EXECUTIVE SUMMARY

A CONTINUED MOVE TOWARDS INTEGRATION AND QUANTIFICATION

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The Belgian target figure for the contribution of electricity production from renewable energy sources is 13% of the total energy consumption, which is to be achieved by 2020. Offshore wind farms in the Belgian part of the North Sea (BPNS) are expected to make an important contribution to achieve this goal. When all Belgian wind farms are built, there will be almost 500 wind turbines in the BPNS. The 9 wind farms will have a capacity of 2200 MW and will cover up to 10% of the total electricity needs of Belgium or nearly 50% of the electricity needs of all Belgian households. As of 2016, an installed capacity of 870 MW, consisting of 232 offshore wind turbines, is operational in the BPNS. With 238 km² reserved for offshore wind farms in Belgium and 344 km² in the adjacent Dutch Borssele offshore wind farm (cumulative), ecological impacts are inevitable, which is why an extensive environmental impact monitoring programme was set up. This monitoring programme started with an explorational phase in 2005 and has been fully operational since 2008.

The monitoring programme targets physical (*i.e.*, hydro-geomorphology and underwater sound), biological (*i.e.*, hard substrate epifouling and fish communities, soft substrate macrobenthos, epibenthos and demersal-benthopelagic fish, seabirds and marine mammals), as well as socio-economic (*i.e.*, seascape perception and offshore renewables appreciation) aspects of the marine environment although not all components are studied every year. The Operational Directorate Natural Environment (OD Nature) of the Royal Belgian Institute of Natural Sciences (RBINS) coordinates the monitoring and specifically covers hydro-geomorphology, underwater noise, hard substrate epifauna, radar detection of seabirds, marine mammals and socio-economic aspects. In 2016, 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), and soft substrate macrobenthos (Marine Biology Section, Ghent University). For details on the specific research, strategies followed and methodologies used, one is referred to the individual chapters.

This executive summary summarises the individual report chapters targeting the ecosystem components under consideration in the monitoring programme, *i.e.*, hard substrate epifouling organisms, soft sediment macrobenthos, epibenthos and demersal-benthopelagic fish, underwater sound, seabirds and marine mammals. We particularly emphasise the progress made in our continuous move towards increased levels of integration and quantification, as such moving away from data-rich, yet information-poor monitoring programmes (*sensu* Wilding *et al.* 2017) towards information-rich monitoring.

The knowledge and expertise in relation to sampling technicalities and designs for offshore wind farm monitoring gained from the first phase of basic monitoring in Belgian waters (2005, 2008-2016) was revisited in 2015 (Degraer *et al.* 2016). The workshop concluded 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, and (3) how to plan the most appropriate sampling design for the basic monitoring program. The revised monitoring program for the benthic and the pelagic realm excludes sources of noise in the data by means of an adaptation of the monitoring design as far as possible. 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) in contrary were targeted for and are to be used as explicit drivers for restructuring the monitoring programme.

The revised basic monitoring programme was first implemented in 2016. In its attempt to exclude unwanted variability in the data collected, this revision targets *e.g.*, a stratified rather than a randomly distributed sampling design. For the soft sediment macrobenthos for example, samples were taken at two distances from the turbines, *i.e.*, 350-500 m and 50 m (Chapter 4). The aim was to investigate whether the macrobenthic community continues to shift away from the *Nephtys cirrosa* and *Ophelia limacina-Glycera lapidum* communities that used to dominate the offshore wind farm zone, towards the richer *Abra alba-Kurtiella bidentata* community, typical for muddy sands (Coates *et al.* 2014). Differences in community composition could indeed be detected at the Thornton Bank, with richer macrobenthic communities further away from the turbine. This difference could not statistically be related to differences in environmental conditions (*i.e.*, grain size distribution and total organic matter). On the Bligh Bank however, higher organic matter contents were indeed found further from the turbines, but these did not coincide with significantly different communities. No clear differences in community composition were detected between foundation types (jacket versus gravity based foundations). While this may be linked to the low number of samples available for the gravity-based foundation (n = 3), the effect of turbine presence and foundation type might manifest itself mainly or only in close vicinity of the turbines (< 50 m) and as such remain unconcealed by the current sampling design. Sediment refinement and organic enrichment may indeed be restricted to the immediate proximity of turbines, and hence out of reach of the current monitoring design. Future monitoring of the macrobenthic community structure may hence need to be refocused on closer distances to the turbines as to reveal turbine impacts.

