

# Environmental impacts of offshore wind farms in the Belgian part of the North Sea: Learning from the past to optimize future monitoring programmes

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## **The Belgian offshore wind farm monitoring programme**

Belgium has allocated a 238km<sup>2</sup> zone in the Belgian part of the North Sea (BPNS) to offshore renewable energy production, for example offshore wind farms. The first wind turbines were built in 2008. At present (October 2013), 109 turbines are operational in the BPNS. The installed wind turbines differ in foundation type and generated power: while the first six wind turbines have gravity based foundations (GBF), the majority are monopiles (55) followed by jacket foundations (48). The power that can be generated ranges between 3 and 6.15 megawatt (MW) per wind turbine. In the next few years, several hundreds of turbines will be up and running. The offshore wind farms are expected to contribute for about 43% of the Belgian 2020 targets for renewable energy.

Prior to construction, a developer needs to obtain 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 imposes a monitoring programme to assess the potential impacts on the marine environment. These assessments enable the authorities to impose mitigation measures or even halt the activities in case of extreme damage to the marine ecosystem. The monitoring programme equally allows understanding and evaluating the underlying ecological processes in support of an environment-friendly offshore wind farm policy and management. The programme started in 2005 and 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 Management Unit of the North Sea Mathematical Models (MUMM), a Scientific Service of 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 MUMM 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.

This report presents an integrated overview of all scientific findings of the Belgian offshore wind farm monitoring programme, with the specific aim of drawing lessons from these findings to optimise future monitoring programmes. A series of anticipated negative and positive impacts are covered, but the report also targets an insight in the underlying ecological processes. The report further elaborates on context setting and nuancing the results, and ends with some reflections to optimise the future monitoring programme.

## **Anticipated negative impacts**

Anticipated negative impacts on the marine environment also affect social acceptance of offshore wind farm developments. The lack of social acceptance is actually considered one of the most important challenges of energy project developers worldwide. The social acceptance of offshore wind farms in Belgian waters was investigated through questionnaires in 2002 and 2009, i.e. prior to and after the first wind turbines had been constructed in 2008. The research demonstrated an increasing positive attitude towards offshore wind farms with 68% in support of the initiatives in 2009 versus 53% in 2002, and only 8% opponents in 2009 versus 21% in 2002. More than 90% of the 2009 respondents considered wind energy to be a good alternative to non-renewable energy sources. In Belgium, offshore wind farm siting is socially and environmentally more acceptable than onshore wind farms, even when seascape is taken into account. Interestingly, getting informed on environmental impacts of offshore wind farms was valued highest by the public. A follow up study on social acceptance is proposed when the wind farms closest to the coast are constructed.

Anticipated negative ecological impacts cover the risks of increased turbidity, increased sediment erosion and surfacing of the electricity export cable. Detailed morphological investigations found that increases in turbidity are mainly due to meteorological events rather than to the construction

and operation of the wind farms. Sediment erosion stayed within acceptable limits: the erosion protection around GBFs wind turbines functioned without any secondary erosion, while the monopile erosion pits ranging from 2 to 6.5m were adequately confined by an erosion protection layer. However, there were substantial sediment losses (30 to 35%) during the dredging and dumping activities to install the GBFs, leaving a series of dredging pits that have been refilled by using sand from the second phase of wind farm development. Electricity export cables further proved susceptible to exposure because of the dynamic sand dune migration. A continued monitoring of turbidity using satellite images is advised. The follow-up with multibeam of erosion near the foundations, wind turbine stability and cable burial, should be continued.

Negative impacts on seabirds through habitat change, habitat loss, barrier-effects and collision are major environmental concerns. While some species avoided the wind farms (i.e. northern gannet *Morus bassanus*, common guillemot *Uria aalge* and razorbill *Alca torda* at the most offshore Bligh Bank, and common gull *Larus canus* at the most onshore Thorntonbank), other species seemed to be attracted (i.e. lesser black-backed gull *Larus fuscus* and herring gull *Larus argentatus* at the Bligh Bank, and little gull *Hydrocoloeus minutus*, great black-backed gull *Larus marinus*, Sandwich tern *Sterna sandvicensis* and common tern *Sterna hirundo* at the Thorntonbank). Large gulls were often seen flying at rotor height (15-22%). Based on daytime observations, each year up to about 1300 birds, mainly gulls, are expected to collide with the turbines once all wind farms will be operational in the BPNS. During strong migration periods, thrush *Turdus* spp. collisions can reach 200 victims during a single night. Visual census combined with radar observations will aid a future accurate bird mortality assessment. Future monitoring of the local seabird distribution will further increase the likelihood of displacement effect detection and will allow discerning possible habituation effects.

