchiata	Aonipauc
				Scolelepis bonnieri	Scolbonn
				Scolelepis foliosa	Scolfoli
				Scolelepis squamata	Scolsqua
				Scoloplos armiger	Scolarmi
				Spio filicornis	Spiofili
				Spio goniocephala	Spiogoni
				Spiophanes bombyx	Spiobomb
		Terebellida	Terebellidae	Ampharetinae sp.	Amphsp.
				Lanice conchilega	Laniconc
				Thelepus cincinnatus	Thelcinc
			Pectinaridae	*Pectinaria koreni*	Pectkore
Arthropoda	Insecta	/	/	Diptera larva	Diptlarv
	Malacostraca	Amphipoda	/	Amphipode sp.	Amphsp.
			Atylidae	*Atylus falcatus*	Atylfalc
				Atylus sp.	Atylsp.

				Atylus swammerdami	Atylswam
			Caprellidae	*Pariambus typicus*	Paritypi
			Corophiidae	*Corophium volutator*	Corovolu
			Dexaminidae	*Dexamine thea*	Dexathea
			Gammaridae	Gammaridae sp.	Gammsp.
			Leucothoidae	*Leucothoe incisa*	Leucinci
				Leucothoe lilljeborgi	Leuclill
			Lysianassidae	*Orchomonella nana*	Orchnana
			Melitidae	*Abludomelita obtusata*	Abluobtu
				Maerella tenuimana	MaerTenu
			Melphidippidae	*Megaluropus agilis*	Megaagil
			Oedicerotidae	*Perioculodes longimanus*	Perilong
				Pontocrates arenarius	Pontaren
			Pontoporeiidae	*Bathyporeia elegans*	Batheleg
				Bathyporeia gracilis	Bathgrac
				Bathyporeia guilliamsoniana	Bathguil
				Bathyporeia juv.	Bathjuv.
				Bathyporeia pelagica	Bathpela
				Bathyporeia pilosa	Bathpilo
				Bathyporeia sarsi	Bathsars
				Bathyporeia sp.	Bathsp.
			Urothoidae	*Urothoe brevicornis*	Urotbrev
				Urothoe elegans	Uroteleg
				Urothoe poseidonis	Urotpose
				Urothoe pulchella	Urotpulc
		Cumacea	/	Cumacea sp.	Cumasp.
			Bodotriidae	*Bodotria arenosa*	Bodoaren
				Bodotria pulchella	Bodopulc
				Diastylis rathkei	Diasrath
				Diastylis rugosa	Diasrugo
			Pseudocumatidae	*Pseudocuma gilsoni*	Pseugils
				Pseudocuma longicorne	Pseulong
		Decapoda	/	*Brachyura* juv.	Bracjuv.
				Brachyura sp.	Bracsp.
				Decapoda juv.	Decajuv.
			Callianassidae	*Callianassa tyrrhena*	Calltyrr
			Corystidae	*Corystes cassivelaunus*	Corycass
			Crangonidae	*Crangon crangon*	Crancran
				Philocheras trispinosus	Philtris
			Oregoniidae	Oregoniidae sp.	Oregsp.
			Paguridae	*Pagurus bernhardus*	Pagubern
				Pagurus forbesii	Paguforb
				Pagurus pubescens	Pagupube
			Pinnotheridae	*Pinnotheres pisum*	Pinnpisu
			Portunidae	*Liocarcinus marmoreus*	Liocmarm
				Portunidae sp.	Portsp.
			Processidae	*Processa modica*	Procmodi
				Processa nouveli holthuisi	Procnouv
			Thiidae	*Thia scutellata*	Thiascut
			Upogebiidae	*Upogebia deltaura*	Upogdelt
				Upogebia sp.	Upogsp.
		Isopoda	/	Isopoda sp.	Isopsp.
			Cirolanidae	*Eurydice spinigera*	Euryspin
		Mysida	/	Mysida sp.	Mysisp.
			Mysidae	*Paramysis arenosa*	Paraaren
				Gastrosaccus spinifer	Gastspin
	Maxillopoda	Calanoida	/	Cyclopoida sp.	Cyclsp.
			Centropagidae	*Centropages* sp.	Centsp.
			Pontellidae	*Labidocera* sp.	Labisp.

			Temoridae	*Eurytemora* sp.	Eurysp.
				Eurytemora velox	Euryvelo
Chaetognatha	/	/	/	*Chaetognatha* sp.	Chaesp.
Chordata	Actinopterygii	/	/	*Callionymus* sp.	Callsp.
				Pomatoschistus microps	Pomamicr
		Perciformes	Ammodytidae	*Ammodytes tobianus*	Ammotobi
				Ammodytidae sp.	Ammosp.
	Leptocardii		Branchiostomidae	*Branchiostoma lanceolatum*	Branlanc
Cnidaria	Anthozoa	/	/	Anthozoa sp.	Anthsp.
		Actiniaria	/	*Actinaria* sp.	Actisp.
			Edwardsiidae	*Edwardsia* sp.	Edwasp.
	Hydrozoa	/	/	Hydrozoa *sp.*	Hydrsp.
Echinodermata	Echinoidea	Echinoida	Fibulariidae	*Echinocyamus pusillus*	Echipusi
			Spatangoidae	*Echinocardium cordatum*	Echicord
	Ophiuroidea	Asteroidea	Asteriidae	*Asterias rubens*	Asterube
		Ophiurida	Ophiuridae	*Ophiura albida*	Ophialbi
				Ophiura ophiura	Ophiophi
Mollusca	Bivalvia	/	/	Bivalvia sp.	Bivasp.
		Arcoida	Arcidae	*Arca* sp.	Arcasp.
			Noetiidae	*Striarca lactea*	Strilact
		Euheterodonta incertae sedis	Ungulinidae	*Diplodonta rotundata*	Diplrotu
		Veneroida	Mactridae	*Spisula elliptica*	Spiselli
				Spisula subtruncata	Spissubt
			Semelidae	*Abra alba*	Abraalba
			Solenidae	*Ensis arcuatus*	Ensiarcu
				Ensis ensis	Ensiensi
			Tellinidae	*Tellina fabula*	Tellfabu
				Macoma balthica	Macobalt
				Tellina pygmaea	Tellpygm
				Tellina tenuis	Telltenu
	Cephalopoda	Sepiolida	Sepiolidae	*Sepiola atlantica*	Sepiatla
	Gastropoda	Hypsogastropoda	Naticidae	*Euspira pulchella*	Eusppulc
		Nudibranchia	Eubranchidae	*Eubranchidae* sp.	Eubrsp.
			Onchidoridoidea	*Onchidoridoidea* sp.	Onchsp.
Nematoda	/	/	/	Nematoda sp.	Nemasp.
Nemertina	/	/	/	Nemertina sp.	Nemesp.
Sipuncula	/	/	/	Sipunculidae sp.	Sipusp.