Since 2005, the potential effects of wind farms on soft sediment epibenthos, and demersal-benthopelagic fish are investigated by means of a basic beam trawl monitoring programme targeting the Thornton Bank and Bligh Bank wind farms (Chapter 5). For both wind farms, the number of epibenthic and demersal-benthopelagic fish species remained similar over the years and was not affected by the construction of the wind farms. Epibenthic density and biomass showed a similar trend in both wind farms, with an increase in the first two years after construction (mainly because of higher densities and biomasses of the common star fish *Asterias rubens*, the hermit crab *Pagurus bernhardus*, the flying crab *Liocarcinus holsatus* and the serpents' table brittle star *Ophiura albida*; year- and wind farm-dependent). In both wind farms, these higher values however levelled off three years after construction. As for epibenthos, demersal-benthopelagic fish seemed to show more variance in densities only in the first few years after construction. These results indicate that the soft sediment ecosystem in between the turbines (at distances > 200 m) has not really changed five to six years after construction and that species assemblages within the offshore wind farms seem to be mainly structured by temporal variability playing at larger spatial scales (*e.g.*, temperature fluctuations, hydrodynamic changes, plankton blooms). One species, plaice *Pleuronectes platessa*, however seems to be positively affected by the offshore wind farms. Plaice densities steadily increased after construction, possibly linked to (locally) increased food availability and/or fisheries exclusion inside the wind farms.

Given the uncertainty about the impact of pile-driving sound on (commercial) fish health, a field experiment was designed to determine the direct effect of pile driving on the health status of Atlantic cod *Gadus morhua* (Chapter 3). Large netted cages with one year old cod individuals (length: 31 ± 4 cm) were positioned at various distances (75 m, 400 m, 1400 m and 1700 m) from a pile driving location and exposed to the pile driving sound for about 16 hours. Average single strike sound exposure levels decreased from 175 dB re 1 μPa^2 s at 400 m distance to 168 dB re 1 μPa^2 s at 1700 m distance. A steep increase in swim bladder barotrauma was detected with decreasing distance from the pile driving source, with no swim bladders ruptured at 1700 m and up to 90% of swim bladders ruptured at 75 m distance. Although most fishes in the cages close to the sound source survived the experiment, they all showed many haemorrhages and a high degree of abnormal swimming behaviour. Possibly, some of the abnormal swimming behaviour could be related to inner ear damage (not investigated here). Both internal bleeding and abnormal swimming behaviour however hint towards a reduced longer term survival rate for those fish hit by the impulsive pile driving sound at short distance. These results indicate that with the current sound limits applicable to Belgian waters (*i.e.*, zero to peak level $L_{z\text{-}p}$ up to 185 dB re 1 µPa at 750 m), swim bladder barotrauma can occur in fish within a radius of 750 m from the pile driving location. Interpretation of these results in relation to optimal sound limits however remains challenging as this field experiment represents a worst-case scenario with fish caged and no chance to escape, and cod having a closed swim bladder, which is most sensitive to swim bladder injuries.

As an example of maximal exploitation of the data available, the hard substrate epifauna data was explored based on biological trait composition rather than the species composition of the epifouling communities. We were particularly interested in qualifying the differences of natural (*e.g.*, gravel beds) versus artificial (*e.g.*, turbine foundations and scour protection) hard substrates and if the latter could be put forward as surrogate for the threatened and declining natural hard substrata. Both habitats harbour a rich species diversity and share a number of species. The initial results show that natural hard substrata harbour a much higher species number and also more unique species than the artificial ones and there are also some differences in life traits. Therefore, it seems that artificial hard substrata cannot act as alternatives to the loss of natural hard substrata.

The influence of offshore wind farms on seabirds and marine mammals remains a major concern during licensing, construction and operation. For this reason, two extensive monitoring programmes were set up in Belgian waters. Within the framework of the revised basic monitoring programme, both programmes are exploring new ways of investigation. Examples presented in this report are mainly focused on fine-scale distribution patterns of seabirds and marine mammals in space and time as a response to the presence of offshore wind farms (seabirds) and pile driving activities (marine mammals). These quantitative approaches (*e.g.*, seabird tele metry in relation to seabird behaviour and passive acoustic monitoring in relation to short-term spatial distribution changes in marine mammals) represent new ways towards a full understanding of the ecological impacts of offshore wind farms and hence bridge basic and targeted monitoring.

