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WinMon Activity Report 2013-2014

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For approval:

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Preface

Belgium has allocated a 238 km² zone of the Belgian part of the North Sea to offshore renewable energy production, for example offshore wind farms. Prior to construction, a developer needs obtaining a domain concession and an environmental permit. The latter includes a number of terms and conditions to minimise or mitigate the environmental impact of the wind farm project. This also imposes a monitoring programme to assess the potential impacts on the marine environment.

The environmental monitoring programme targets physical (hydro-geomorphology and underwater noise), biological (epifouling community on the hard substratum, macro and epibenthos of the soft substratum, fish, seabirds and marine mammals), as well as socio-economic (seascape perception and offshore renewables appreciation) aspects of the marine environment. The Operational Directorate Natural Environment (OD Nature) of the Royal Belgian Institute of Natural Sciences (RBINS) coordinates the monitoring programme. To cover all necessary scientific expertise OD Nature collaborates with several institutes: the Research Institute for Nature and Forest (INBO), the Institute for Agricultural and Fisheries Research (ILVO - Bio-Environmental research group), Ghent University (Marine Biology Research Group and INTEC), International Marine and Dredging Consultants (IMDC) and Grontmij Belgium NV.

The Belgian offshore wind farm environmental monitoring programme started in 2005 with the t_{-1} data collection at C-Power wind farm on the Thorntonbank, where the first wind turbines were installed in 2008. The monitoring programme is running continuously since 2008 (i.e. t_0) and now (July 2015) covers three wind farms (i.e. C-Power, Belwind and Northwind) with a total of 181 wind turbines.

This report provides an overview of the monitoring activities that took place in the years 2013 and 2014. These cover the investigation of soft sediment benthos and fish, hard substrate benthos, seabirds and marine mammals. The activity overview distinguishes between basic and targeted monitoring, with basic monitoring focusing on the observation of the overall offshore wind farm impact and targeted monitoring aiming at the understanding of the ecological mechanisms behind a selection of observed impacts. For each activity, its objectives, methodologies used and data collected in 2013 and 2014 are presented. If further information on specific sections would be needed, do not hesitate getting in touch with the contact point as identified for each section.

Steven Degraer

Scientific coordinator of the Belgian offshore wind farm environmental monitoring programme

1. Soft sediment macrobenthic community

1.1. Basic monitoring

1.1.1. Effects of offshore wind farms on the soft-sediment macrobenthos

Jan Reubens*, Jan Vanaverbeke, Magda Vincx, Tom Moens (the Marine Biology Research group of Ghent University)

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Objectives

Since 2009, offshore wind farms (OWFs) are being installed on the Belgian part of the North Sea (Belgian part of the North Sea). The C-Power OWF was finalised in 2013. Phase 1 of the Belwind OWF was completed in 2011, and Northwind OWF in 2014. As a result, 181 turbines were operational on the Belgian part of the North Sea in October 2014. The installation of these man-made structures can have an effect on the marine environment, including the benthos inhabiting the soft sediments around the OWFs. The objective of the basic monitoring programme is to investigate whether the OWFs are indeed affecting the community composition, diversity and biomass of the soft-sediment fauna. Therefore, samples are collected within, in the vicinity of, and further away from each OWF, and compared with samples collected at the Goote Bank reference area.

Methods and data collected

Sampling was conducted in October of 2013 and 2014 onboard of RV Belgica. Samples were collected on the Goote Bank (Reference Area – 4 stations), Thorntonbank (C-Power OWF – 20 stations) and Bligh Bank (Belwind – 23 stations) (see Figure 1.1. and Annex).

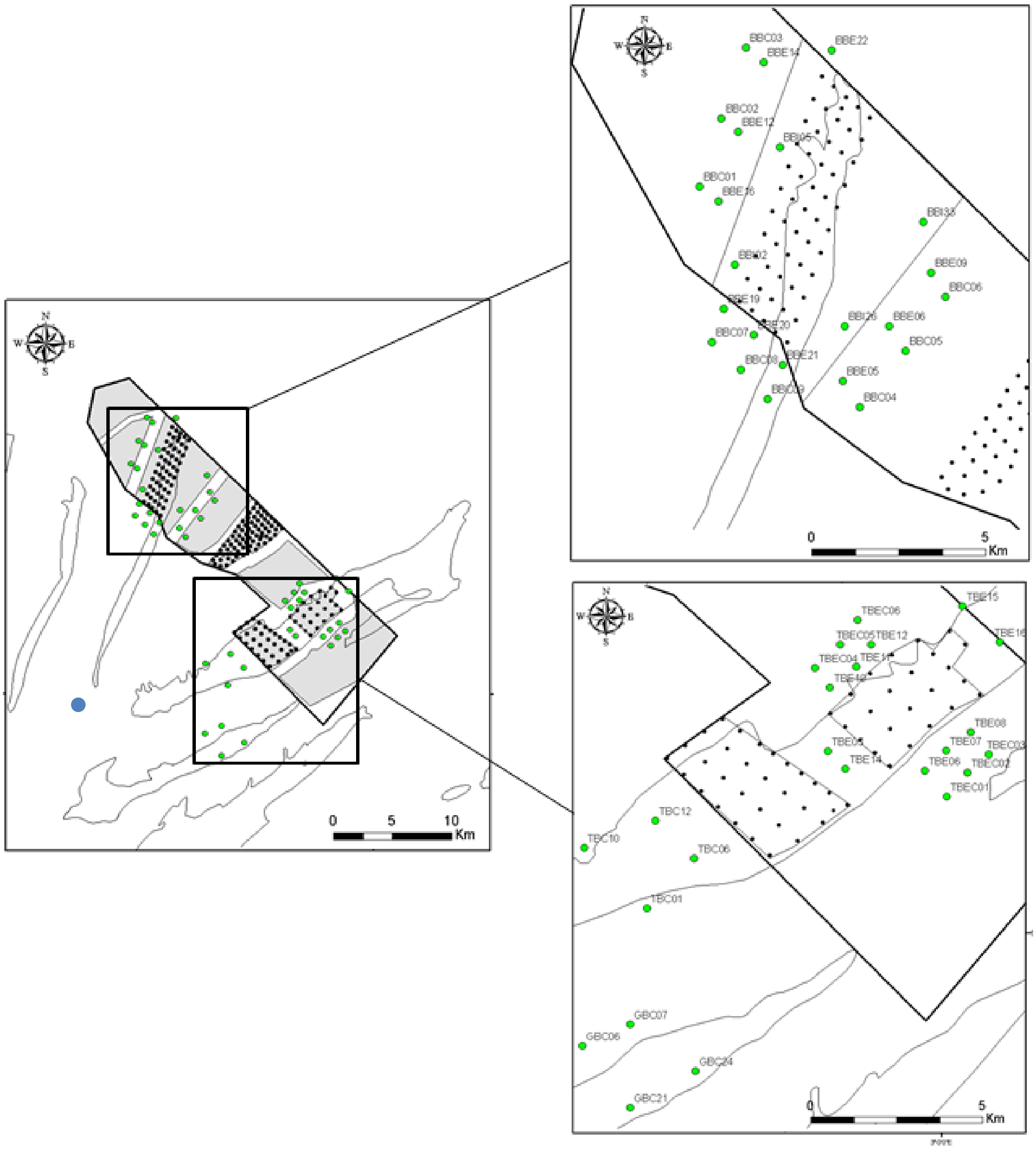

Figure 1.1. Location of the sampling stations at the Bligh Bank, Thorntonbank, and Gootebank (green dots) and indication of shipwreck 'John Mahn' (blue dot).

Per station, 3 samples were collected by means of a Van Veen grab (0.1 m²). From each grab sample, a subsample (50 ml) was collected for grain size analysis and determination of the total organic matter content (TOM%). The remaining part of the sample was sieved on-board over a 1 mm sieve and subsequently fixed in an 8% formaldehyde-seawater solution. In the laboratory, samples were stained with 1% Rose Bengal, sorted and identified to species level. Biomass (wet weight) was determined for every species per sample.

Median grain size was analysed on dried samples (60°C) with a Malvern Mastersizer 2000G, hydro version 5.40 (laser diffraction model). Grain size fractions were expressed as volume percentages with a range from fine clay (<4 µm) to coarse gravel/shell-fragments (>1600 µm). TOM% was measured for every sample by applying the following equation: TOM%= [(DW-AW)/(DW-CrW)] x 100. Dry weight (DW) was determined after 48 h at 60°C; Ash weight (AW) was determined after 2 h 20 min at 550°C. Crucible weight (CW) is the weight of the crucibles used.

1.2. Targeted monitoring

1.2.1. Food web structure at artificial reefs in the Belgian part of the North Sea

Jan Vanaverbeke*, Jan Reubens, Yana Deschutter, Magda Vincx, Tom Moens (the Marine Biology Research group of Ghent University)

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Objectives

The introduction of hard substrates in an originally sandy environments has consequences for the community composition of the fauna in the vicinity of these hard substrates (Coates et al., 2014; Reubens et al., 2013). In addition, the piles provide habitat for fouling communities (De Mesel et al. 2013). As such, the altered faunal composition in the vicinity of OWF could affect the local food web, as different prey items and predators are present. Other introduced hard substrates on the Belgian part of the North Sea include ship wrecks. Different shipwrecks in the Belgian part of the North Sea harbour a different fouling community, depending on their geographic location (Zintzen et al., 2008).

While details on the changes in community composition around introduced hard substrates on the Belgian part of the North Sea are known, there is no knowledge on (1) whether these introductions affected the local food web, and (2) whether these changes would be similar/different between OWFs and ship wrecks.

Investigating food webs requires, among others, analysis of the stable isotopes of C and N from representative species from the various taxonomic groups present. This requires different sampling techniques, and a combination of ship-based sampling and scuba-diving. As such, we set up a feasibility study to investigate whether such integrated sampling was possible, both in an OWF and in the vicinity of shipwrecks

Methods and data collected

Based on accessibility and existing data, we chose wind turbine D5 in the C-Power OWF on the Thorntonbank and the shipwreck John Mahn (51.48228 N, 2.68898 E) (figure 1.1). Sampling was performed in October 2013 and March 2014. Sampling methods included line fishing, scraping of fouling fauna, handpicking of large fauna by scuba divers, sediment core and water sampling (Table 1.1). Sampling with a hyperbenthic sledge, hamon grab and beam trawl was only possible in the vicinity of the John Mahn shipwreck.

Table 1.1. Overview of samples collected at the Thornton Bank (D5) and the John Mahn shipwreck.