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).

Annex 3 SIMPER analyses

SIMPER analysis based on densities: Similarities within locations at the Bligh Bank, Goote Bank and Thorntonbank in 2009

Group 2009	**Biotic similarity %**
BBE	29,67
BBI	35,59
GBC	34,99
TBE	34,44
TBC	40,63
TBI (A)	36,06
TBI (B)	43,4

SIMPER analysis based on densities: Dissimilarities between the Bligh Bank, Goote Bank and Thorntonbank in 2009

Group 2009	**Biotic dissimilarity %**
BBE - BBI	71,35
BBE - GBC	74,91
BBI - GBC	69,84
GBC - TBC	63,44
GBC - TBE	67,01
TBC - TBE	63,39
GBC - TBI (A)	66,18
TBC - TBI (A)	60,99
TBE - TBI (A)	64,18
GBC - TBI (B)	63,01
TBC - TBI (B)	58,48
TBE - TBI (B)	63,46
TBI (A) - TBI (B)	60,76

SIMPER analysis based on densities: Dissimilarities between 2005, 2008 and 2009

Group	Average dissimilarity %
BBE 08 - BBE 09	80,53
BBI 08 - BBI 09	71,6
GBC 08 - GBC 09	76,54
TBE 08 - TBE 09	73,95
TBC 08 - TBC 09	73,45
TBI (A) 08 - TBI (A) 09	74,85
TBI (B) 08 - TBI (B) 09	70,86
TBE 05 - TBE 09	71,92
TBC 05 - TBC 09	65,04
TBI (A) 05 - TBI (A) 09	64,11
TBI (B) 05 - TBI (B) 09	64,44
GBC 05- GBC 09	70,91
TBE 05 - TBE 08	75,68
TBC 05 - TBC 08	73,47
TBI (A) 05 - TBI (A) 08	76,64
TBI (B) 05 - TBI (B) 08	75,52
GBC 05 - GBC 08	75,57

SIMPER analysis based on biomass: Dissimilarities between 2005, 2008 and 2009

Group	Average dissimilarity %
BBE 08 - BBE 09	84,97
BBI 08 - BBI 09	74,02
GBC 08 - GBC 09	80,87
TBE 08 - TBE 09	77,8
TBC 08 - TBC 09	80,96
TBI (A) 08 - TBI (A) 09	80,24
TBI (B) 08 - TBI (B) 09	77,9
TBE 05 - TBE 09	68,74
TBC 05 - TBC 09	70,18
TBI (A) 05 - TBI (A) 09	68,55
TBI (B) 05 - TBI (B) 09	62,7
GBC 05- GBC 09	77,9
TBE 05 - TBE 08	81,28
TBC 05 - TBC 08	82,18
TBI (A) 05 - TBI (A) 08	81,99
TBI (B) 05 - TBI (B) 08	80,5
GBC 05 - GBC 08	82,26

Annex 4: Similarities within locations at the Bligh Bank, Goote Bank and Thorntonbank (SIMPER based on densities)

Group BBE 08 Av. similarity: 20,83					**Group BBE 09** Av. similarity: 33,91			
Species	Av.Abund	Av.Sim	Contrib%		Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	7,5	4,01	19,24		*Nephtys cirrosa*	9,15	17,62	51,97
Nephtys caeca	4,73	3,89	18,67		*Bathyporeia guilliamsoniana*	5,94	6,36	18,76
Spiophanes bombyx	8,17	2,77	13,3		*Spiophanes bombyx*	3,15	3,33	9,81
Bathyporeia elegans	5,42	2,21	10,63		*Thia scutellata*	1,77	1,09	3,21
Group BBI 08 Average similarity: 36,08					**Group BBI 09** Average similarity: 35,59			
Species	Av.Abund	Av.Sim	Contrib%		Species	Av.Abund	Av.Sim	Contrib%
Spiophanes bombyx	12,43	9,13	25,3		*Nephtys cirrosa*	8,42	10,96	30,8
Nephtys cirrosa	10,21	7,93	21,97		*Bathyporeia guilliamsoniana*	6,25	4,62	12,98
Bathyporeia elegans	6,54	3,31	9,18		*Bathyporeia elegans*	4,27	3,72	10,44
Nemertea sp.	3,71	2,03	5,64		*Spiophanes bombyx*	4,03	2,35	6,6
Eteone longa	3,38	1,8	4,98		*Glycera lapidum*	2,89	1,8	5,06
Nephtys caeca	3,2	1,78	4,93		*Spio goniocephala*	2,49	1,77	4,96
Group GBC 08 Average similarity: 25,59					**Group GBC 09** Average similarity: 34,99			
Species	Av.Abund	Av.Sim	Contrib%		Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	8,58	6,66	26,03		*Nephtys cirrosa*	7,85	11,28	32,25
Spiophanes bombyx	10,58	6,44	25,16		*Nemertina sp.*	4,19	4,1	11,72
Spio goniocephala	3,19	1,83	7,14		*Spio goniocephala*	3,35	3,51	10,04
Nephtys caeca	3,45	1,41	5,52		*Spiophanes bombyx*	3,35	3,11	8,88
Urothoe brevicornis	2,61	1,2	4,71		*Ophelia limacina*	3,27	2,84	8,13
Nemertea sp.	3,46	0,94	3,67		*Bathyporeia elegans*	2,28	1,83	5,24

Group GBC 05
Av. similarity: 40,17

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	8,03	14,27	35,52
Urothoe brevicornis	9,69	10,24	25,49
Spiophanes bombyx	3,54	4,56	11,36
Bathyporeia guilliamsoniana	3,13	2,3	5,74
Spio goniocephala	1,98	1,83	4,54

