EXECUTIVE SUMMARY

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INTRODUCTION

Offshore renewable energy development in the Belgian part of the North Sea has matured since our previous report in 2013. At present, nine Belgian projects representing a capacity of 2.2 GW were granted both a domain concession and an environmental permit. Three projects are operational, one is under construction, and the last five will need to be constructed in the near future, if Belgium is to meet its 2020 targets for renewable energy. These latter include the Mermaid project, which will generate a certain amount of energy from waves as well as wind. By 2018-2019, the number of wind farms constructed will have doubled with the realization of the Nobelwind, Rentel and Norther projects. The latter will entail the installation of the largest individual turbines (8.4 MW – reaching 187 m above mean sea level) in our waters. The near future may also see the first co-use of wind farm zones with aquaculture projects being developed in the areas of the C-Power and Belwind wind farms. In the meanwhile the electricity grid is undergoing necessary reinforcements, both onshore with the Stevin project and offshore with the proposed shared connection or 'plug-at-sea'. In the adjacent Dutch wind farm zone, the Borssele project entails the installation of 1.4 GW of wind energy and the resultant transboundary wind energy zone requires both consistent management measures and a comprehensive environmental monitoring program that adequately assesses cumulative environmental impacts.

To allow for a proper evaluation and auditing of the environmental impacts of offshore wind farms, the environmental permit includes a monitoring program to ensure (1) the ability to mitigate or even halt the activities in case of severe 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 is tackled mainly by the basic monitoring program, the latter by the so called targeted monitoring program. In 2014 the existing basic environmental monitoring program was evaluated and a decision was made to focus on integrating work on several ecosystem components and streamlining research efforts (see below, reloading basic environmental impact monitoring).

The monitoring program targets physical (i.e. hydro-geomorphology and underwater noise), biological (i.e. hard substrate epifouling and fish communities, soft substrate macrobenthos, 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 although not all components are yearly studied or extensively reported on. The Operational Directorate Natural Environment (OD Nature) of the Royal Belgian Institute of Natural Sciences coordinates the monitoring and specifically covers hydro-geomorphology, underwater noise, hard substrate epifauna, radar detection of seabirds, marine mammals and socio-economic aspects. In 2014 and 2015, OD Nature further collaborated with different institutes to complete the necessary expertise in the following domains: seabirds (Research Institute for Nature and Forest, INBO), soft substrate epibenthos and fish (Institute for Agricultural and Fisheries Research, ILVO-Fisheries), and soft substrate macrobenthos (Marine Biology Research

Group, Ghent University). For details on the specific research strategies followed and methodologies used, one is referred to the individual chapters.

RELOADING BASIC ENVIRONMENTAL IMPACT MONITORING

The knowledge and expertise in relation to sampling technicalities and designs for offshore wind farm (OWF) monitoring gained from the Phase I basic monitoring (2005, 2008-2016; Degraer *et al.,* 2013) was revisited and discussed during a workshop with all scientists involved in the program, external experts and invitees from the OWF industry. The workshop focused on (1) How best to deal with variability (natural, anthropogenically induced) and spatio-temporal gradients?; (2) How to continue and optimise the basic monitoring program?; (3) How to plan the most appropriate sampling design for the basic monitoring program? An adapted monitoring program for the benthic and the pelagic realm was formulated, which excludes as far as possible sources of noise in the data by means of an adaptation of the sampling design. Management-relevant sources of variability in the data (i.e. benthic realm: e.g. distance to the coast, sedimentology, foundation type; pelagic realm: e.g. distance to the coast, seasonality) are used as explicit drivers for restructuring the monitoring program.

RESULTS OF THE ENVIRONMENTAL MONITORING PROGRAM

OPERATIONAL UNDERWATER SOUND EMISSION

Previous reports (e.g. Norro *et al.* 2013) analysed the underwater impulsive sound produced during construction activities. In the current report, the continuous underwater sound emitted by steel jacket and monopile foundation wind turbines is quantified, characterized and compared for low wind speeds (0-12 m/s). A maximum increase of SPL of about 20 dB re 1 µPa is observed at frequencies below 3 kHz. The addition of underwater sound increases with wind speed with a rate dependent on the type of foundation. For a mean wind speed of 10 m/s, a steel monopile will emit some 10 dB re 1 µPa more than a jacket foundation. Work is ongoing to expand this study to higher wind speeds and to quantify and qualify the cumulative effect of adjacent wind farms. Possible impacts on marine life like fish, marine mammals or invertebrates remain unclear mainly due to the lack of knowledge in disturbance or behavioral response levels for the species found at these sites.