Increased noise levels generated by wind farms, may harm the marine environment. For example, the maximum detected above water sound pressure level during pin piling activities for the installation of jacket foundations, reached 145 dB(A). The operational sound pressure level mainly generated by the blades passing through the air, amounted to 105-115 dB(A) at wind speeds higher than 12m/s and could hence be detected up to a distance of 10km. Underwater noise generated during the installation of gravity based foundations (about 115 dB re 1  $\mu$ Pa root mean square) was close to ambient noise levels. In contrast, monopile piling produced excessive underwater noise levels of 179-194 dB re 1 $\mu$ Pa (zero to peak level at 750m), attenuating to ambient noise levels at a distance of up to 70km. For pin piling (jacket foundations) lower noise levels of 172-189 dB re 1 $\mu$ Pa were measured, but the total number of blows per megawatt installed is 57% higher than for a monopile. When in operation, steel monopile sound pressure is double of that emitted by a jacket foundation turbine, in its turn twice the sound pressure of the background or GBF foundation turbine. Future monitoring will mainly target continuous underwater noise measurements, which can be compared with other types of human-induced noise in the marine environment.

Piling noise in fact is a major concern to marine mammals and fish. For the harbour porpoise *Phocoena phocoena* occurring in Belgian waters with densities of up to 2.7 ind/km<sup>2</sup>, aerial surveys during a piling event showed a distance of disturbance of porpoises of up to at least 20km from the piling location. A model allowed reproducing the porpoise displacement in a wide area around the piling zone, but outside this area larger differences between the observations and the model were detected. The latter difficulties may be caused by the spatial variability in food availability or seasonal movements. Further fine tuning and testing of the model in different piling conditions and based on aerial surveys and passive acoustic monitoring data, is therefore advised. The impact of construction and operational noise on fish eggs and larval development in Belgian waters only started recently, and needs more attention in the future monitoring programme. These 'passive drifters' cannot actively escape from the exposure to human-induced noise. Especially fish with a swim bladder, for which the European sea bass *Dicentrarchus labrax* will be used as a model species, will be targeted through an experimental study.

#### **Anticipated positive impacts**

The protection against fishing activities inside the wind farms is undoubtedly the main anticipated positive impact of offshore wind farms on the marine environment. Based on VMS data (Vessel Monitoring System), it can be concluded that fishing vessels - mainly trawlers - are virtually everywhere in Belgian waters, except in the wind farms. A moderate increase in fishing activities, mostly from Dutch fishing vessels, is noted in the zone surrounding the wind farm concessions. Recreational anglers, mostly targeting pelagic and benthopelagic fish, first concentrated close to the gravity-based foundations at the Thorntonbank, but recently seem to have almost left the area.

Combined with a possible reef effect, the exclusion of fisheries was expected to have a significant positive impact on the soft sediment benthos. A macrobenthic *Nephtys cirrosa* community was found at the Thorntonbank and Gootebank, corresponding to a typical sedimentology with a median

grain size between 331µm and 410µm. The community is dominated by a few species, like the polychaetes *N. cirrosa* and *Spiophanes bombyx*, the mysid shrimp *Gastrosaccus spinifer* and the amphipod *Urothoe brevicornis*. A natural interannual variability in densities between about 200 and 800 ind./m<sup>2</sup>, was detected. While the macrobenthic community structure was similar in the control and concession sites before construction, significant differences were found in 2008. In this year, i.e. shortly after major construction works, high densities (dominated by *S. bombyx*) were detected. However, no large scale effects could be detected, as the differences between control and impact sites disappeared again after two years. The Benthic Ecosystem Quality Index (BEQI) confirmed the recovery of the community after the construction works. Long term and larger-scale effects could hence not be detected. Future monitoring will focus on the fisheries exclusion and smaller-scale enrichment effects, and aim at detecting these effects at the scale of a complete wind farm.