Group GBC 08
Av. similarity: 25,59

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	8,58	6,66	26,03
Spiophanes bombyx	10,58	6,44	25,16
Spio goniocephala	3,19	1,83	7,14
Nephtys caeca	3,45	1,41	5,52
Urothoe brevicornis	2,61	1,2	4,71

Group GBC 09
Av. similarity: 34,99

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	7,85	11,28	32,25
Nemertina sp.	4,19	4,1	11,72
Spio goniocephala	3,35	3,51	10,04
Spiophanes bombyx	3,35	3,11	8,88
Ophelia limacina	3,27	2,84	8,13

Group TBC 05
Av. similarity: 49,09

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	9,57	17,29	35,22
Urothoe brevicornis	12,89	13,64	27,78
Spiophanes bombyx	4,84	5,64	11,49
Bathyporeia guilliamsoniana	4,59	3,85	7,85
Thia scutellata	2,84	2,78	5,66
Spio goniocephala	2,56	2,71	5,52

Group TBC 08
Av. similarity: 28,49

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	7,57	7,5	26,34
Nephtys caeca	5,17	4,7	16,5
Spiophanes bombyx	6,96	4,49	15,75
Spio goniocephala	3,1	2,47	8,66
Bathyporeia elegans	3,36	1,57	5,51
Bathyporeia guilliamsoniana	2,61	1,47	5,15

Group TBC 09
Av. similarity: 40,63

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	11,4	16	39,39
Spiophanes bombyx	8,93	6,3	15,5
Bathyporeia elegans	5,25	3,53	8,68
Spio goniocephala	2,99	2,9	7,14
Ophelia limacina	2,64	2,66	6,54
Urothoe brevicornis	6,22	2,11	5,2

Group TBE 05
Av. similarity: 35,39

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	7,62	17,23	48,7
Urothoe brevicornis	9,94	6,15	17,38
Spio goniocephala	2,13	2,76	7,79
Spiophanes bombyx	3,52	2,5	7,08
Thia scutellata	2,31	2,02	5,71
Leucothoe incisa	1,93	0,74	2,09

Group TBE 08
Av. similarity: 32,32

Species	Av.Abund	Av.Sim	Contrib%
Spiophanes bombyx	16,9	8,88	27,48
Nephtys cirrosa	7,15	5,19	16,07
Urothoe brevicornis	8,32	4,94	15,29
Nephtys caeca	4,93	2,61	8,08
Nemertea sp.	4,1	1,49	4,61
Bathyporeia elegans	3	1,23	3,82

Group TBE 09
Av. similarity: 34,44

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	10,54	15,46	44,89
Urothoe brevicornis	7,22	3,29	9,56
Spiophanes bombyx	6,27	2,91	8,46
Nemertina sp.	5,2	2,67	7,75
Echinocardium cordatum	4,96	2,21	6,41
Bathyporeia elegans	2,32	1,23	3,59

Group TBI A 05
Av. similarity: 50,36

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	9,44	20,38	40,47
Urothoe brevicornis	9,93	13,07	25,96
Bathyporeia guilliamsoniana	6	7,2	14,29
Spiophanes bombyx	4,3	3,63	7,21

Group TBI A 08
Av. similarity: 13,26

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	5,17	3,66	27,61
Spiophanes bombyx	4,41	3,25	24,54
Bathyporeia guilliamsoniana	2,67	1,42	10,72
Bathyporeia pelagica	2,89	1,25	9,43

Group TBI A 09
Av. similarity: 43,33

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	11,83	21,3	49,14
Spiophanes bombyx	6,09	5,71	13,18
Bathyporeia elegans	5,41	5,64	13,02
Urothoe brevicornis	4,2	2	4,62

Group TBI B 05
Av. similarity: 43,10

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	7,87	24,62	57,14
Spio goniocephala	2,84	5,68	13,18
Urothoe brevicornis	5,95	4,96	11,52
Gastrosaccus spinifer	1,68	2,07	4,79
Spiophanes bombyx	2,35	1,79	4,14

Group TBI B 08
Av. similarity: 28,54

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	7,23	8,13	28,5
Spiophanes bombyx	6,08	5,07	17,77
Nephtys caeca	3,73	3,65	12,77
Nemertea sp.	3,61	1,91	6,69
Spio goniocephala	2,87	1,54	5,4

Group TBI B 09
Av. similarity: 43,40

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	11,46	22,68	52,25
Spiophanes bombyx	4,42	5,13	11,82
Spio goniocephala	3,58	4,72	10,88
Bathyporeia elegans	2,67	2,15	4,96
Ophelia limacina	2,62	1,96	4,52

Annex 5: Similarities within locations at the Bligh Bank, Goote Bank and Thorntonbank (SIMPER based on biomass)

Group BBI 08
Average similarity: 31,17

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	16,69	9,1	29,19
Spiophanes bombyx	13,47	8,27	26,52
Nephtys caeca	9,64	3,01	9,67
Bathyporeia guilliamsoniana	4,78	1,99	6,38
Bathyporeia elegans	4,24	1,78	5,71
Eteone longa	3,45	1,32	4,25
Urothoe brevicornis	3,92	1,14	3,64
Glycera lapidum	3,51	0,97	3,1

Group BBI 09
Average similarity: 32,64

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	18,33	16,21	49,66
Bathyporeia guilliamsoniana	9	4,54	13,92
Bathyporeia elegans	3,85	2,2	6,73
Glycera lapidum	3,72	1,56	4,79
Processa modica	4,14	1,05	3,22
Tellina pygmaea	2,29	0,83	2,55
Ophelia limacina	3,37	0,82	2,52
Spiophanes bombyx	2,34	0,78	2,4

Group BBE 08
Average similarity: 20,29

Species	Av.Abund	Av.Sim	Contrib%
Nephtys caeca	16,42	9,11	44,91
Nephtys cirrosa	10,75	3,18	15,68
Spiophanes bombyx	7,78	1,89	9,33
Ophelia limacina	5,54	1,73	8,52

Group BBE 09
Average similarity: 30,75

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	20,48	21,21	68,98
Bathyporeia guilliamsoniana	8,61	4,84	15,75
Ophiura ophiura	11,88	1,02	3,32
Spiophanes bombyx	1,3	0,73	2,39

Group GBC 08
Average similarity: 20,08

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	15,66	5,6	27,88
Spiophanes bombyx	12,49	4,72	23,48
Nephtys caeca	9,65	2,75	13,69
Ophiura albida	9,95	0,84	4,16
Urothoe brevicornis	2,11	0,81	4,05
Spio goniocephala	1,68	0,57	2,82
Echinocardium cordatum	18,07	0,52	2,61