Date	Ship	Location	Sampling method
14/10/13 -17/10/13	Belgica	D5	Scraping, line fishing, sediment core, handpicking by divers, water sample
30/10/13 -30/10/13	Simon Stevin	D5	Line fishing
10/03/14 -12/03/14	Simon Stevin	D5	Line fishing
24/03/14 -28/03/14	Belgica	John Mahn	Hamon grab, beam trawl, sediment cores, scraping, handpicking by divers, hyperbenthic sledge, water sample

Where possible, samples were sorted on board and macrofauna were starved in seawater (24h) to allow evacuation of their gut contents and stored at -20°C before further treatment.

Samples were prepared for analysis of C and N stable isotope ratios following standard procedures (e.g. Vafeiadou et al. 2013). In case of smaller invertebrates, such as polychaetes, amphipods and mysids, entire individuals were selected, whereas for fish and larger invertebrates, such as bivalves, crabs and the brown shrimp *Crangon crangon*, only muscular tissue (dorsal fin, foot, cheliped and tail muscle tissue respectively) was prepared for analysis. Entire specimens and the dissected tissue samples were rinsed thoroughly with milli-Q water to avoid contamination and subsequently dried overnight at 60°C. Dried samples were ground with a pestle and mortar, homogenized, weighted and encapsulated. The selection of the capsule depends on the need for acidification to remove carbonate traces (Jacob et al., 2005), which was tested in advance. Invertebrates with calcareous structures such as shrimp, isopods and juvenile crabs were transferred to Ag capsules (8 × 5 mm, Elemental Microanalysis UK) and acidified by adding dilute (10%) HCl drop-by-drop, until no more release of CO_2 was observed (Jacob et al., 2005). Following acidification, samples were rinsed with milli-Q water and stored dry until analysis. Carbonate-free tissue samples on the other hand, were encapsulated in Sn capsules (8 × 5 mm, Elemental Microanalysis UK) and immediately stored dry awaiting analysis. Samples were analysed at the UC Davis Stable Isotope Facility (University of California, USA) using a PDZ Europa ANCA-GSL elemental analyser, interfaced to a PDZ Europa 20-20 isotope ratio mass spectrometer (Sercon Ltd., Cheshire, UK).

At the moment, stable isotope data of C and N for 77 taxa (macrofauna, hyperbenthos, fouling fauna and fish) are available. Stable isotope signatures for possible food sources (Particulate Organic Matter in the water column and sediment organic matter) are available as well. To our knowledge, this is one of the most complete stable isotope datasets collected in coastal seas so far. This dataset can certainly act as a reference dataset for further assessment of possible changes in the food web of OWF.

An exploratory analysis revealed that stable isotope data for 7 different feeding guilds collected at the John Mahn, spanned a $\delta^{15}N$ range of 14 ‰. At the OWF at the Thornton Bank, the same 7 feeding guilds were sampled, however the $\delta^{15}N$ range here only spanned 9 ‰. Since $\delta^{15}N$ is indicative of trophic level, this suggests a longer and more complex food chain at the John Mahn. A further detailed scientific analysis of these data is planned for 2016. We intend to use Bayesian statistics to describe the structure of the food web using Layman metrics (Layman et al. 2007).

Relative changes of the position of certain species in both food webs will be investigated using circular statistics. This will allow to assess whether the introduction of hard substrates has either a "universal" effect or a type-specific effect on food web structure.

This feasibility study revealed that it is possible to collect a wealth of stable isotope data, informative about aspects of resource utilization, food web complexity and trophic niche breadth and diversity, in the vicinity of introduced artificial hard substrates within a relatively limited amount of time. Careful planning and integration of ship-based and scuba-diving sampling proved to be of high importance to guarantee efficient sampling. The ability to collect samples of hyperbenthos, and the possible use of baited traps and passive fishing nets within an OWF, remain to be explored. Both devices have been developed in 2014, but limited sampling time prevented *in situ* testing. Based on the outcome of the more detailed analysis of the available stable isotope data, it can be decided if further efforts to complete the database are required.

1.2.2. An experimental pilot study on the effect of offshore wind farms on benthic ecosystem functioning

Jan Vanaverbeke*, Delphine Coates, Whubhareg Belay Kassa, Magda Vincx (the Marine Biology Research group of Ghent University)

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Objectives

Sediments on the sandbanks of the Belgian part of the North Sea consist of coarse, permeable sediments. Installation of the OWFs has led to a fining of the sediment close to the turbines (Coates et al., 2014), which can affect the functioning of these sediments (Ehrenhauss and Huettel, 2004; Ehrenhauss et al., 2004). As part of the targeted monitoring programme, we set up a series of experiments, testing whether filtration capacity, oxygen consumption, efficiency of diatom trapping and fluxes of nutrients across the sediment-water interface of permeable sediments is affected by fining.

Methods and data collected

Permeable sediments were collected from Station 330, in the vicinity of the Gootebank. Fine sands were collected from an intertidal mudflat in the Westerschelde estuary (Paulina). A third type of sand was commercially available. The latter sediment and the sediment from Paulina were burnt for 4 h in a muffle furnace and washed with distilled water to remove excess organic matter. Sediments were mixed to create a gradient from naturally occurring sediments in the sandbank area to finer sediments. The experimental gradient reflected the observed gradient in permeability around the gravity based foundation of windmill D5 on the Thorntonbank. The experiments were run in benthic stirring chambers to mimic the natural advective flow through permeable sediments. In a first experiment, a red dye (Rhodamine) was added to the water column of each treatment. The results showed that water penetration depth in the sediment significantly decreased from >6 cm in the natural sediments to 0.8 cm in the finest sediments. An experiment where naturally occurring diatoms (*Skeletonema costatum)* were added showed a lowered coupling of the pelagic and the benthic ecosystem. In the fully permeable sediments, diatom cells were more effectively trapped in the sediment, and efficiently mineralised as revealed by large effluxes of NH_4^+ out of the sediment. The observed efflux of NH_4^+ out of the artificial sediments was 2.6 – 5.5 times lower. Our results show that the efficient benthic-pelagic coupling occurring in the natural sediments was not observed at the artificially fined sediments. We acknowledge that our experiments were preliminary, but the observed effects are striking, and call for a further evaluation of the functional effects of OWFs on the soft sediments of the Belgian part of the North Sea.

2. Soft substrates: epibenthos and demersal fish

2.1. Basic monitoring

2.1.1. Effect of wind farms on soft substrate epibenthos and fish

Jozefien Derweduwen*, Sofie Vandendriessche, Kris Hostens (Institute for Agricultural and Fisheries Research)
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Objectives

With the construction of wind farms, new hard substrates are introduced in the marine environment. Although, the sediment between the turbine rows and around the wind farms remains soft, the inhabiting fauna can be influenced by the presence of the turbines and the absence of fisheries. These effects were investigated for epibenthos, demersal fish and benthopelagic fish in the C-Power (Thorntonbank) and Belwind (Bligh Bank) wind farms.

Methods

During the RV Belgica Cruises 2013/08a,b (March 11th 2013 – March 22th 2013), 2013/26a,b,c (September 23th 2013 – October 10th 2013), 2014/06 (March 10th 2014 – March 21th 2014) and 2014/24 (September 23th 2014 – October 10th 2014) beam trawl samples were taken within the wind farms, i.e. between the turbine rows, just outside the concessions and at reference stations away from the concessions. A number of stations could not be sampled due to bad weather conditions and logistic problems (Figure 2.1., Table 2.1. and Figure 2.2.). Demersal fish fauna and epibenthos were sampled with an 8-meter shrimp trawl (22 mm mesh in the cod end) equipped with a bolder-chain in the ground rope. Epibenthos and demersal fish are organisms living on or in the vicinity of the sea bottom and which can efficiently be sampled with this shrimp trawl. The net was towed over 1 nautical Mile, approximately covering 15 minutes at an average speed of 3.5 to 4 knots with the currents. Data on time, start and stop coordinates, trajectory and sampling depth were noted to enable a correct conversion towards sampled surface units. The fish tracks are more or less positioned following depth contours that run parallel to the coastline, thereby minimizing the depth variation within a single track, except for track 2 and track 3 in the C-power concession due to the positioning of the electricity cables.

Data collected

All samples gathered in spring and autumn 2013 and 2014 (text box 1) have been processed (on board and in the lab). All data are entered in the ILVO database (developed and maintained in close cooperation with VLIZ).

Text box 1

- Epibenthos: species, density, biomass (wet weight) (+ sex, length, parasites for some species)
- Fish: species, length, density
  - For two seasons (spring and autumn)
  - For two wind farms (Thorntonbank and Bligh Bank)
  - For two subhabitats (sandbank and gullies)
  - In a BACI (CI) design

Detailed analyses and comparison with previous years (BACI) are in progress.

Bligh Bank			
Spring 2013	Autumn 2013	Spring 2014	Autumn 2014
 ft WBB04	 ft WBB02s	 ft WBB02s	 ft WBB08s
Thorntonbank			
Spring 2013	Autumn 2013	Spring 2014	Autumn 2014
 ft WT11	 ft WT9s	 ft WT7	 ft WT2bis

Figure 2.1. Some impressions of the beam trawl catches in and around the C-power and Belwind wind farms.