EXPANSION OF SMALL-SCALE CHANGES IN MACROBENTHIC COMMUNITY INSIDE AN OFFSHORE WIND FARM?

Changes in hydrodynamics, presence of epifaunal coverage along the turbine and fisheries exclusion are expected to be the main causes influencing the macrobenthic community inside a wind farm. In this report we investigate whether previously observed changes in sediment characteristics and macrobenthic community (Coates *et al*., 2014) can also be observed at larger distances from the turbines. Stations in the close vicinity of the turbines (50 m distance, close samples) and further away (350-500 m distance, far samples) were sampled with a Van Veen grab in autumn 2015. No significant differences in abiotic factors are observed between the two distances. All samples are characterized by coarse sediments, with a low mud and total organic matter contents. Macrobenthic densities on the other hand differ significantly between the two distances with both higher densities and number of species for the far samples compared to the close samples. The latter are dominated by the amphipod *Urothoe brevicornis* and the mysid shrimp *Gastrosaccus spinifer*, while the amphipod *Bathyporeia elegans* and the polychaete *Spiophanes bombyx* are more abundant in far samples. Although this might be related to the turbine type, it remains unclear what underlying ecological processes are responsible for the difference in community structure between both distances as the current results are not consistent with results from previous studies. The current sampling design will be continued for the coming years. A targeted monitoring study will be required to elucidate changes in sedimentology and organic enrichment in the close vicinity of different turbine types.

EFFECT OF BELGIAN WIND FARMS ON THE EPIBENTHOS AND FISH OF THE SOFT SEDIMENTS

Many studies have demonstrated the reef effects on epibenthos and fish in the immediate vicinity of the turbine foundations (e.g. Reubens *et al.*, 2013, Bergström *et al.*, 2014), but the influence on demersal fish in the wider wind farm area is less clear (van Hal *et al.*, 2012; Bergström *et al.*, 2013). In Belgian wind farms, Vandendriessche et al. (2015) indicated several wider wind farm effects, including an increase in epibenthos biomass and densities and a possible ‘refugium effect’. By including the period 2013-2014, earlier observed positive short-term effects seem to have disappeared, and should be seen as a short-term reaction of opportunistic species directly after construction. Also, the earlier reported signals of a ‘refugium effect’ are no longer observed. For sandeel (*Ammodytes tobianus*), episodic increases and short-term positive effects on juveniles are observed, but no clear long-term sandeel trends are visible. Long-lived species are not yet encountered but may get a chance to establish and recover when the ongoing expansion of the wind farm area extends to one large continuous no-trawling area.

To investigate the effect of wind farms on the feeding behaviour of demersal fish, stomach content analyses were performed for lesser weever (*Echiichthys vipera*) and dab (*Limanda limanda*) in and around the C-Power wind farm. For both species there are no significant differences in stomach fullness inside or outside the wind farm. However, since the presence of the wind mill foundations, both fish species consume more prey species that are directly associated with hard substrates, both inside and in the direct vicinity of the wind farm. This demonstrates the expanding reef effect into the surrounding soft sediments.

THE EFFECTS OF HIGH INTENSITY IMPULSIVE SOUND ON YOUNG EUROPEAN SEA BASS (*DICENTRARCHUS LABRAX*), WITH SPECIAL ATTENTION TO PILE DRIVING

Pile driving generates strong impulsive noise that can affect the health and wellbeing of marine life. The impact of pile driving on young European sea bass (*Dicentrarchus labrax*), more specifically, the acute and delayed mortality, acute and chronic physiological stress responses and the impact of lower intensity impulsive sound on the fish behaviour were assessed through field and laboratory experiments (Debusschere, 2016). A field experiment at 45 m from the pile driving activity revealed no acute or delayed mortality but the fish showed strong acute secondary stress responses, a 50% decrease in oxygen consumption rate, in addition to behavioural responses as could be observed in laboratory experiments. Juvenile fish reduced their swimming activity and ceased all attacks on conspecifics at the onset of the impulsive sound exposure, but showed behavioural recovery within 25 minutes. The results also showed that the initial response change under repeated exposure. More research on multiple species and at population level are required as well as long-term data, especially on behavioural responses, in order to determine the ecological relevance of pile driving effects on young fish.