Group GBC 09
Average similarity: 28,42

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	14,06	14,28	50,23
Ophelia limacina	3,23	1,8	6,34
Nephtys caeca	4,28	1,36	4,79
Scolelepsis bonnieri	3,04	1,25	4,41
Bathyporeia elegans	2,08	1,24	4,36
Spio goniocephala	1,51	1,21	4,27
Spiophanes bombyx	1,7	1,17	4,11

Group GBC 05
Av. similarity: 26,79

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	15,07	13,24	49,41
Urothoe brevicornis	4,51	2,87	10,71
Ophiura albida	18,73	2,22	8,28
Spiophanes bombyx	2,2	1,52	5,66
Bathyporeia guilliamsoniana	3,38	1,12	4,17
Ophelia limacina	4,13	1,1	4,11
Thia scutellata	3,97	0,74	2,75

Group GBC 08
Av. similarity: 20,08

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	15,66	5,6	27,88
Spiophanes bombyx	12,49	4,72	23,48
Nephtys caeca	9,65	2,75	13,69
Ophiura albida	9,95	0,84	4,16
Urothoe brevicornis	2,11	0,81	4,05
Spio goniocephala	1,68	0,57	2,82
Echinocardium cordatum	18,07	0,52	2,61

Group GBC 09
Av. similarity: 28,42

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	14,06	14,28	50,23
Ophelia limacina	3,23	1,8	6,34
Nephtys caeca	4,28	1,36	4,79
Scolelepsis bonnieri	3,04	1,25	4,41
Bathyporeia elegans	2,08	1,24	4,36
Spio goniocephala	1,51	1,21	4,27
Spiophanes bombyx	1,7	1,17	4,11

Group TBI A 05
Av. similarity: 40,19

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	21,77	22,37	55,66
Bathyporeia guilliamsoniana	6,97	4,74	11,8
Urothoe brevicornis	4,95	4,09	10,17
Ophiura albida	13,47	3,11	7,74
Spiophanes bombyx	3,68	1,75	4,35

Group TBI A 08
Av. similarity: 8,53

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	9,53	2,89	33,87
Spiophanes bombyx	6,83	1,93	22,59
Ophelia limacina	6,17	0,87	10,24
Bathyporeia pelagica	2,93	0,81	9,44
Bathyporeia guilliamsoniana	3,55	0,8	9,33

Group TBI A 09
Av. similarity: 37,24

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	18,47	26,02	69,88
Echinocardium cordatum	22,14	2,58	6,92
Spiophanes bombyx	3,24	2,52	6,76
Bathyporeia elegans	2,93	2,06	5,54
Scolelepsis bonnieri	3,06	1,1	2,95

Group TBI B 05
Av. similarity: 41,74

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	22,71	33,61	80,51
Spio goniocephala	1,62	1,78	4,26
Urothoe brevicornis	3,09	1,4	3,36

Group TBI B 08
Av. similarity: 22,07

Species	Av.Abund	Av.Sim	Contrib%
Nephtys caeca	11,65	6,16	27,93
Nephtys cirrosa	9,65	5,99	27,13
Spiophanes bombyx	6,42	3,43	15,53

Group TBI B 09
Av. similarity: 40,28

Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	22,87	28,26	70,15
Echinocardium cordatum	12,83	3,4	8,44
Spio goniocephala	1,77	1,62	4,01

Gastrosaccus spinifer	2,53	1	2,4	*Ophiura albida*	17,08	1,58	7,15	*Spiophanes bombyx*	2,48	1,62	4,01
Group TBE 05 Av. similarity: 37,98				**Group TBE 08** Av. similarity: 24,42				**Group TBE 09** Av. similarity: 37,58			
Species	Av.Abund	Av.Sim	Contrib%	Species	Av.Abund	Av.Sim	Contrib%	Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	20,59	26,61	70,06	*Nephtys caeca*	18,3	6,18	25,3	*Nephtys cirrosa*	22,31	21,85	58,14
Ophiura albida	18,16	2,2	5,79	*Spiophanes bombyx*	19,35	5,98	24,48	*Echinocardium cordatum*	27,68	7,48	19,92
Urothoe brevicornis	4,25	1,84	4,85	*Nephtys cirrosa*	9,5	4,44	18,19	*Urothoe brevicornis*	4,17	1,7	4,52
Processa modica	7,67	1,72	4,54	*Urothoe brevicornis*	5,16	1,51	6,2	*Spiophanes bombyx*	4,21	1,2	3,19
Spio goniocephala	1,45	1,23	3,23	*Ophiura albida*	11,73	0,88	3,59	*Thia scutellata*	5,4	1,08	2,88
Spiophanes bombyx	2,83	1,1	2,88	*Bathyporeia guilliamsoniana*	3,16	0,68	2,77	*Scolelepsis bonnieri*	2,43	0,96	2,56
Group TBC 05 Av. similarity: 36,49				**Group TBC 08** Av. similarity: 24,02				**Group TBC 09** Av. similarity: 37,10			
Species	Av.Abund	Av.Sim	Contrib%	Species	Av.Abund	Av.Sim	Contrib%	Species	Av.Abund	Av.Sim	Contrib%
Nephtys cirrosa	19,19	19,85	54,4	*Nephtys caeca*	16,41	10,42	43,38	*Nephtys cirrosa*	21,51	22,18	59,79
Urothoe brevicornis	5,84	3,54	9,71	*Nephtys cirrosa*	7,64	4,14	17,24	*Spiophanes bombyx*	5,68	2,92	7,87
Spiophanes bombyx	4,1	2,89	7,91	*Spiophanes bombyx*	7,73	3,28	13,65	*Echinocardium cordatum*	21,75	2,79	7,51
Bathyporeia guilliamsoniana	4,61	2,49	6,81	*Bathyporeia guilliamsoniana*	2,56	1,08	4,5	*Bathyporeia elegans*	5,66	2,74	7,38

Annex 6: Systematic species list of demersal and bentho-pelagic fish and soft substratum epibenthos