Table 2.1. Stations per sandbank system, with indication of sampling activities in spring and autumn 2013 and 2014.

sandbank system	station	imp/ref/fri	top/gully	spring 2013	autumn 2013	spring 2014	autumn 2014
Gootebank	WG2	ref	top	X	X	X	X
	330	ref	gully	X	X	X	X
Thorntonbank	WT1(bis)	ref	gully	X	X	X	X
	WT2(bis)	ref	top	X	X	X	X
	WT3	ref	gully	X	X	X	X
	WT7	fringe	gully	X	X	X	X
	WT9	fringe	gully	X	X	X	X
	WT10	fringe	gully	X	X	X	X
	WT11	fringe	gully	X	X	X	X
	track 2	impact	top	X	X	X	
	track 3	impact	top	X	X	X	
	track 5	impact	top	X	X	X	X
	track 6	impact	top	X	X	X	X
Lodewijckbank	BZN01	impact	top	X			
Bligh Bank	WBB01	ref	gully	X	X	X	X
	WBB02	ref	top	X	X	X	
	WBB03	ref	gully	X	X	X	X
	WBB04	fringe	gully	X	X	X	X
	WBB05	impact	gully	X	X	X	X
	WBB06a	impact	top	X	X	X	
	WBB06b	impact	top	X	X	X	
	WBB07	impact	gully	X	X	X	X
	WBB08	fringe	gully	X	X	X	X
Oosthinder	WOH01	ref	gully	X	X	X	
	WOH02	ref	top	X	X	X	
	WOH03	ref	gully	X	X	X	

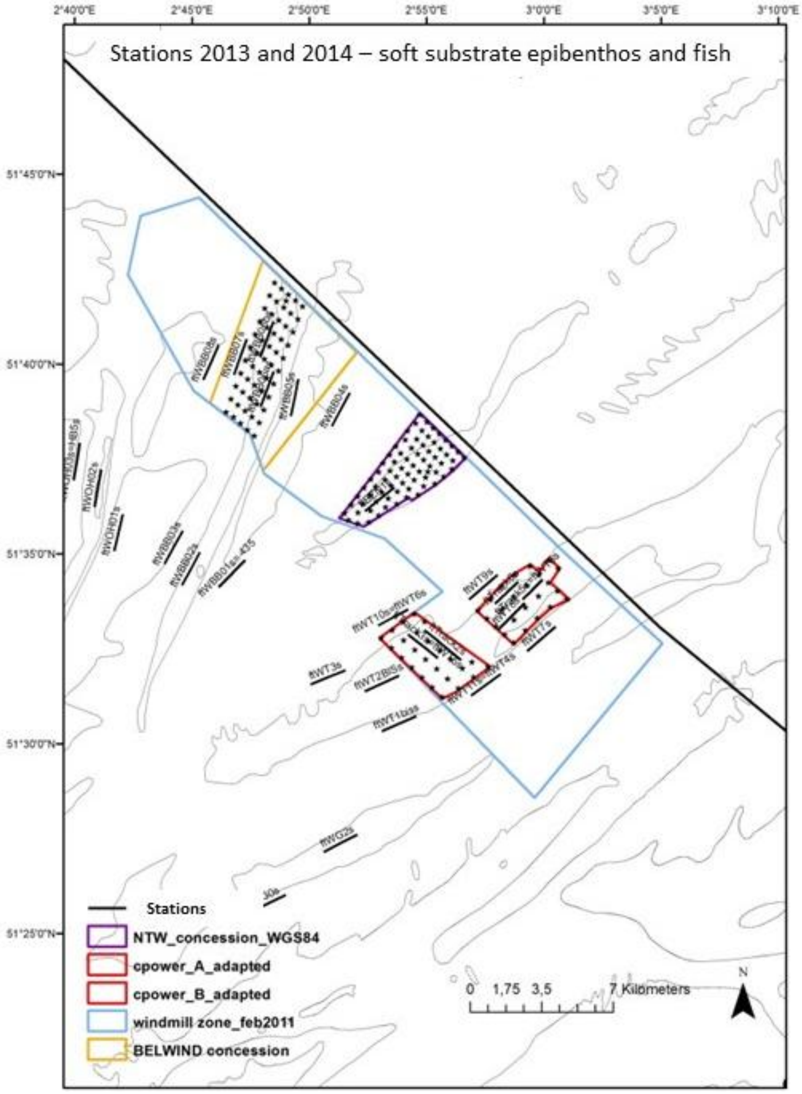

Figure 2.2. Map showing the 2013 and 2014 sampling stations at the wind farm concession areas of C-power, Belwind (and Northwind).

2.2. Targeted monitoring

2.2.1. Feeding behaviour of demersal fish at wind farms

Jozefien Derweduwen*, Sofie Vandendriessche, Arne Adam, Kris Hostens (Institute for Agricultural and Fisheries Research)
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Objectives

This analysis aims to reveal possible changes in feeding patterns of three fish species in and around the Thorntonbank and Bligh Bank wind farms. Stomach analyses were conducted to investigate (1) whether the presence of the turbines had an effect on the fish diet, and (2) whether there were fringe effects with regard to the diet composition at the border of the concession areas.

Methods

Samples for stomach analyses were collected from 2009 to 2013 at the Thorntonbank and Bligh Bank from a selected number of trawls as described above. No additional samples for stomach analyses have been collected in 2014. Per station, up to 15 individuals per species for three fish species (*Limanda limanda, Echiichthys vipera, Merlangius merlangus*) were collected, on board injected with formaldehyde (35%) and stored in formaldehyde (8%) until analysis. Stomachs were removed in the lab and all prey items encountered in the stomachs were identified and counted.

Data collected

Stomach content analyses of three fish species (L. limanda, E. vipera, M. merlangus) are still ongoing. Following indices will be calculated: Fullness Index (FI); Frequency of occurence (FO%) and Numerical percentage (N%).

2.2.2. Effect of underwater sound generated by wind farms on fish

Elisabeth Debusschere*, Dick Botteldooren, Sofie Vandendriessche, Kris Hostens, Magda Vincx, Steven Degraer (Institute for Agricultural and Fisheries Research, Marine Biology Research group of Ghent University, Royal Belgian Institute of Natural Sciences, Department of information Technology research Group Acoustics of Ghent university)
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Objectives

Pile-driving for wind farm constructions has triggered a range of ecological questions regarding the impact of anthropogenically generated low frequency impulsive underwater sound on marine wildlife. This study tackles the impact of pile-driving sound on fish mortality, stress, behaviour and fitness. This study uses cultured juveniles (< 2g), of European sea bass *Dicentrarchus labrax* as a model species. In 2013, no acute or chronic mortality after exposure to pile driving at 45 m from the piling activity was observed. In 2014, our goal was to study the acoustic stress in juvenile sea bass through *in situ* and laboratory experiments.

Methods and data collected

In situ experiment

An experiment was conducted during the piling activity at the construction of the Northwind NV offshore wind farm in June and August 2013. This experiment was carried out in close cooperation with the concession holders of North Wind. From the piling platform, sea bass (*Dicentrarchus labrax*) juveniles were lowered into the sea and exposed to a complete piling event (Figure 2.3.), at a distance of 45m from the pile-driving source. Respiration rates were monitored, whole-body cortisol, lactate and RNA samples were taken and surviving juveniles were reared in the lab to examine effects on development and growth. As a control, the same procedures and measurements were done for juveniles lowered into the sea during a piling pause. A third treatment consisted of non-handled fish that stayed in the aquaria at ILVO, which were directly stored in liquid nitrogen for whole-body cortisol, lactate and RNA analyses.

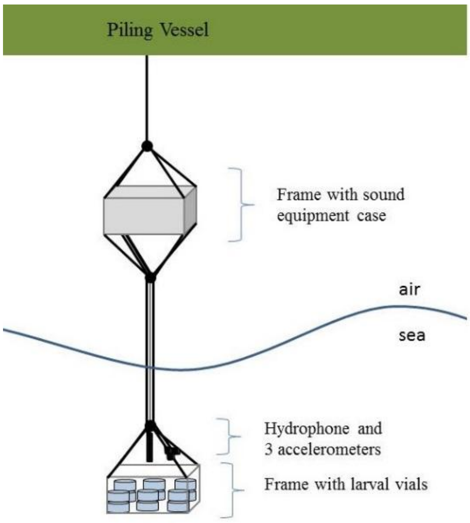

Figure 2.3. Experimental set-up on board of the piling platform

The SIG Sparker experiment

The SIG Sparker, utilised in seismic research, was used in a laboratory experiment to investigate the acute stress response of juvenile sea bass under the mid and high frequency impulsive sound. This experiment was carried out in close cooperation with UGent-RCMG and VLIZ. Cortisol, lactate, glucose and RNA samples were taken and oxygen consumption rate during the experiment was monitored. The experiment existed of three treatments: (1) a non-handled treatment; (2) a control treatment with handling stress and (3) an sound exposure treatment.

The Larvaebrator experiment

The larvaebrator is a device built specifically to enable controlled exposure of fish to sound in a laboratory setting. This experiment was carried out in close cooperation with IMARES (NL). In this case, a recording of pile driving at 100 m from the sound source was played back to the fish, with most energy in the lower frequency range (< 1kHz). The experiment was built out of three treatments: (1) a non-handled treatments; (2) a control treatment in the larvaebrator and (3) an sound exposure treatment in the larvaebrator. Measurements of oxygen consumption rate were taken and samples for whole-body cortisol, lactate and RNA were stored in -80°C upon analysis.

Pilot study behavioural impact of pile driving

An experiment was carried out to determine the impact of one hour of impulsive sound on the behaviour and condition of juvenile fish. A recording of pile driving sound at 45 m from the sound source was played back in the aquaria at ILVO at a lower sound pressure level (SELss= 165 dB re 1µPa), mimicing the impact further away from the sound source. Swimming behaviour was monitored 5 days before the sound exposure, during the sound exposure hour, just after exposure and up to five days after the sound exposure. Feeding behaviour, length and weight were monitored.

This work is part of the Phd research of Elisabeth Debusschere who acknowledges an IWT predoctoral grant. One manuscript has been published, one manuscript has been submitted and several other manuscripts are in preparation.

2.2.3. Ichthyoplankton: wind farms as spawning sites and nurseries?

Sofie Vandendriessche, Ana Margarida Ribeiro da Costa and Kris Hostens* *(*Institute for Agricultural and Fisheries Research)
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Objectives

Populations of fish species depositing their eggs on the seafloor are strongly influenced (positively or negatively) by changes in the seafloor structure as a result of wind farm constructions. In the Belgian part of the North Sea, these fish species include herring, bream, sculpin, hooknose, wrasse, sandeel, gobies, dogfish and rays. Generally, the creation of hard substrates is expected to have positive effects, except for species that require sandy or muddy substrates for spawning. The importance of offshore wind farms as spawning sites and nursery areas is estimated by analyzing fish larvae densities in the concession areas and in adjoining reference stations.

Methods and data collected

This work was carried out at the C-power concession on the Thornton bank. At three reference locations (WFL1-3) and three wind farms locations (WFL4-6) (Figure 2.4. left), a Bongo net (Figure 2.4. right) was deployed, fitted with 500 µm mesh nets, a fly weight and a flow meter. The net was towed for 10 min in an undulating fashion. At each station, a CTD SBE-19plus was used to obtain vertical profiles of temperature and salinity. Turbidity was measured with a Secchi disk and chlorophyll a data were obtained from fixed fluorimeters on board of the Belgica.
Samples were taken at each station during the spring and autumn campaigns from 2010 to 2013. Bongo net samples were sorted and partly analysed in the lab (only for ichtyoplankton):

- Fish larvae: identification to species level – counts
- Fish eggs: counts
- Squid larvae: identification to species level – counts

In total, 66 samples -over different years and seasons- have been analysed.