SEABIRD MONITORING AT OFFSHORE WIND FARMS IN THE BELGIAN PART OF THE NORTH SEA

Improvements to the modelling strategy of the long-term seabird monitoring program show significant avoidance by northern gannet (*Morus bassanus*) and common guillemot (*Uria aalge*) and attraction by great black-backed gull (*Larus marinus*) at the first two Belgian wind farms. Lesser black-backed gull (*Larus fuscus*), herring gull (*Larus argentatus*) and Sandwich tern (*Thalasseus sandvicensis*) appear to be attracted to only one wind farm. While the avoidance of common guillemot and northern gannet seems readily interpretable from a disturbance perspective, it is still difficult to pinpoint the observed increases in seabird numbers, even more so because these are not always consistent between study sites. Gaining more insight in the diurnal and tidal-dependent variation in numbers and behaviour of birds occurring inside the offshore wind farms seems indispensable for understanding the observed patterns and learning whether birds come to the wind farms merely for roosting and the related stepping stone function, or whether offshore wind farms also offer increased food availability. This will need to be investigated through targeted research using bird radar data, GPS tracking data of tagged gulls, fixed cameras and/or visual observations from a fixed location inside the wind farm.

SEASONAL AND INTERANNUAL PATTERNS IN THE PRESENCE OF HARBOUR PORPOISES (*PHOCOENA PHOCOENA*) IN BELGIAN WATERS FROM 2010 TO 2015 AS DERIVED FROM PASSIVE ACOUSTIC MONITORING

Passive acoustic monitoring data of harbour porpoise from the period 2010 and 2015 reveal a significant seasonal trend in detections with peaks in late winter - early spring and late summer, consistent with both results of aerial surveys and strandings data. The experiences gained are used to design a strategy to monitor the effects of offshore wind farm construction and operation on harbour porpoises in Belgian waters.

ANTICIPATING FUTURE DEVELOPMENTS

UNDERWATER NOISE REGULATIONS FOR PILING NOISE IN BELGIUM AND THE NETHERLANDS

From 2017 onwards, new regulations with regard to impulsive underwater noise will make it necessary to use noise mitigation measures during piling in the Belgian wind farm zone and the adjacent Dutch wind energy zone of Borssele. However, these regulations are quite different and at times even contradictory and developers could benefit from an alignment of regulatory practices on a regional basis. Measurements of piling noise from constructed wind farms are used to extrapolate the anticipated noise levels of the next two wind farms to be constructed, and these are evaluated in relation to the regulations on underwater sound. Wind farm developers are already developing strategies for cost-effective piling noise reduction but uncertainty remains with regards to both the level of underwater noise produced during piling as well as with the effectiveness of the noise mitigation measures being applied. Our results indicate that a combination of noise mitigation measures will need to be used to comply with regulations.

RECREATIONAL FISHERMEN AND WIND FARMS

The closure of offshore wind farms for commercial fisheries combined with the installation of artificial hard substrates has favorably affected demersal and benthopelagic fish in the wind farm zones and could thus, in theory, provide opportunities for recreational fishermen. However, in Belgium, recreational fishermen are not allowed in the wind farm area and have to keep a minimum distance of 500 m from the turbines. As a result, less than 2% of Belgian recreational fishermen reported to go fishing in the larger wind farm area, even when 30% to 40% of the respondents either expected more fish, bigger fish or other fish species inside the wind farm. Data were derived from the annual fisheries Data Collection Framework survey for recreational fishermen. 40% of the respondents would consider fishing inside wind farms if it were allowed.