Order	Family	Species	English Name	Dutch Name
Atheriniformes	Atherinidae	Atherina presbyter*	sand smelt	koornaarvis
Clupeiformes	Clupeidae	*Alosa alosa**	Allis shad	elft
		Alosa fallax	twaite shad	fint
		Clupea harengus	herring	haring
		Sprattus sprattus	sprat	sprot
	Engraulidae	*Engraulis encrasicolus*	anchovy	ansjovis
Gadiformes	Gadidae	*Merlangius merlangus*	whiting	wijting
		Trisopterus luscus	bib / pouting	steenbolk
		Trisopterus minutus	poor cod	dwergbolk
		Gadus morhua	cod	kabeljauw
	Lotidae	*Enchelyopus cimbrius**	4 bearded rockling	4-dradige meun
		Ciliata mustela	5 bearded rockling	5-dradige meun
		*Gaidropsarus vulgaris**	3 bearded rockling	3-dradige meun
Perciformes	Gobiidae	*Aphia minuta**	transparent goby	glasgrondel
		Pomatoschistus lozanoi	Lozano's goby	Lozano's grondel
		Pomatoschistus minutus	sand goby	dikkopje
		Pomatoschistus pictus	painted goby	kleurige grondel
		Gobius niger	black goby	zwarte grondel
	Trachinidae	*Trachinus draco*	greater weever	grote pieterman
		Echiichthys vipera	lesser weever	kleine pieterman
	Ammodytidae	*Hyperoplus lanceolatus*	great sandeel	zandspiering
		Ammodytes tobianus	zandspiering	sandeel
		Gymammodytes semisquamatus	smooth sandeel	/
	Labridae	*Labrus bergylta*	ballan wrasse	gevlekte lipvis
	Carangidae	*Trachurus trachurus*	horse mackerel	horsmakreel
	Callionymidae	*Callionymus lyra*	dragonet	pitvis
		Callionymus reticulatus	reticulated dragonet	rasterpitvis
	Mulidae	*Mullus surmuletus*	mullet	mul
	Scombridae	*Scomber scombrus*	mackerel	makreel
	Moronidae	*Dicentrarchus labrax*	sea bass	zeebaars
	Mugilidae	*Chelon labrosus*	mullet	diklipharder
Pleuronectiformes	Pleuronectidae	*Limanda limanda*	dab	schar
		Platichthys flesus	flounder	bot
		Pleuronectes platessa	plaice	pladijs
		Microstomus kitt	lemon sole	tongschar
	Soleidae	*Buglossidium luteum*	solenette	dwergtong
		Pegusa lascaris	Dover sole	Franse tong
		Solea solea	sole	tong
	Bothidae	*Arnoglossus laterna*	scaldfish	schurftvis
	Scopthalmidae	*Psetta maxima*	turbot	tarbot
		Scophthalmus rhombus	brill	griet
Scorpaeniformes	Cyclopteridae	*Liparis liparis*	striped sea-snail	slakdolf
		Cyclopterus lumpus	lumpfish	snotolf
	Triglidae	*Trigla lucerna*	tub gurnard	rode poon
		Eutrigla gurnardus	grey gurnard	grauwe poon
		Aspitrigla cuculus	red gurnard	Engelse poon
	Cottidae	*Myoxocephalus scorpius*	scorthorn sculpin	zeedonderpad
	Agonidae	*Agonus cataphractus*	hooknose	harnasmannetje
Syngnathiformes	Syngnathidae	*Syngnathus rostellatus*	Nilsson's pipefish	kleine zeenaald
		Hippocampus hippocampus	short-snouted seahorse	kortsnuitzeepaardje
		Entelurus aequoreus	snake pipefish	adderzeenaald
		Syngnathus acus	greater pipefish	grote zeenaald
Carcharhiniformes	Scyliorhinidae	*Scyliorhinus canicula*	dogfish	hondshaai
	Triakidae	*Mustelus asterias**	starry smooth-hound	gladde haai
		*Mustelus mustelus**	smooth-hound	gladde haai
* new in 2009				

(Sub)phylum	Class/Order/ Infra order	Species	English Name	Dutch Name
Crustacea	Anomura	*Callianassa tyrrhena*	mud shrimp	graafgarnaal
		Diogenes pugilator	south claw hermit crab	kleine heremietkreeft
		Pagurus bernhardus	hermit crab	heremietkreeft
	Brachyura	*Cancer pagurus*	North sea crab	Noordzeekrab
		*Carcinus maenas**	common shore crab	strandkrab
		Corystes cassivelaunus	masked crab	helmkrab
		*Hyas coarctatus**	toad crab	rode spinkrab
		Liocarcinus depurator	harbour crab	blauwpootzwemkrab
		Liocarcinus holsatus	flying crab	gewone zwemkrab
		Liocarcinus marmoreus	marbled swimming crab	gemarmerde zwemkrab
		Liocarcinus navigator	arch-fronted swimming crab	gewimperde zwemkrab
		Liocarcinus vernalis	vernal crab	grijze zwemkrab
		*Liocarcinus pussilus**	dwarf swimming crab	kleine zwemkrab
		Macropodia rostrata	long legged spider crab	gewone hooiwagenkrab
		Necora puber	velvet swimming crab	fluwelen zwemkrab
		Pinnotheres pisum	pea crab	erwtenkrabbetje
		Pisidia longicornis	long clawed porcelain crab	porseleinkrabbetje
		Striarca lactea	/	melkwitte arkschelp
		Thia scutellata	thumbnail crab	nagelkrab
	Caridea	*Crangon allmanni*	Almann shrimp	groefstaartgarnaal
		Crangon crangon	brown shrimp	grijze garnaal
		Palaemon serratus	common prawn	steurgarnaal
		Pandalus montagui	Aesop shrimp	ringsprietgarnaal
		Philocheras trispinosus	/	driepuntsgarnaaltje
Mollusca	Bivalvia	*Abra alba*	white furrow shell	witte dunschaal
		Aequipecten opercularis	queen scallop	wijde mantel
		Diplodonta rotundata	round double-tooth	ronde komschelp
		Donax vittatus	banded wedge-shell	zaagje
		Dosinia exoleta	rayed Artemis shell	Artemisschelp
		Ensis arcuatus	sword rasor	grote zwaardschede
		Ensis directus	Atlantic jacknife clam	Amerikaanse zwaardschede
		Glycymeris glycymeris	dog cockle	marmerschelp
		Lutraria lutraria	common otter shell	otterschelp
		*Mactra stultorum**	rayed trough shell	grote strandschelp
		Mytilus edulis	mussel	mossel
		Spisula elliptica	elliptic trough shell	elliptische strandschelp
		Spisula solida	thick trough shell	stevige strandschelp
		Spisula subtruncata	cut trough shell	halfgeknotte strandschelp
	Cephalopoda	*Alloteuthis subulata*	/	dwergpijlinktvis
		Loligo vulgaris	common squid	gewone pijlinktvis
		Sepia officinalis	common cuttlefish	zeekat
		Sepiola atlantica	atlantic bobtail	dwerginktvis
	Gastropoda	*Buccinum undatum*	common whelk	wulk
		Crepidula fornicata	common slipper limpet	muiltje
		Nassarius reticulatus	netted dogwhelk	fuikhoorn
Echinodermata	Asteroidea	*Asterias rubens*	common sea star	gewone zeester
	Echinoidea	*Echinocardium cordatum*	common heart urchin	zeeklit
		Psammechinus miliaris	green sea urchin	gewone zeeëgel
	Ophiuroidea	*Ophiothrix fragilis*	brittle star	brokkelster
		Ophiura albida	lesser brittle star	kleine slangster
		Ophiura ophiura	common brittle star	gewone slangster
Cnidaria	Anthozoa	*Anthozoa* sp.	anemone	anemoon
Chordata	Ascidiacea	*Ascidiacea* sp.	sea squirt	zakpijp
Annelida	Polychaeta	*Aphrodita aculeata*	sea mouse	fluwelen zeemuis
		Lanice conchilega	sand mason	schelpkokerworm
		Nephtys sp.	catworm	zandzager
		Nereis sp.	sand worm	zeeduizendpoot
		Ophelia limacina	/	/
		Owenia fusiformis	/	/
		Pectinaria koreni	trumpet worm	goudkammetje
Porifera		*Porifera* sp.	sponge	spons