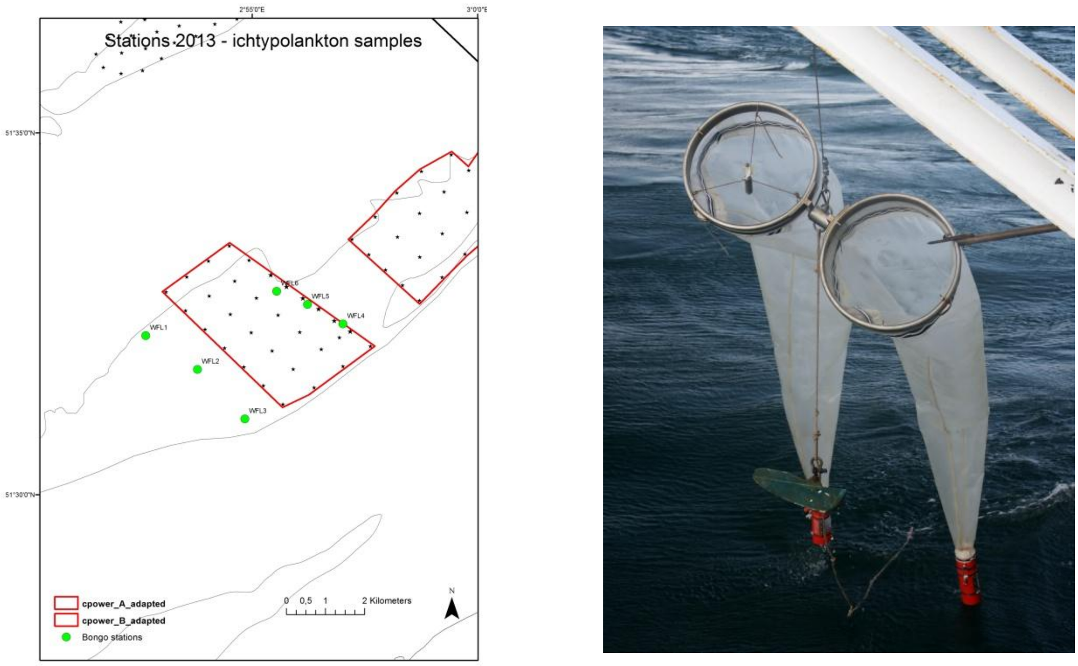

Figure 2.4. Left: Map showing the western part of the C-Power concession area, with indication of the ichthyoplankton sampling locations. Right: Bongonet

This work has been partly published in the MSc thesis of Ana Margarida Ribeiro da Costa (Da Costa, A.M.R. (2014) Do offshore wind farms influence the occurrence of ichthyoplankton and squid larvae? MSc Thesis Marine Biodiversity and Conservation (Erasmus Mundus), Ghent University, 72p.).

2.2.4. Changes in commercial and recreational fisheries in and in the vicinity of the wind farms

Sofie Vandendriessche and Kris Hostens* *(*Institute for Agricultural and Fisheries Research)
Contact: kris.hostens@ilvo.vlaanderen.be

Objectives, methods, and data collected

Changes in commercial fisheries intensity in and in the vicinity of the wind farms are investigated by means of VMS data in the Belgian part of the North Sea. All VMS data are stored in the ILVO-database for further analyses. Detailed overview has already been given in a previous report.

The research on changes in recreational fisheries activity in and in the vicinity of the wind farms is part of the MSc thesis of Kilian Persoon (UGent - EMBC) which started in 2015, entitled "A wind of change in recreational fisheries?'

2.2.5. Pelagic fish in the wind farms

Kris Hostens* and Sofie Vandendriessche *(*Institute for Agricultural and Fisheries Research)
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Objectives

The availability of pelagic fish for seabirds is regarded as an important gap in our current knowledge of the Belgian marine ecosystem. In 2014, ILVO further investigated the presence of pelagic fish in the Belgian part of the North Sea. For this targeted monitoring study we want to explore the possibility of obtaining quantitative data on pelagic fish in the Belgian part of the North Sea in general and in the wind farm area in particular. What are the needs for an optimal sampling program?

Methods

Three types of fishing gear can be compared: an 8-m shrimp beam trawl, a semi-pelagic otter trawl and a small pelagic trawl. These have been deployed over several years from RV Belgica, RV Zeeleeuw and RV Simon Stevin.

Data collected

Mainly the pelagic trawl was tested in 2014 on several campaigns, but many logistic problems were encountered. Moreover, the samples near the water surface were always less successful, questioning the efficiency of this gear towed behind our research vessels.

3. Hard substrate and invertebrates

3.1. Basic monitoring

3.1.1. Hard substrate and invertebrates

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Objectives

With the construction of wind turbine in the Belgian part of the North Sea, a new habitat of artificial hard substrate is being introduced in a region mostly characterized by sandy sediments. This will increase the heterogeneity of the region and the effect of the introduction of these hard substrates – the so-called reef effect – is regarded as the most important change of the original marine environment caused by the construction of windmill farms.

The structures will be colonized and successively develop fouling assemblages, which may or may not resemble epibioses on natural substrata. They will also allow for the establishment of species previously not present in this environment dominated by soft sediment habitats, as well as for the further spread of non-indigenous species (stepping stone effect) and certain warm water species take advantage of the increasing presence of hard substrate to further spread into the North Sea.

The aim of this part of the monitoring programme is to gather data concerning the new habitat, in particular information on the epifouling assemblage zonation and its succession on the scour protection and the concrete foundation. Emphasis will also be laid on the colonisation of the structures by non–indigenous species, warm water species and reef-forming organisms.

Methods

Sampling

Samples were collected in spring and later summer in the intertidal and subtidal zones and the scour protection of selected turbines of the C-Power and Belwind wind parks on the Thornton Bank and Bligh Bank respectively.

Intertidal sampling

Intertidal scrape samples (including the splash zone) were collected in a non-quantitative manner – i.e. sampling surface differed between samples – because of practical constraints linked to operating from a detached rigid-hulled inflatable boat.

The samples were preserved in buffered formalin prior to further processing. An estimate of the relative abundance of the organisms was made. Depending on the growth form – encrusting or solitary – and size or percentage coverage, species are categorised according to the levels defined in the SACFOR scale (Superabundant, Abundant, Common, Frequent, Occasional, Rare) as developed by the Joint Nature Conservancy Council (JNCC).

Subtidal sampling

In the subtidal, samples were collected in spring and late summer by scientific divers. Scrape samples of the fouling on the turbines were collected at 15 m depth, since based on the results of the first year, the zone at 15 m below water level was found representative for the deeper subtidal. Additionally stones of the scour protection were gathered. In both cases three replicates were collected.

Subtidal samples were scraped off the surface of the turbines by using a putty knife and deploying a square quadrat of 25 cm by 25 cm (6,25 dm²) and the biota were collected in a sealed plastic bag. All samples were preserved in buffered formalin prior to further processing, i.e. preservation (75% ethanol), sieving (over a 1 mm mesh sieve), sorting and identification. The organisms were identified to species level wherever possible, and the number of individuals was counted. A distinction was made between countable and colonial species. Average density (ind./m²) was calculated for the countable species and an estimate was made of the coverage of the colonial species..

In addition to the scraped quadrats, high definition video footage taken by SCUBA along the side of the pile 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 invertebrates. Video footage was collected by means of a Sony HDR-HC9 video camera in a Bluefin Light & Motion housing with a Light & Motion Sunray 2000 LED lighting system.

Data collected

Table 3.1. Overview of the collected samples during 2013 and 2014.

Date	Ship	Aim	Method	Location	Number of samples
29/04/2013	Belgica	subtidal	Diving	C-power (D6)	3 scrape samples 3 rocks
		intertidal	RHIB	C-power (D5, D6 and F1)	3 scrape samples
30/04/2013	Belgica	subtidal	Diving	Belwind (B08)	2 scrape samples 1 rock
		Intertidal	RHIB	Belwind (B08 and A08)	3 scrape samples
5/09/2013	Aquatrot	Subtidal	Diving	Belwind (C2) C-Power (E5)	3 rocks & 3 scrapings 3 scrapings Video
14 & 16/10/2013	Belgica	subtidal	Diving	C-Power (D5) Belwind (C2)	3 rocks & 3 scrapings 3 rocks & 3 scrapings Video
7/8/2014	Aquatrot	subtidal	Diving	C-Power (D5) C-Power (E5)	3 rocks & 3 scrapings 3 scrapings Video
31/10/2014	Stream	subtidal	Diving	Belwind (C2)	3 scrape samples 3 rocks

3.2. Targeted Monitoring

3.2.1. Testing the stepping stone hypothesis (*Patella vulgata*)

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Objectives

Additionally, we have started to investigate the role of the foundations as stepping-stones for species typically associated with hard substrates. Focus will be on the common limpet *Patella vulgata.* This species lives attached to the hard substrata in the intertidal zone as adult, and disperses through pelagic larvae.

The collected data will facilitate comparison with other windmill parks elsewhere in the North Sea and with other hard substrates (natural or artificial).

Methods

Individuals of *Patella vulgata* have been collected from the intertidal zone of the GBFs in the C-power wind park. Genetic markers will be compared with individuals collected on the Belgian groynes, and from hard coastal structures in 5 to 7 locations between Norway (Bodø) and Portugal (Ria de Vigo).

Data collected

The laboratory analyses on all of the samples are in progress.

Table 3.2. Overview of the collected samples during 2013 and 2014.

Date	Ship	Aim	Method	Location	Number of samples
9/09/2013	Belgica	Intertidal	RHIB	C-Power D4 & D5	Collection of patella specimen

4. Seabirds at offshore wind farms in the Belgian part of the North Sea

4.1. Basic and targeted monitoring

4.1.1. The impact of offshore wind farms on the density and distribution of seabirds

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Objectives

The seabird monitoring program executed by the Research Institute for Nature and Forest (INBO) is designed to determine local changes in seabird densities following the construction of offshore wind farms (OWFs). The main objective of the 'seabirds at sea' (SAS) monitoring is thus the assessment of displacement effects on local seabirds, and a tailored data modelling process assures statistical founding of the obtained results. The observed densities can also serve as input for collision risk modelling, aiming to estimate the number of collision victims among flying and migrating birds. Ideally, for the latter, visual censuses are complemented with radar research. While SAS surveying offers a high taxonomic resolution of bird densities and flying heights during limited time frames, radar research provides continuous data collection yet low taxonomic resolution.