Demersal fish, benthopelagic fish and epibenthos from soft sediments may be positively impacted as well. For example, epibenthos biomass and length of whiting *Merlangius merlangus* slightly increased at the edge of the Thorntonbank, while (temporarily) increased abundances of sole *Solea solea* and dab *Limanda limanda* were observed at the edge of the Bligh Bank. Inside the wind farms, several local and temporal impacts were detected. At the Thorntonbank, increases in dab mean length (2012), epibenthos biomass (2009) and number of demersal fish species (2009) were observed. At the Bligh Bank, densities of the common starfish *Asterias rubens* and sole increased over the monitoring period, and several 'larger' plaice *Pleuronectes platessa* and turbot *Psetta maxima* were noted. Some short time construction effects were seen shortly after the start of the piling activities, like increased sandeel *Ammodytes tobianus* densities and decreased densities in dab, ophiuroids *Ophiura ophiura*, squid *Allotheutis subulata* and dragonet *Callionymus lyra*. A continued monitoring, taking into account the high natural spatio-temporal variability, will ensure an increased power of impact detectability.

Some fish may be directly attracted to the artificial hard substrata, in search for food or shelter. The offshore wind turbine fish community (near the gravity-based foundations) was dominated by pouting *Trisopterus luscus* and cod *Gadus morhua*, while also other species such as poor cod *Trisopterus minutus*, saithe *Pollachius virens* and black seabream *Spondylus cantharus* were exclusively detected close to the turbines. Cod and pouting catches were up to 12 and 30 times higher, respectively, compared to the wrecks, and up to > 100 times higher compared to the nearby sandy areas. The density peaks of both species (May-November for cod and September-December for pouting), probably reflect a seasonal spawning migration. Young individuals dominated the local cod and pouting populations. Future monitoring will focus on the representativeness of GBF wind turbines compared to steel monopile turbines, the latter having a smaller erosion protection layer and are positioned in more offshore waters.

Fouling organisms colonising artificial hard substrata, increase the local species richness. Different communities can be detected along the depth gradient: the marine splash midge *Telmatogeton japonicus* dominated the splash zone; the intertidal fringe was characterised by barnacles and the blue mussel *Mytilus edulis*; a *Jassa-Tubularia*-Actiniaria community in the subtidal zone was dominated by the amphipod *Jassa herdmani* (up to 3 105 ind./m<sup>2</sup>) and the hydroids *Tubularia indivisa* and *T. larynx* (up to 90% coverage). The patterns in species richness, density and coverage were best illustrated at the Thorntonbank, where they showed an increase mainly during the first two to three years, after which they stabilised. These long-term dynamics are superimposed by seasonal dynamics with highest densities (generally ranging between 1-1.5 105 ind./m<sup>2</sup>) and coverage (on average 60-70%) in spring and summer. In addition to the settling of new species, competition and predation are important biological processes shaping hard substrata communities. Future monitoring will focus on a better understanding of the spatial heterogeneity, the dynamics along the onshore-offshore gradient, and the use of the artificial reefs by larger invertebrates, such as crabs and lobsters.

#### Understanding ecological process behind the observed impacts

A proper understanding of the ecological processes underlying the observed impacts is indispensable to deliver science-based advice for an environment-friendly design of future wind farms. For example, understanding the effects of organic enrichment on soft sediment macrobenthos at a small scale, allows extrapolating these small-scale effects to large-scale and long term impacts. Lower median grain sizes of the sediment and increased organic matter levels were found close to the gravity based foundations at the Thorntonbank. These phenomena could be linked to a macrobenthic community evolving away from the typical *N. cirrosa* community in this area. Close to the turbines, elevated macrofaunal densities (up to 11500 ind./m<sup>2</sup>), biomasses (up to 9540 mg/m<sup>2</sup>) and number of species (up to 32 spp.) were found, especially along the Northwest and Southwest transects. Juvenile common starfish *A. rubens*, the sand mason *Lanice conchilega*, the bee spionid *S. bombyx*, and the typical hard substrate species *Monocorophium acherusicum* and *J. herdmani* tend to dominate in this enriched environment. The local enrichment was detectable to

a distance of 50m from the turbines. Future monitoring will target the spatial extension of this effect through time and at other types of wind turbine foundations.