* new in 2009

Annex 7: Evaluation of short tracks

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1. Introduction

When evaluating the 2008 campaigns, it became clear that an adaptation of the sampling technique, and more precisely the length of a fish track and the number of fish tracks, was needed for the following reasons:

The installation of cables on the seafloor for the transmission of the generated electricity impairs the passage of the beam trawl and hence the completion of a fish track of 3500m, which is the average length of the normal monitoring tracks of ILVO so far

Local effects in the vicinity of the turbines are hard to detect using long tracks, since all fauna over a length of 3500m are pooled in a single catch and information about the small-scale ‘patchiness’ of fauna is largely lost. A shortening of the tracks (and an increase in the number of tracks) would result in a higher spatial resolution in the analysis (especially in the close vicinity of the turbines), which would increase the chance of detecting local changes.

However, before implementing shortened fish tracks in the monitoring program, the representativity of such tracks was tested experimentally during the autumn campaign of 2009.

2. Material en methods

Six fish tracks of the ILVO monitoring program were sampled both at full length (average 3454m) and along a shortened trajectory (average 1792m) in the close vicinity of the original track (Figure 1). The catches were analysed and the data were processed according to the standard ILVO procedure. The resulting density, diversity and biomass data were analysed concerning the intercomparability of standard tracks and corresponding shorter tracks.

The analysed tracks originated from different communities (see Vandendriessche *et al.* in prep). Track 230 is situated in a coastal community characterised by high densities and relatively high dominance of shrimps, the ophiuroid *Ophiura ophiura* and crabs. Track 215 is situated in a transition zone between coastal communities and offshore communities, combining high densities, high diversities and a mix of coastal and offshore species. The tracks on the Thorntonbank yielded typical offshore samples with low densities but high diversities and the presence of lesser weever, hermit crabs and the ophiuroid *Ophiura albida* (Data from: Vandendriessche *et al*, in prep).

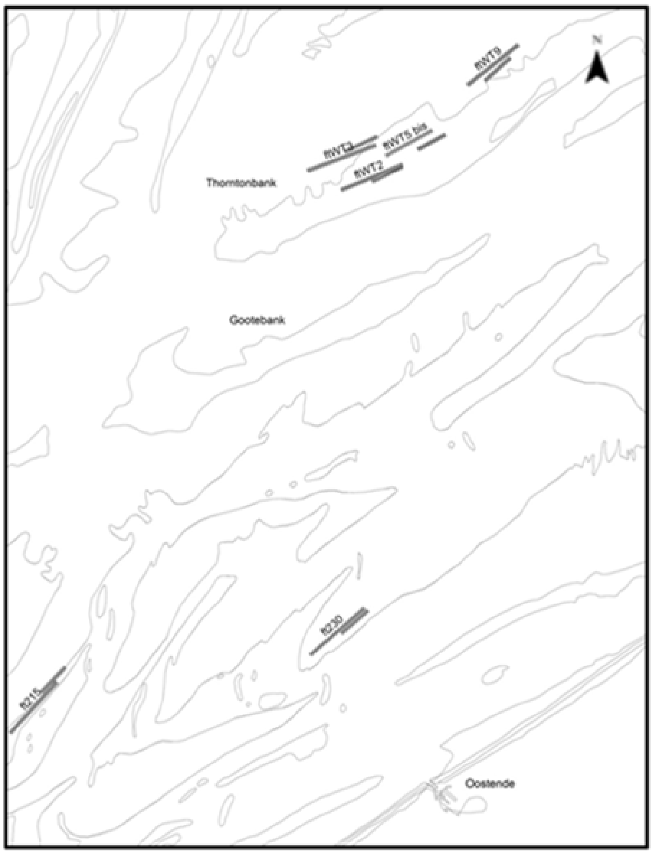


Figure 1. Map showing positions of a selection of ILVO long term monitoring tracks and corresponding short tracks.

3. Differences in density, biomass and diversity

Comparison of fish density, epifaunal density and epifaunal biomass showed that the standardization of short tracks to number or weights per 1000m² resulted in an underestimation of fish densities (average 16%) and strong overestimations of epifaunal densities (average 55%) and biomasses (average 70%) compared to the standard tracks. This however, was mainly due to patterns observed at the coastal stations 215 and 230. When only considering the four tracks at the Thorntonbank, fish and epifauna densities were underestimated by 12% on average, while average epifauna biomass was almost identical.