SAS monitoring further allows to collect information on the (foraging) behaviour of individual seabirds. As such, INBO also aims to provide an answer to the question why certain seabirds occur in lower or higher densities. To gain true insight in the ecological incentives behind the interaction between seabirds & OWFs however, monitoring should not be limited to above-water observations, but also needs to include research on the seabirds' pelagic prey communities.

Methods

Seabird surveys

Seabird surveys are conducted according to the standardised and internationally applied 'European seabirds at sea' (ESAS) method (Tasker et al. 1984). The focus is on a 300 m wide transect along one side of the ship's track. While steaming, all birds in touch with the water (swimming, foraging) located within this transect are counted ('transect counts'). In contrast, flying birds are counted by 'snapshot counts': right at the start of each minute all birds flying within a quadrant of 300 by 300 m inside the transect are counted. As the ship covers a distance of approximately 300 m per minute (when sailing the prescribed speed of 10 knots), the full transect length is covered by means of these subsequent 'snapshots'. Taking in account the transect width and distance travelled, the combined count result can be transformed to seabird density.

In practice, we count all birds observed while surveying, but those not satisfying a set of preset conditions are not included in density analyses afterwards. We also note down as much information as possible regarding the birds' age, plumage, behaviour, flight direction, association with objects, vessels, other birds and so on. The distance of the observed bird(s) to the ship is estimated, allowing to correct for decreasing detectability with increasing distance ('distance correction'). To this purpose the transect is divided in four distance categories (A = 0–50 m, B = 50–100 m, C = 100–200 m & D = 200–300 m). During data processing, observation time is linked to the corresponding GPS coordinates saved by the ship's board computer, and data are aggregated in two-minute bouts.

BACI monitoring

When 'before' data are available and the inclusion of a suitable 'control' is possible, before–after control–impact (BACI) monitoring is the suggested approach for environmental impact assessments. The inclusion of a control area allows to account for temporal variability other than that caused by the investigated impact (Stewart-Oaten & Bence, 2001; Drewitt & Langston, 2006). The 'impact area' is considered to be the zone where effects of turbine presence can be expected, which was delineated by surrounding the wind farms with a buffer zone of 3 km. This buffer distance is based on the avoidance distances as found for scoters and long-tailed ducks during the Danish research project at the Nysted OWF (Petersen et al., 2006). Next, a control area was delineated, this area harbouring comparable numbers of seabirds and showing similar environmental conditions. Considering the large day-to-day variation in observation conditions and seabird densities, the distance from the control to the impact area was chosen to be small enough to be able to count both areas on the same day by means of a research vessel.

Data collected

Throughout 2013 & 2014, INBO performed 33 SAS monitoring surveys, mainly in the reference and impact areas of the OWFs at the Bligh Bank (14 visits) and Thorntonbank (18 visits). In contrast, due to construction activities and limited access, effort was low in the Lodewijckbank site (5 visits).

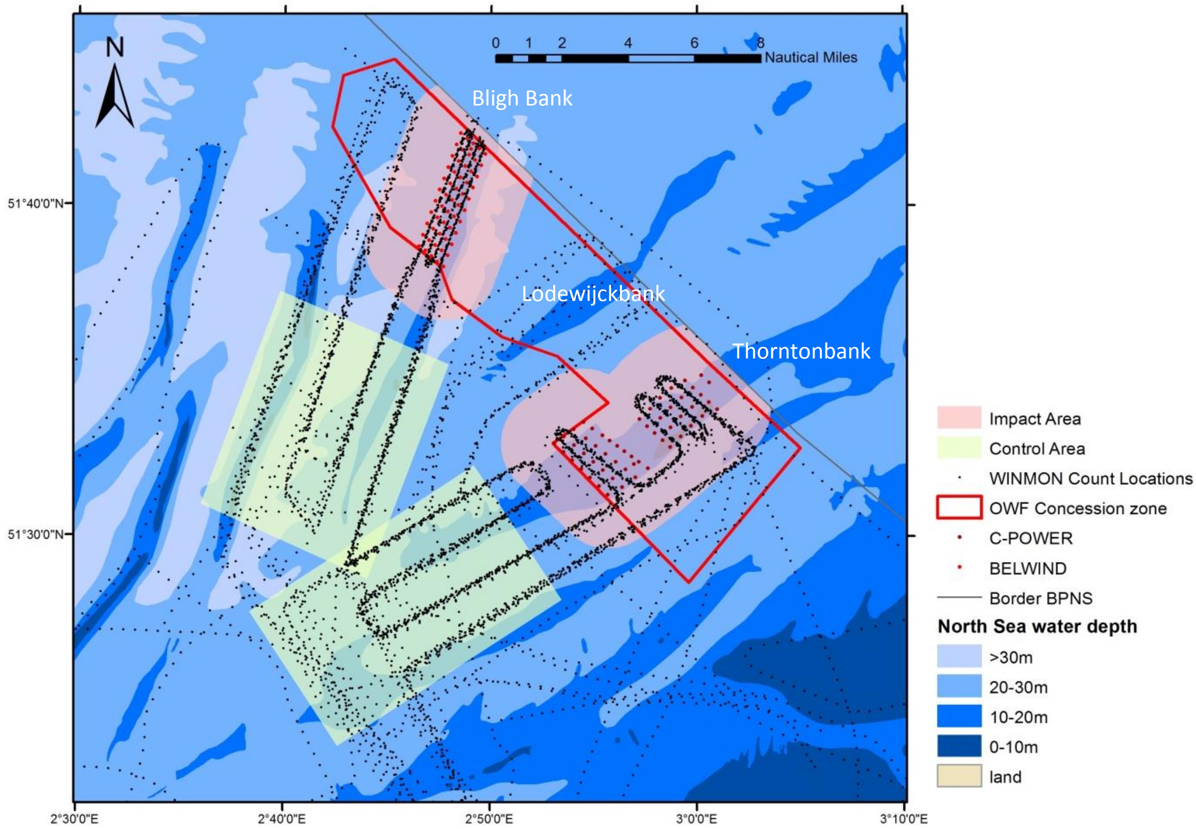

Figure 4.1. BACI monitoring set-up for the Thorntonbank & Bligh Bank OWF sites, and location of the seabird counts performed throughout 2013 & 2014.

Table 4.1. Overview of the monitoring surveys performed in 2013 & 2014 (BB=Bligh Bank, TTB=Thorntonbank, LB=Lodewijckbank).

Year	Month	Date	Monitoring	Research vessel
2013	January	25/01/2013	LB	RV Simon Stevin
		28/01/2013	TTB	RV Belgica
	February	27/02/2013	TTB	RV Simon Stevin
		28/02/2013	BB	RV Simon Stevin
	March	27/03/2013	BB	RV Belgica
		29/03/2013	TTB & LB	RV Belgica
	April	15/04/2013	BB	RV Belgica
		16/04/2013	TTB & LB	RV Belgica
	May	7/05/2013	BB & LB	RV Belgica
		8/05/2013	TTB	RV Belgica
	June	-	-	-
	July	2/07/2013	BB	RV Belgica
		3/07/2013	TTB	RV Belgica
	August	22/08/2013	TTB & BB	RV Belgica
	September	30/09/2013	TTB	RV Simon Stevin
	October	-	-	-
	November	28/11/2013	BB	RV Simon Stevin
	December	10/12/2013	TTB	RV Belgica
		11/12/2013	BB	RV Belgica
		12/12/2013	BB	RV Belgica
2014	January	30/01/2014	BB	RV Simon Stevin
	February	4/02/2014	TTB	RV Simon Stevin
	March	20/03/2014	TTB	RV Simon Stevin
	April	2/04/2014	TTB	RV Belgica
		3/04/2014	BB	RV Belgica
		4/04/2014	LB	RV Belgica
	May	-	-	-
	June	26/06/2014	TTB	RV Simon Stevin
	July	-	-	-
	August	26/08/2014	TTB	RV Simon Stevin
	September	9/09/2014	TTB	RV Belgica
		10/09/2014	BB	RV Belgica
	October	29/10/2014	TTB	RV Simon Stevin
		30/10/2014	BB	RV Simon Stevin
	November	18/11/2014	TTB	RV Belgica
		19/11/2014	BB	RV Belgica
	December	15/12/2014	TTB	RV Belgica

4.1.2. Bird radar research

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Objectives:

Complementary to the seabird surveys, also a continuous monitoring of birds to study the impact of wind farms, making use of a bird radar, is performed.

The goals of this study are:

(1) to assess to what extent wind farms are a barrier to local and migrating birds;
(2) to measure the flux of birds through the wind farm area and the temporal variation thereof (e.g. seasonal, diurnal);
(3) to estimate the number of birds colliding with the turbines based on the flux data, by using a mathematical bird collision risk model;
(4) to determine the temporal variation of bird intensity and direction of flight in the area to the south of the radar location and how this will change once the Norther wind farm is being built and operational.

Method

These objectives will be achieved making use of a dedicated bird radar which is installed on the offshore platform in the C-Power wind farm on the Thorntonbank. The radar system consists of two radar antennas, one scanning in the horizontal pane and one in the vertical. The detection range of the radar antennas can be specified in the system's settings. For the horizontal scanning radar (HSR) the range is maximum seven nautical miles, but is usually set at four nautical miles. The range of the vertical scanning radar (VSR) is set to track to a height of two nautical miles. The radar will record birds continuously year-round and the system is remotely controlled. The system is developed by DeTect-inc. (Florida, USA) and is operated by software called Merlin which is specifically designed to track individual birds.

The flight paths can be determined with the horizontal scanning radar. This radar registers targets 360° around its location. The Merlin software links consecutive registrations of a target, and thus registers the flight path of a moving target. This way it is possible to determine a bird's flight path, flight direction and changes in that direction.

The flux of birds (birds/km/hr) can be deducted from the VSR-data. By rotating in the vertical pane the VSR is creating a 'radar screen' that registers all the targets moving through that screen. As this 'radar screen' is fairly narrow (opening angle 22°) every registration can be seen as one or a group of birds passing through that area. The flux of birds is expressed as mean traffic rate (MTR), i.e. number of birds that pass through a certain area during a certain time period (Krijgsveld et al., 2011).