This is a clear indication that the enforcement of wind farm closure for fisheries and shipping is vital when aiming at the creation and/or restoration of nursing grounds in the area. However, the large distance to the wind farms will probably continue to limit fishing pressure, even if wind farms would (partly) be opened for recreational fisheries.

WIND FARMS AND THEIR INFLUENCE ON THE OCCURRENCE OF ICHTYOPLANKTON AND SQUID LARVAE

The expected large scale increase in wind farms is expected to influence both fish and cephalopod egg deposition by modifying the sea floor and providing additional egg deposition opportunities respectively. This is expected to manifest as higher densities of early life stages at the hard substrates (eggs) and in the water column (larvae) at the wind farms. This was investigated at the Thornton bank wind farm by repeatedly sampling three impact stations and three reference stations with a Bongo net from 2010 to 2013. The results do not show significant effects of the wind farm on fish eggs, fish larvae and squid larvae. However, the data provide good baseline information about ichthyoplankton and squid larvae at offshore stations that can be used in future monitoring.

DO WIND FARMS FAVOUR INTRODUCED HARD SUBSTRATA SPECIES?

Offshore wind farms, like other artificial structures in the marine environment, are hypothesised to favour introduced species and as such pose a threat to the native fauna. Previous reports described the colonization of this new habitat (Kerckhof *et al.,* 2010) and the emerging prominence of introduced species in the intertidal zone (Kerckhof *et al.,* 2011). In this report, we investigate introduced species on Belgian offshore wind farms with particular interest in (1) the position of introduced species on offshore wind farms in relation to other hard substrata in the Belgian part of the North Sea (BPNS), (2) the distribution of introduced species in the subtidal versus intertidal zone and (3) the potential of offshore wind farms for future flourishment of the introduced species. Overall eleven introduced and two cryptogenic species are observed on the wind turbines, seven of which are intertidal species and four are subtidal species. All but one introduced species observed on the offshore wind farms in Belgian waters (i.e. *Fenestrulina delicia*), is already known from the BPNS. In the subtidal zone, the offshore wind farms will only marginally contribute to the further spread of introduced species given the vast amount of both natural and artificial hard substrata already available in the North Sea, which already contain established populations of the same introduced species. However, for the intertidal zone, the wind farms may have the potential to substantially increase the risk of the further spreading of introduced species, given that offshore intertidal habitat still is relatively rare. It is however expected that offshore wind farms may significantly contribute only to the spread of clear water, intertidal introduced species, as such nuancing the introduction and invasion risk posed by offshore wind farms.

BIRD RADAR STUDY IN THE BELGIAN PART OF THE NORTH SEA: DEVELOPMENTS TO IMPROVE BIRD DETECTION

Dedicated bird radars are used in ornithological studies as they provide continuous data on a large scale for many years. However, the recorded radar data have a low taxonomic resolution and contain a lot of clutter i.e. records of objects other than birds (e.g. sea surface, ships, rain). A filter has been developed based on the differences in target characteristics as recorded by the radar, which allows removing as much clutter as possible from the vertical radar data. The filter tests showed very high scores for the criteria accuracy, sensitivity and specificity. However, a relatively high number of false positives remains in the model results. This will be improved in the future by including variables in the decision tree analysis which are linked to the bird track level, instead of only using the variables recorded by the radar which describe the single point records. This will result in a more accurate bird flux and therefore an improved outcome of bird collision models.

BATS IN THE BELGIAN PART OF THE NORTH SEA AND POSSIBLE IMPACTS OF OFFSHORE WIND FARMS

To evaluate and quantify the risk of offshore wind farms in the southern North Sea to bat populations we need first to determine the spatio-temporal distribution of bats in Belgian waters. During two full bat migration periods an automated acoustic recorder was installed on the Belgian research vessel 'Belgica' to record bats while the vessel is at sea at night. Over a hundred call sequences belonging to four different species were registered although calls were limited to only a few nights (Brabant *et al.,* 2016). In 2015 and 2016, an expanded network of nine Batcorders was collecting data in the Dutch and Belgian part of the North Sea and along the coastline. This detector network will increase our knowledge about the impact of offshore wind farms on bats as it will increase the number of detections of bats at sea and will allow direct comparison between data collected at the different locations, without seasonal or meteorological bias.

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