With over 1000 individuals observed, bird counts at the Thornton Bank (wind farm and control area) showed great black-backed gull to be by far the most numerous species (Chapter 7). The seabird displacement surveys demonstrated the Thornton Bank wind farm to be avoided by 4 species (*i.e.*, northern gannet *Morus bassanus* [-97%], little gull *Hydrocoloeus minutus* [-89%], black-legged kittiwake *Rissa tridactyla* [-75%) and common guillemot *Uria aalge* [-69%]) compared to the control area and the period before impact. In contrary, the wind farm attracted great black-backed gull *Larus marinus* (x 6.6), Sandwich tern *Thalasseus sandvicensis* (x 5.7; buffer zone only) and herring gull *Larus argentatus* (x 2.9). When zooming into the behaviour of some species making use of transect count data, GPS tracking data and observations with a fixed camera installed on turbine I5 of the Thornton Bank OWF, great black-backed gulls tend to favour outer turbines for roosting, suggesting a partial barrier effect. Lesser black-backed gulls on the other hand seemed to spend half of the time inside the wind farm area roosting on the jacket foundations, and to spend relatively less time (15%) flying inside compared to outside the wind farm (44% for the wider BPNS; 20% for the nearby control area). Telemetry data showed this species' presence in the study area to be highest between 6 am to 12 am with the proportion of non-flying birds mostly above 70% during the full diurnal cycle. 11% of the large gulls observed on the jacket foundation of turbine I5 was found foraging on its intertidal. A continued study of this behavioural shift (*e.g.*, decrease in relative time period flying) may shed a new light onto the anticipated collision mortality among large gulls.

Not only seabirds are potentially impacted by offshore wind farms. They are also of concern for other bird species like passerines (*i.e.*, non-seabird species). Large numbers of non-seabirds are indeed known to migrate at sea and over-seas mass migration events frequently occur (mostly blackbird *Turdus merula*, song thrush *Turdus philomelos*, redwing *Turdus iliacus*, robin *Erithacus rubecula* during night time, and meadow pipits *Anthus pratensis*, European starling *Sturnus vulgaris* and chaffinch *Fringilla coelebs* during day time). The development of offshore wind farms in the North Sea might impact these migrating birds as they can collide with the turbines. As to investigate the spatial and temporal patterns of bird migration at a large spatial scale and at high altitudes (in this study restricted to 1.8 km), we made use of a bird radar (Chapter 8). Bird migration traffic rates (MTR, birds.km^{-1}.hr^{-1}) showed that migration at sea was most intense during the nights of October and early November (up to ~800 birds.km^{-1}.hr^{-1}). Especially in October a clear peak in MTR values occurs at dusk. A second smaller peak is noticeable at dawn. The altitude profile suggests migration at night to happen at higher altitudes compared to daytime movements (maximum MTR at 100-150 m altitude during daytime and 200 to 300 m at night; note: radar data less reliable below 150 m altitude). While passerines tend to dominate night time migration, daytime migration tends to be a mixture of seabird and non-seabird species. Although no clear correlation with weather conditions could be revealed, MTR values seemed higher when the wind blew from the N, NE, E and SE and when wind speed was lower than 13 m/s. In the future, the recorded bird fluxes will be analysed with an explanatory model approach to identify the variables driving the observed migration at sea (*e.g.*, wind direction and speed, hour of day, Julian day, bird flux at the previous day).

From May to September 2016 pile driving was taking place at the Bligh Bank. The investigation of 5 complete piling events of five steel monopiles of 5 m diameter (no sound mitigation measures in place) revealed a maximum sound exposure level (single strike) ranging between 166 and 174 dB re 1µPa^2 s at 750 m distance and a cumulative sound exposure level (full piling of a monopile) ranging between 201 and 209 dB re 1 µPa^2 s at 750 m distance from the source (Chapter 2). Applying these data to the pile driving activities foreseen for 2018 and 2019, the behavioural response zone for harbour porpoises *Phocoena phocoena* could reach some 2800 km^2, in the worst case scenario presented in this report.

During piling, porpoise detections, as detection positive minutes per 10 minutes interval, decreased by up to 75% at stations located up to 20 km from the location of the piling event. Inside the work area, detections decreased well before the start of piling works. At larger distances (20-55 km) porpoise detections nearly doubled during piling events, which may be due to displaced porpoises entering the area. Pile driving sound levels at the furthest distance where reductions in porpoise detections were observed were ~159 dB re 1 µPa (L_{z-p}), which is close to the threshold level for major disturbance for harbour porpoise proposed in literature.

References

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