A major problem with the collected data is that the radar does not only record birds. It also registers rain, waves, wind turbines, ships, etc. This is referred to as clutter. The biggest problem offshore is the clutter caused by waves, i.e. seaclutter. All this clutter needs to be filtered from the data before being able to study the bird movements in the area. The first focus of this research is to develop a filter to remove as much clutter from the database as possible. This filter will be based on the differences in target characteristics as recorded by the radar. There hence is a need for a reference dataset for which it is known if a target is a bird or clutter. Such a dataset will be collected by doing visual observations at the radar location. This process is called groundtruthing. During groundtruthing, visual observations are linked with radar registrations and marked with a certain class (e.g. bird, ship, rain, interference, seaclutter, …). Some objects can be groundtruthed via remote access because they are unmistakably (e.g. rain, rotating blades from turbines).

Data collected

Persistent technical problems hampered adequate data collection with the bird radar in 2013. Corrosion of the radar antenna motors and of the cable connectors led to shut-down of the system for several longer periods.

Both the cables and the motors were replaced in 2013, and again in early 2014. The motors which were installed in 2014 have a new design which is more resistant to the harsh offshore conditions. Since then, the system has been operating continuously, except during periods with very high wind speeds. Data are hence successfully collected since April 2014 .

There was also a need to improve the radar signal, as the signal depleted rapidly with distance from the radar in the different radar pulse regions, causing significant gaps in the detection volume of the radar. To improve the signal detection, the manufacturer developed a new firmware and updated the bird detection software. The new firmware was installed in October 2013, which significantly improved the target detection.

A limited dataset from fall and winter was analysed and used to estimate the number of birds colliding with the offshore wind turbines. These results are presented in the integrated report about the environmental monitoring of the impact of the Belgian offshore wind farms and in a paper, ‘Towards a cumulative collision risk assessment of local and migrating birds in North Sea offshore wind farms’

Based on groundtruthed reference data, which were collected in 2014, we developed a filtering model to remove clutter from the database as effective as possible. This was done in collaboration with the radar manufacturer. The results of this model are very promising and after further fine tuning in the upcoming months, it will be applied to all historical data and (near) real-time to the new data.

5. Marine mammal monitoring at offshore wind farms in the Belgian part of the North Sea

5.1. Basic monitoring

5.1.1. Marine mammal at offshore wind farms

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Objectives

The Royal Belgian Institute of Natural Sciences monitors marine mammals in the framework of offshore wind farm construction and operation. The monitoring is based on anticipated effects on protected species, and is required according to national and international legislation and commitments such as the national legislation on the protection of marine species (Royal Decree of 21 December 2001 and 7 February 2014), the Marine Strategy Framework Directive (2008/56/EC), the Habitats Directive (92/43/EEC) and ASCOBANS (UNEP/CMS, 1991). The objectives are to identify any effects on marine mammals, both negative as positive. It also includes a baseline monitoring to obtain information about the temporal and spatial presence of marine mammals in Belgian waters, independently of e.g. construction activities, and more particularly in and around offshore wind farm areas. Results of the monitoring of marine mammals are combined with the results of the monitoring of underwater sound, habitat changes, and changes in fish communities.

The main questions to be answered in the monitoring are related to the temporal and spatial distribution of marine mammals. As the most common marine mammal in Belgian waters is the harbour porpoise *Phocoena phocoena*, the monitoring focuses on that species, acknowledging that similar effects could occur on other species. Given that physical injuries are only likely to occur close to piling sites, the main effects to be considered are displacement and habitat exclusion. Small endotherm animals, such as the harbour porpoise, living in a cold environment, need to feed very regularly to stay fit. Repeated disturbance from piling activities can thus have serious consequences, especially if such disturbance would occur simultaneously or consecutively in areas within tens of km from one another.

Methods

To investigate the distribution and abundance of marine mammals, a combination of methods was used. Passive acoustic monitoring (PAM) yields data on the relative abundance of small cetaceans in a high temporal but low spatial resolution. Aerial line transect surveys allow estimating of the distribution and absolute abundance of marine mammals with a relatively high spatial but low temporal resolution.

Aerial surveys

Visual aerial line transect surveys (Buckland et al., 2001) yield absolute estimates of density over a large area and for a short time period. They rely on good meteorological conditions (sea state), good observation conditions (glare, turbidity), they are limited to daylight hours and animals under water are not detected, requiring the use of correction factors. Therefore estimates of average density can only be given within relatively wide confidence limits.

Digital strip transect were made in 2014 using a high resolution still or video camera. The number of animals recorded over a known surface can be used to estimate density. Possibly vertical images can contribute to the visual data, or even stand alone (in the future) as strip transect surveys (vs. line transect surveys).

PAM

A relatively new and promising method for monitoring small cetaceans is (static) passive acoustic monitoring (PAM), an automated data collection system in which the presence of a cetacean species in the vicinity of a PAM device can be detected through the distinctive sounds the animals produce (Au, 1993; Tregenza, 1999; Mellinger et al., 2007). In contrast to visual line transect methods, PAM is a cue counting method, and it cannot usually directly provide an estimate of absolute density. Within certain limitations, static PAM can provide a continuous measure of the presence or absence of a cetacean species close to the moored device at a high temporal resolution for up to many months, but with an inherently low spatial coverage.

The PAM devices used are C-PODs. These record a summary of all tonal ultrasounds detected, including the frequency, duration, time and bandwidth of each acoustic event (Tregenza, 1999). During post-processing dedicated software (Chelonia Ltd; www.chelonia.co.uk; C-POD software v2.043 was used to analyse all data; www.chelonia.co.uk) seeks coherent trains of sounds and the most probable source of the noise (dolphin, porpoise, SONAR, doubtful origin) is attributed to each possible train found. As a quantitative measure to describe PAM results we use the number of detection positive minutes per day (DPm/d), which is the number of minutes per day during which the presence of harbour porpoises was detected by the POD. Next to that, we also use the total time present per day (TP/d). While DPm/d is a good measure for presence/absence, TP/d is a better measure for density, as it is more independent of the actual swimming speed of the animals. The data are treated as in figure 5.1.

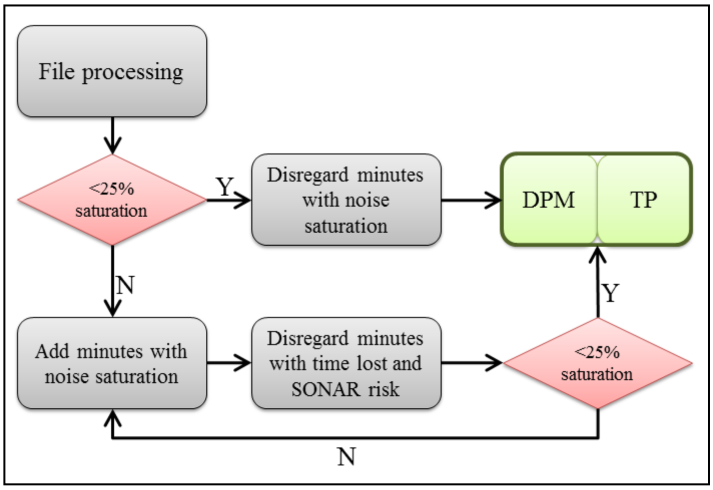

Figure 5.1. Description of the treatment of PoD data

Data collected

Aerial surveys

During 2013 and 2014 the RBINS succeeded in performing seven successful. An overview of the surveys is presented in Table 5.1. Next to the porpoises, in total 5 seal sp. were observed (on task) and 1 humpback whale *Megaptera novaeangliae* (off task).

Table 5.1. Overview of aerial surveys

Date	Survey length (nm, on task)	Survey duration (on task)	Number of porpoises observed	Estimate of average density (n/km²)
14-17 January 2013	239.3	2:22:37	49	0.84
13 February 2013	309.5	3:01:40	71	0.94
6-7 May 2013	304.2	2:53:29	131	1.72
3-4 September 2013	382	3:42:28	57	0.61
Total 2013	1235.0	12:00:14	308	
1 April 2014	357.8	3:33:19	331	3,96
7-8 September 2014	390.1	3:53:42	41	0,45
29 September – 30 October 2014	394.3	3:54:21	23	0,25
Total 2014	1142.2	11:21:22	395	

The aerial surveys on 14-17 January, 13 February and 3-4 September 2013 were undertaken partly during pile driving activities. The estimates of the average density of harbour porpoises are given for the survey area, which is covering most of Belgian waters.

Next to the aerial surveys given in Table 5.1, digital test flights were performed in 2014 using a vertically mounted 30 Mpix still camera equipped with a fixed 50mm lens, automatically taking an image every 2 to 5 s. Table 5.2 gives the data of the vertical aerial photography test flights, which partly overlapped with the visual surveys. Harbour porpoises were observed in the images, but technical ameliorations are needed, and the method still needs to be evaluated.

Table 5.2. Overview of aerial surveys in which vertical photographs were taken

Date	Time start	Time stop	Total time	Number of images
27 August 2014	11:01	12:08	1:07	387
2 September 2014	13:05	14:25	1:20	470
7 September 2014	10:45	12:43	1:58	955
8 September 2014	9:13	10:27	1:14	875
Total			5:39	3121

PAM

The effort in PAM data collection in 2013 and 2014 is presented in Table 5.3. Moorings were performed at, or in the vicinity of offshore wind farms (Thornton Bank) and in control areas (Gootebank, MOW1, Oostdyck West; figure 5.2.). All moorings used platforms of opportunity, as such reducing the costs and the risk of losses of C-PoDs. The moorings on the Thornton Bank, the Gootebank and on the Oostdyck West used navigational buoys, while for the mooring on the MOW1 location a tripod, already containing other oceanographic instruments, was used. For the mooring on the tripod it was made sure that none of the other instruments affected the PoD detections or small cetacean presence. No PoDs were lost during 2013 or 2014, while some data were not collected due to batteries running down early. Also, the Thornton Bank location was abandoned during 2013 due to the removal of the navigational buoy. The PAM data are being analysed together with those collected during previous years. The effective number of days PoDs were moored, and yielded data, has steadily risen (Figure 5.3.).

