Chapter 1. Executive summary

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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

[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.