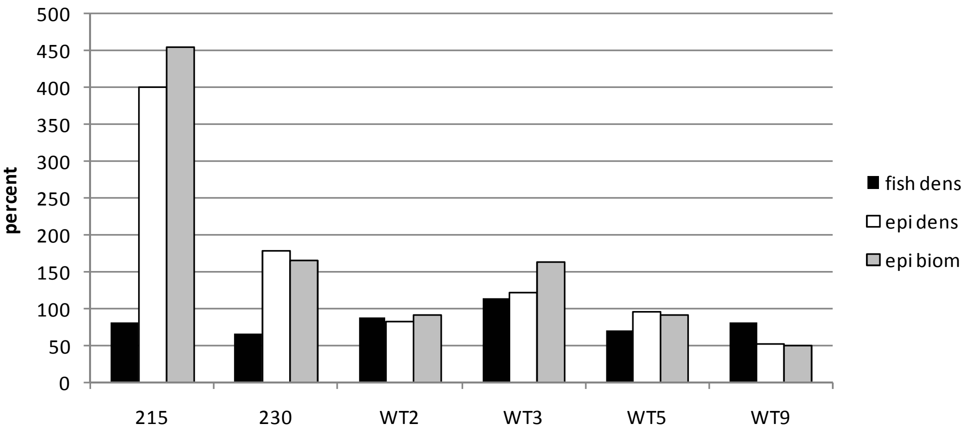
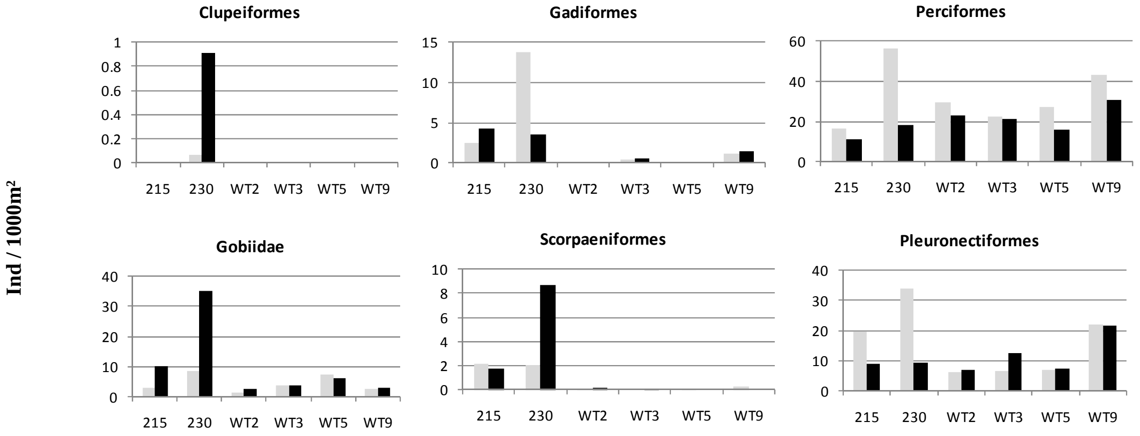


Figure 2. Difference between standard tracks and short tracks per station. Bars represent the deviation of short track data compared to standard track data: 100% indicates a perfect match, lower values indicate underestimation, higher values represent overestimation.

Table 1. Average deviation percentages (based on density data) per species groups for the Thorntonbank tracks only. Positive values represent overestimation, negative values represent underestimation.

Fish	**Average deviation (%)**		**Epifauna**	**Average deviation (%)**
Clupeiformes	/		Anomura	78
Gadiformes	4		Bivalvia	/
Gobiidae	17		Brachyura	-11
Perciformes	-24		Caridea	-19
Pleuronectiformes	26		Cephalopoda	227
Scorpaeniformes	/		Echinodermata	-6
			Gastropoda	/

The rate of overestimation or underestimation varied between tracks and between species groups. Large differences in estimated densities and biomasses were found at stations 230 and 215 for almost all species groups (Figure 3). For the Thorntonbank tracks, a better correspondence between estimates was found with similar values for Gadiformes, Gobiidae, Brachyura, Caridea and Echinodermata, but with strong deviations for Perciformes, Pleuronectiformes, Anomura and especially Cephalopoda (Table 1).



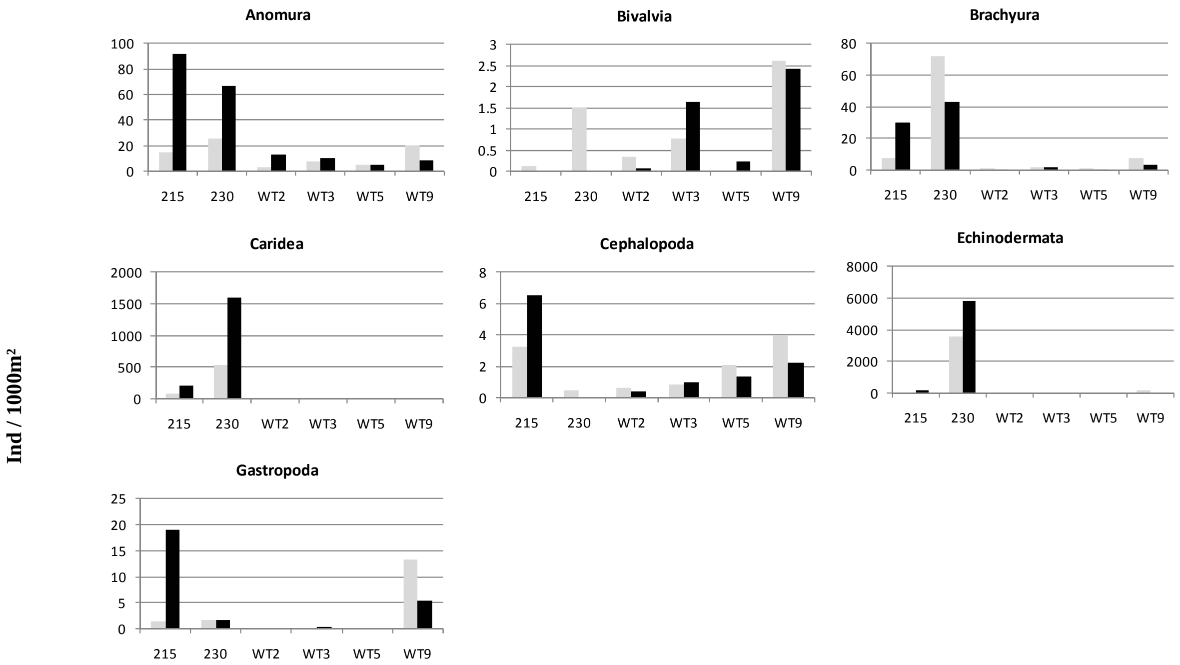


Figure 3. Density differences between standard tracks and short tracks per station for the main species groups of fish and epifauna. Grey bars represent standard tracks; black bars represent the corresponding short tracks. Epifaunal biomass showed the same trends as density and was not depicted.