Table 5.3. Overview of C-PoD moorings

Location	**Days in 2013**	**Days in 2014**
Bligh Bank		143
Gootebank	143	341
MOW1	352	360
Oostdyck W	295	315
Thorntonbank	212	
Total	**1002**	**1159**

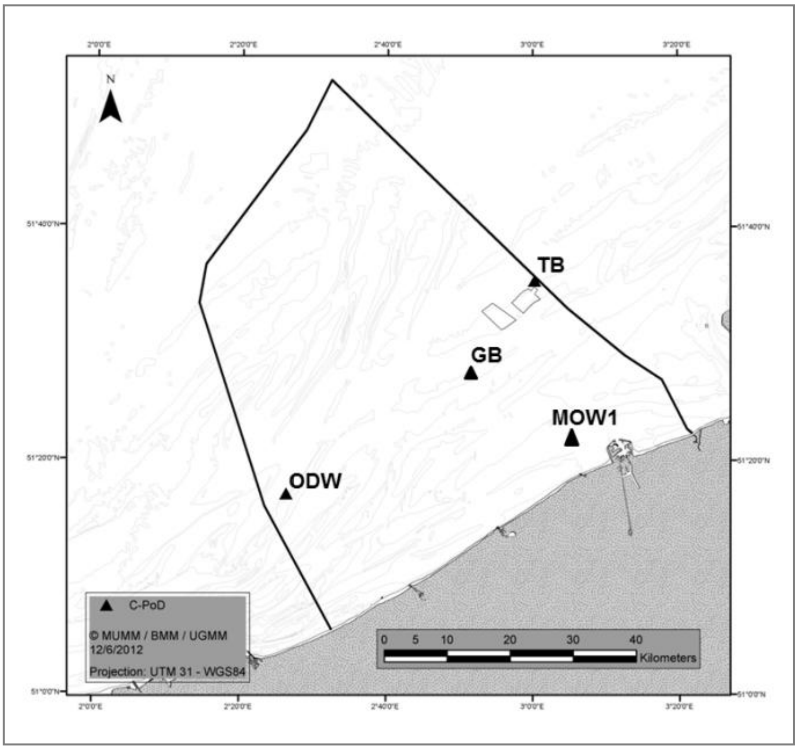

Figure 5.2. Position of C-PoD moorings.

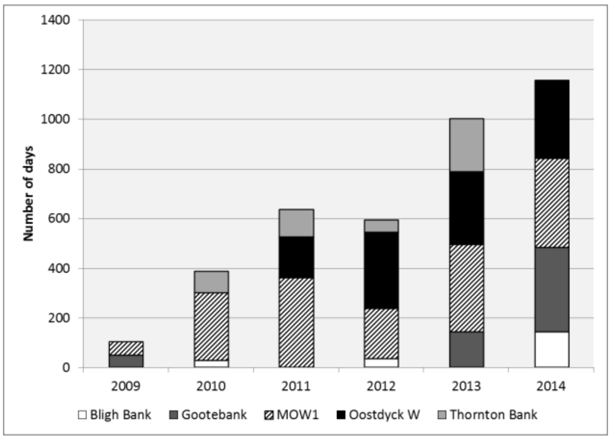

Figure 5.3. Number of days in which PAM data were collected between 2009 and 2014

5.2. Targeted monitoring

5.2.1. Modelling

Jan Haelters*, Valérie Dulière, Laurence Vigin, Steven Degraer (Royal Belgian Institute of Natural Sciences)

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Objectives, methods and data collected

The results of the nationally undertaken aerial surveys are being used to develop a numerical model that can reproduce harbour porpoises' redistribution patterns during disturbance. The model can be useful to predict or simulate their redistribution in cases when field investigations are not possible or impractical, for pre-construction environmental impact assessments and for impact assessments in case of multiple piling operations ongoing in the same area. The results of the model, based on data collected during aerial surveys, were published (Haelters et al., 2014) and they were used in an environmental impact assessment (Rumes et al., 2015) to simulate the consequences of pile driving in a worst case scenario (Figure 5.4.).

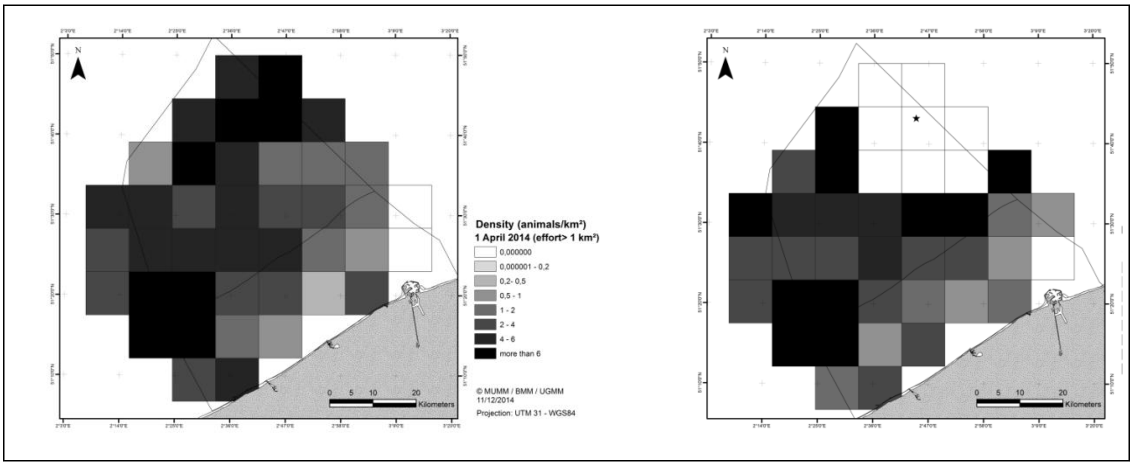

Figure 5.4. Modelling of the displacement of harbour porpoises in Belgian waters two hours after simulated pile driving (jacket pile; lasting two hours) at a location northwest of the Bligh Bank (right); as a reference situation the density distribution of 1 April 2014 presented in a grid with cells of 10 km by 10 km was chosen.

As harbour porpoises are highly mobile animals, it is useful to assess their spatio-temporal distribution on a wider scale. Therefore, nationally collected data from Belgium, The Netherlands, Germany and Denmark (and including relevant SCANS II data) are collated to present a wider picture of harbour porpoise distribution (southern and central North Sea; Gilles et al., 2014). This is made possible thanks to the use of the standardized methodology. A publication of the model results is in preparation (Gilles et al., in prep.).

6. Wind farm generated underwater sound

6.1. Basic monitoring

6.1.1. Wind farm generated underwater sound

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Objectives

As part of the environmental monitoring program of the zone reserved for energy production in the Belgian part of the North Sea, underwater sound generated by the offshore windmills is monitored during the various phases of the wind parks' life cycle.

In 2013, Northwind wind park was constructed and was monitored. The Belwind and C-Power parks were in operational phase in 2013 and were monitored. In addition, a new instrument for continuous underwater sound registration was deployed. The first deployment was foreseen to obtain far-field measurements from the construction sound of the Northwind wind park as well as ambient sound measured at MOW1 just outside the Zeebrugge harbor entrance.

In 2014, no construction works took place and the monitoring hence focused on operational noise at the Belwind, C-Power & Northwind parks.

Methods

Lagrangian- and Eulerian-type measurements

The same measurement protocol, as used for previous underwater sound measurements in Belgian wind parks was used for the present study (see Haelters *et al.* 2009). In summary, measurements of wind farm construction and operation sound were performed from a rigid hull inflatable boat (RHIB) in the vicinity of the piling site or drifting throughout the wind park for operational sound measurements. To avoid interaction with the hydrophone, the engine, radar and echosounder, if present on board, were turned off. The geographic position and time of measurement were recorded with a handheld GPS GARMIN GPSMap60 at a frequency of one position every 5 seconds. The clock of the recorder was synchronized beforehand with the GPS-time (UTC). At the start and the end of each measurement a reference signal was recorded. Weather conditions encountered during that part of the fieldwork featured wind of 1-4 BF and a sea state ranging from 1 to 2-3.

In addition to this Lagrangian measurement strategy, an Eulerian approach was started in 2013. It includes a new instrument that can be moored to the seabed using a tripod structure (Figure 6.1.). This measurement strategy does not suffer from weather limitations except for deployment and recovery of the instrument.

Figure 6.1. Tripod as used to deploy the underwater noise recorder to the seabed

Acoustic measurement equipment

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

For every Eulerian-type measurement, the Aural M2 datalogger and hydrophone was deployed 1 m above the seabed on a tripod (Figure 6.1.). The instrument records in a continuous way with a sampling rate of 32768 Hz. Data files are created every 2 h. These files are stored in .wav format into an internal hard drive. The batteries power the complete system for about 60 days (Table 6.1.).

Data collected

Table 6.1. Underwater noise measurements realized in 2013 and 2014. Measurements identified by * are operated by the moored equipment (i.e. Eulerian-type measurements). All the other measurements are collected from a silently drifting RHIB (i.e. Lagrangian-type measurements). Due to technical problems with the mooring line, most of the records of the 02/04- 30/05/2014 deployment are corrupted by mooring noise (metal over metal noise).

Park name	*Date*	*Number of records*	*Type of measurements*	*Location*
C-Power	29/4/2013	3 * 20 minutes	Operational	N51 33.34 E2 57.68
Belwind	30/4/2013	3 * 20 minutes	Operational	N51 39.69 E2 47.50
Northwind	24/7/2013	6 of various length	Piling	N51 36.83 E2 53.53
Northwind	4/9/2013	2 of various length	Piling	N51 35.82 E2 52.09
Northwind	9/9/2013	4 of various length	Scour protection deployment	N51 37.41 E2 56.06
MOW1	23/9—16/10/2013	23 days	Ambient noise *	N51 22 E23 07.5
Belwind	5/5/2014	3 * 20 minutes	Operational	N51 41.27 E2 48.45
C-Power	6/5/2014	3 * 20 minutes	Operational	N51 33.07 E2 54.29
Belwind-tripod	02/04-30/05/2014	58 days	Operational *	N51 42.18 E2 48.80

6.2. Targeted monitoring

6.2.1. Marven: an externally Funded project in relation to WinMon

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Objectives

The Marven project is a project financed by the European Commission (EC) and targeting an assessment of the environmental impacts of sound, vibrations and electromagnetic emissions of offshore renewable energy installations. The project was run by a consortium led by DHI (Denmark) and within which RBINS brings in its expertise with underwater sound. The Marven project commenced in December 2013 and ended in June 2015.

Methods

Lagrangian- type measurements

The same measurement protocol, as used for previous underwater sound measurements in Belgian wind parks was used for the present study (see Haelters *et al.* 2009). In summary, measurements of wind farm construction and operation sound were performed from a rigid hull inflatable boat (RHIB) in the vicinity of the piling site or drifting throughout the wind park for operational sound measurements. To avoid interaction with the hydrophone, the engine, radar and echosounder, if present on board, were turned off. The geographic position and time of measurement were recorded with a handheld GPS GARMIN GPSMap60 at a frequency of one position every 5 seconds. The clock of the recorder was synchronized beforehand with the GPS-time (UTC). At the start and the end of each measurement a reference signal was recorded. Weather conditions encountered during that part of the fieldwork featured wind of 1-4 BF and a sea state ranging from 1 to 2-3.

Data collected

Within the project, a full week of field work onboard R/V Simon Stevin was done at the renewable energy zone off the Belgian coast from 28/7/14 to 1/08/14 (Table 6.2.). In absence of piling activities in Belgian waters in 2014, the study focused on simultaneous measurements of sound pressure, particle motion and electromagnetic field emissions.

These measurements and more specifically the sound pressure information, directly feed into the WinMon programme. Moreover, Marven added value to the WinMon programme by providing information on particle motion and electromagnetic field for the Belgian offshore renewable energy.

Table 6.2. Underwater noise measurements realized in 2014. Measurements are collected from a silently drifting RHIB (i.e. Lagrangian-type measurements).

Park name	Date	Number of records	Type of measurements	Location
Windpark zone	30/07/14	2 of various length	Calibration Marven	N51 29.32 E2 51.30
Northwind/C-Power	31/7/14	4 of various length	Operational Marven	N51 33.54 E2 57.23

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8. References

- Au, W.W. L., 1993. The sonar of dolphins. New York: Springer-Verlag.
- Brabant, R.*, Vanermen, N.*, Stienen, E.W.M., Degraer, S. (* shared first authorship), 2015. Towards a cumulative collision risk assessment of local and migrating birds in North Sea offshore wind farms. Hydrobiologia 756: 63-74. DOI: 10.1007/s10750-015-2224-2.
- Buckland, S.T., Anderson, D.R., Burnham, K.P., Laake, J.L., Borchers, D.L. & Thomas, L., 2001. Introduction to Distance Sampling: estimating abundance of biological populations. Oxford University Press.
- Coates, D.A., Deschutter, Y., Vincx, M., Vanaverbeke, J., 2014. Enrichment and shifts in macrobenthic assemblages in an offshore wind farm area in the Belgian part of the North Sea. Marine Environmental Research 95, 1-12.
- De Mesel, I., Kerckhof, F., Rumes, B., Norro, A., Houziaux, J.-S., Degraer, S., 2013. Fouling community on the foundations of wind turbines and the surrounding scour protection. In: Degraer, S., Brabant, R., Rumes, B., (Eds.), 2013. Environmental impacts of offshore wind farms in the Belgian part of the North Sea: Learning from the past to optimise future monitoring programmes. Royal Belgian Institute of Natural Sciences, Operational Directorate Natural Environment, Marine Ecology and Management Section. pp. 123-137.
- Drewitt, A.L.,Langston, R.H.W., 2006. Assessing the impact of wind farms on birds. Ibis 148: 29-42.
- Ehrenhauss, S., Huettel, M., 2004. Advective transport and decomposition of chain-forming planktonic diatoms in permeable sediments. J. Sea Res. 52, 179-197.
- Ehrenhauss, S., Witte, U., Janssen, F., Huettel, M., 2004. Decomposition of diatoms and nutrient dynamics in permeable North Sea sediments. Continental Shelf Research 24, 721-737.
- Haelters, J., Norro, A., Jacques, T., 2009. Underwater noise emission during the phase I construction of the C-Power wind farm and baseline for the Belwind wind farm, in: Degraer, S., Brabant, R. (Eds.), Offshore wind farms in the Belgian part of the North Sea. State of the art after two years of environmental monitoring. Royal Belgian Institute of Natural Sciences, Brussels, pp. 17-37.
- Jacob, U., Mintenbeck, K., Brey, T., Knust, R., Beyer, K., 2005. Stable isotope food web studies: a case for standardized sample treatment. Marine Ecology-Progress Series 287, 251-253.
- Krijgsveld, K.L., Fijn, R.C., Japink, M., Horssen, P. van, Heunks, C., Collier, M., Poot, M., Beuker, D., Dirksen,S., 2011. Effect studies Offshore Wind Farm Egmond aan Zee - Final report on fluxes, flight altitudes and behaviour of flying birds. Bureau Waardenburg, Culemborg.
- Layman, C.A., Arrington, D.A., Montaña, C.G., Post, D.M., 2007. Can stable isotope ratios provide for community-wide measures of trophic structure. Ecology 88, 42-48.
- Mellinger, D.K., Stafford, K.M., Moore, S.E., Dziak, R.P., Matsumoto, H., 2007. An overview of fixed passive acoustic observation methods for cetaceans. Oceanography 20(4): 36-45.
- Petersen, I.K., Christensen, T.K., Kahlert, J., Desholm, M., Fox, A.D., 2006. Final results of bird studies at the offshore wind farms at Nysted and Horns Rev, Denmark. National Environmental Research Institute, Denmark.
- Reubens, J.T., Braeckman, U., Vanaverbeke, J., Van Colen, C., Degraer, S., Vincx, M., 2013. Aggregation at windmill artificial reefs: CPUE of Atlantic cod (Gadus morhua) and pouting (Trisopterus luscus) at different habitats in the Belgian part of the North Sea. Fisheries Research 139, 28-34.
- Rumes, B.; Di Marcantonio, M.; Brabant, R.; Demesel, I.; Duliére, V.; Haelters, J.; Kerckhof, F.; Norro, A., Van Den Eynde, D., Vigin, L. en Lauwaert, B. 2015. Milieueffectenbeoordeling van het MERMAID offshore energiepark ten noordwesten van de Bligh Bank. BMM, OD Natuurlijk Milieu, Koninklijk Belgisch Instituut voor Natuurwetenschappen, Brussel, 210 pp. en Annex.

- Stewart-Oaten, A., Bence, J.R., 2001. Temporal and spatial variation in environmental impact assessment. Ecological Monographs 71: 305-339.
- Tasker, M.L., Jones, P.H., Dixon, T.J., Blake, B.F., 1984. Counting seabirds at sea from ships: a review of methods employed and a suggestion for a standardised approach. Auk 101: 567-577.
- Tregenza, N.J., 1999. A new tool for cetacean research - a fully submersible click detector. In European Research on Cetaceans, Vol. 13. Valencia, Spain, 1999.
- Vafeiadou, A.-M., Materatski, P., Adao, H., De Troch, M. & Moens, T., 2013. Food sources of macrobenthos in an estuarine seagrass habitat (Zostera noltii) as revealed by dual stable isotope signatures. Marine Biology 160, 2517-2523.
- Zintzen, V., Norro, A., Massin, C., Mallefet, J., 2008. Spatial variability of epifaunal communities from artificial habitat: Shipwrecks in the Southern Bight of the North Sea. Estuarine, Coastal and Shelf Science 76, 327-344.

9. Annex

Soft-sediment macrobenthos samples for the WINMON project were collected at the Bligh Bank, Thorntonbank and Goote Bank.

Location	Samples	Latitude	Longitude	# Van Veens	Date collected
Bligh Bank	BBI02	51.655106	2.7730616	3	16/10/2014
Bligh Bank	BBI05	51.684861	2.791611	3	16/10/2014
Bligh Bank	BBI26	51.639578	2.8187704	3	16/10/2014
Bligh Bank	BBI33	51.666024	2.8512395	3	16/10/2014
Bligh Bank	BBE09	51.653214	2.8545808	3	16/10/2014
Bligh Bank	BBE06	51.639543	2.8371367	3	16/10/2014
Bligh Bank	BBE05	51.625775	2.8180737	3	16/10/2014
Bligh Bank	BBE14	51.706222	2.784802	3	16/10/2014
Bligh Bank	BBE12	51.68862	2.7744012	3	16/10/2014
Bligh Bank	BBE16	51.671145	2.7661829	3	16/10/2014
Bligh Bank	BBC01	51.674729	2.758216	3	16/10/2014
Bligh Bank	BBC02	51.69194	2.767305	3	16/10/2014
Bligh Bank	BBC03	51.709924	2.777361	3	16/10/2014
Bligh Bank	BBC04	51.61909	2.824985	3	16/10/2014
Bligh Bank	BBC05	51.633346	2.844077	3	16/10/2014
Bligh Bank	BBC06	51.646999	2.860551	3	16/10/2014
Bligh Bank	BBE19	51.643853	2.768525	3	16/10/2014
Bligh Bank	BBE20	51.637251	2.781047	3	16/10/2014
Bligh Bank	BBE21	51.629738	2.793114	3	16/10/2014
Bligh Bank	BBC07	51.635429	2.763744	3	16/10/2014
Bligh Bank	BBC08	51.628599	2.775811	3	16/10/2014
Bligh Bank	BBC09	51.621086	2.786739	3	16/10/2014
Bligh Bank	BBE22	51.709344	2.813136	3	16/10/2014
Thorntonbank	TBE05	51.5486204	2.9524304	3	15/10/2014
Thorntonbank	TBE14	51.543939	2.959807	3	15/10/2014
Thorntonbank	TBE15	51.587591	3.008856	3	15/10/2014
Thorntonbank	TBE16	51.577966	3.024403	3	15/10/2014
Thorntonbank	TBE06	51.5435374	2.9930165	3	15/10/2014
Thorntonbank	TBE07	51.5489043	3.0020033	3	15/10/2014
Thorntonbank	TBE08	51.5537713	3.0121983	3	15/10/2014
Thorntonbank	TBE10	51.5657709	2.9532999	3	15/10/2014
Thorntonbank	TBE11	51.5713212	2.9644317	3	15/10/2014
Thorntonbank	TBE12	51.5772048	2.9706467	3	15/10/2014
Thorntonbank	TBEC01	51.536551	3.002286	3	15/10/2014
Thorntonbank	TBEC02	51.543013	3.010901	3	15/10/2014
Thorntonbank	TBEC03	51.547836	3.019979	3	15/10/2014
Thorntonbank	TBEC04	51.571011	2.946941	3	15/10/2014
Thorntonbank	TBEC05	51.577179	2.957492	3	15/10/2014

Thorntonbank	TBEC06	51.583834	2.964796	3	15/10/2014
Thorntonbank	TBC01	51.5066849	2.8768615	3	15/10/2014
Thorntonbank	TBC06	51.5199189	2.89655	3	15/10/2014
Thorntonbank	TBC10	51.5228517	2.8503055	3	15/10/2014
Thorntonbank	TBC12	51.5301357	2.8803159	3	15/10/2014
Goote Bank	GBC06	51.4697949	2.8498133	3	13/10/2014
Goote Bank	GBC07	51.4754565	2.869829	3	13/10/2014
Goote Bank	GBC21	51.4532919	2.8697684	3	13/10/2014
Goote Bank	GBC24	51.4630499	2.8971875	3	13/10/2014