Since the number of observed species (S ~ N_0) strongly depends on sample size (Soetaert & Heip, 1990), this parameter is logically underestimated during short tracks compared to long tracks. This was obvious in tracks 215, 230 and WT2 (Figure 4). In the other tracks, S remained similar. Next to the actual number of species, the expected number of species per 500 individuals (ES(500)) was calculated using Primer. This diversity measure is less influenced by sample size (Soetaert & Heip, 1990), and therefore yielded similar results for long tracks and short tracks. The use of this diversity measure in future analyses will enable comparisons of diversity between tracks of varying length.

The number of observed species per number of sampled individuals (relationship N/S) showed considerable variation. The overall trend, however, was stable in standard tracks, implying that the length of the track is suitable for obtaining a reliable estimate of diversity. For the short tracks, the observed trend was positively linear, without the onset of an asymptotic evolution. This indicates that the length of the short tracks may be insufficient for a detailed analysis of the species present. These results, however, were based on a limited number of samples and need to be confirmed using a larger dataset.

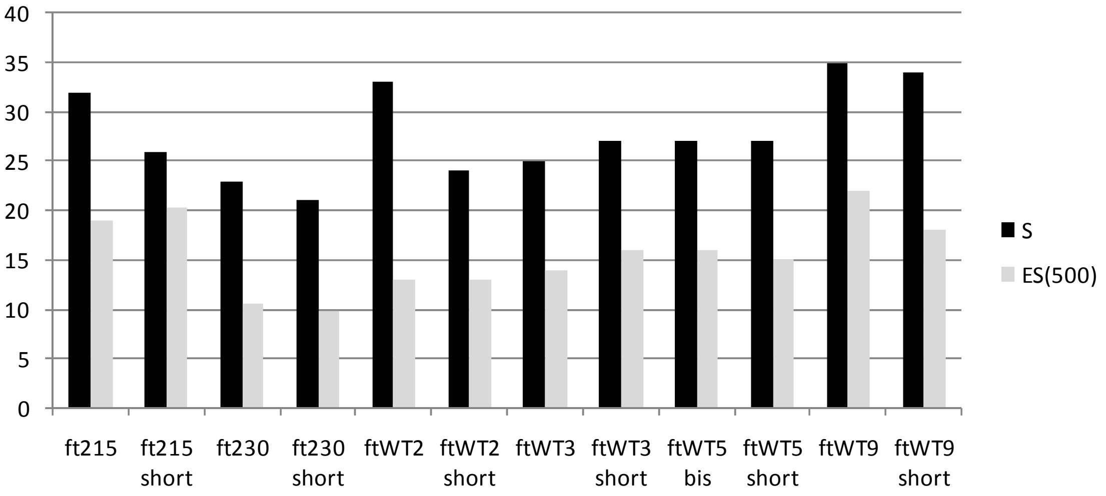


Figure 4. Diversity differences between standard tracks and short tracks per station, represented as observed number of species S and ES(500).

4. Reduction of work load per track

The average volume of the catch was reduced from 125 litres in the standard tracks to 75 litres in the short tracks, which corresponds with an average reduction of 41% (range 10% - 64%). In the case of reasonably small catches that are entirely processed, the work load on board is obviously reduced. In the case of large catches, such as the ones at station 230, the subsampling procedure (including the use of a rinsing and sieving machine) was applied to both track types, and the amount of organisms to be processed remained identical. In this case, only the tow duration and the covered distance were reduced.

5. Discussion

The rate of overestimation or underestimation varied between tracks and between species groups. For the Thorntonbank tracks, a better correspondence between estimates was found than for stations 215 and 230, but these still showed deviations for Perciformes, Pleuronectiformes, Anomura and Cephalopoda.

Given the results for the Thorntonbank offshore community and the practical constraints of sampling near the existing turbines, the application of short tracks is considered acceptable for monitoring the effects of windmill parks on epifauna and demersal fish fauna, and hence will be implemented in the monitoring activities in 2010. Of course, the occurrence of overestimations or underestimations compared to standard tracks taken in the past, should be taken into account during subsequent analyses.

Still, short tracks should not be used for detailed analyses of diversity (e.g. drafting species lists). Estimations of diversity based on short tracks are only reliable when the appropriate measure, i.e. indices not depending on sample size, like the expected number of species (ES(500)) is used.

The use of short tracks in the monitoring of windmill farms does not necessarily mean that the number of tracks, and hence the spatial coverage, can be doubled without increasing the work load and required ship time. In the case of large catches, the work load per track remains the same for long and short tracks. Additionally, the time needed to prepare the beam trawl for operation and to retrieve the catch afterwards is the same for short tracks compared to standard tracks. Hence, short tracks can be used to detect local effects in the vicinity of the turbines, but an increase of the number of tracks to increase the spatial coverage will inevitably lead to an increase in the work load (especially in rich areas) and the required ship time.

It can be noted that next to the possible scientific (detection of local effects) and financial (ship time, processing time) advantages, the use of short tracks during monitoring activities also implies a reduction of bottom disturbance and hence environmental impact of research activities. Of course, the research impact will not change if the number of tracks is increased in order to improve the spatial resolution.

The European directive 2001/77/EG presently imposes each member state a target figure for its contribution to the production of electricity from renewable energy sources that should be achieved by 2010. For Belgium, this target figure was set at 6 % of the total energy consumption. This figure was adjusted in the new European climate plan (January 2008) and is now set at 13 % 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 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 2009, 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), soft substratum macrobenthos and hard substratum fish (Marine Biology Section of Ghent University).

This year's report targets the first scientific results on the evaluation of the early and localized environmental impacts at the C-Power and Belwind sites and the natural spatio-temporal variability.