Zooming into fish habitat use in Belgian offshore wind farms, mainly young individuals of Atlantic cod and pouting were clearly attracted nearby the wind turbines as was observed by divers and by line fishing. Demersal fish species were however not found to be consistently attracted at larger distances (minimum 180m) from the turbines. So far, no clues of increased recruitment or growth in demersal species were detected at larger distance. However a number of larger individuals of plaice *Pleuronectes platessa* were caught at the Bligh Bank. Dab on the other hand occurred in lower numbers, but remarkably had a fuller stomach inside (mean Fullness Index, FI: 0.15) than outside (FI: 0.05) the area. Similarly to cod, pouting showed feeding mainly upon epifaunal species, such as *J. herdmanni* and *Pisidia longicornis*. Cod indeed showed an attraction to the artificial hard substrata with about 90% of the individuals staying within a 40m range from the wind turbines. Future monitoring will focus on attraction and production mechanisms other than food availability, but will also aim at including a wider set of fish species and an energy profiling of their prey species.

Recent sightings of European shag *Phalacrocorax aristotelis*, a seabird species favouring cliffs and rocky shores, in Belgian wind farms and black-legged kittiwakes *Rissa tridactyla* starting to breed on North Sea gas platforms, all point towards the attraction-production potential of offshore wind farms for seabirds. Whether birds are attracted to wind farms from a sheer physical point of view, with the wind farm functioning as a stepping stone or a resting place (attraction), or whether they already learned to exploit the possibly increased food availability (production), remains to be investigated. Black-legged kittiwakes were already regularly observed foraging inside the Bligh Bank wind farm, with the percentage of kittiwakes actively foraging inside the wind farm being much higher than in the control area (5.9% versus 0.3%). Also high numbers of lesser black-backed gulls were foraging close to the Thorntonbank jacket foundations. Future monitoring will pay attention to the behaviour and foraging related activities of seabirds, and to pelagic fish as the most important prey species for seabirds.

Within the attraction-production debate of offshore wind farms we also investigated whether marine mammals were attracted to the increased fish abundance close to wind turbines or rather repulsed by the increased noise levels. Harbour porpoises showed an uneven spatiotemporal distribution in Belgian waters, with a shift from the northern and north-eastern part of the Belgian waters towards the south-west and west between February and April. As the offshore wind farms are relatively small compared to the area that can be covered in a short time period by this highly mobile species, differences in distribution of harbour porpoise within and outside wind farms are probably inferior to seasonal variations within the southern North Sea caused by movements to find suitable prey resources. In addition to continued aerial surveys, future monitoring will target small scale passive acoustic monitoring (PAM) to investigate the potential use of offshore wind farms by harbour porpoises. Attention will also be paid to disentangle the complex link between PAM data and species densities.

#### **Nuancing impact interpretation**

Several impacts have been identified in the Belgian offshore wind farms, varying from seemingly negative to seemingly positive impacts. Species richness increased because hard substrata (wind turbine foundations and erosion protection layers) were introduced. However, offshore wind farms may also increase the risk of invasions in the North Sea, as non-indigenous species (NIS) may now find more suitable place to survive and hence strengthen their competitive position in the North Sea. More than half of the hard substratum intertidal species (e.g. the invasive Pacific oyster *Crassostrea gigas*) in the wind farms can be categorised as NIS. Pouting is attracted to wind farms, but we do not know yet whether these offshore wind farms act as an ecological trap. However, pouting is significantly larger inside than outside the wind farms, their stomach is filled more and their condition is similar, so no evidence was obtained to assume that the habitat quality of offshore wind farms does not fulfil the functional needs of pouting. Preliminary extrapolation of bird collisions (at North Sea population scale) to future expansions of offshore wind farms showed that the existing adult mortality for instance of lesser and great black-backed gull might exceed the accepted threshold of 5%. Future monitoring will take account of the need for up scaling to species population levels and the expansion of offshore wind farms in the North Sea.

Increased species richness, densities and biomass further can be evaluated in different spatial settings, for instance at turbine level or at the level of a wind farm or even the Belgian part of the North Sea. The species pool of soft sediment fish and squid did not change drastically, but the number of hard substrate associated fish species increased from 2 to 8 inside the wind farm concession area. The number of benthic species in the concession area more than doubled, from 91 to 264 species, since the installation of the first turbine foundations, mainly because of the increase of hard substratum species from 10 to 100. Autumn benthic biomass increased ~4000 times at the

scale of a single gravity based foundation from 0.6kg ash-free dry weight (AFDW) before construction to ~2500kg after construction, with the major part of the biomass at the scour protection (89%) and the intertidal *M. edulis* zone (10%). For the entire Thorntonbank wind farm, the autumn biomass increased about 14 times from about 5 to 70 ton AFDW. The offshore wind farms may contribute about 3% of the total biomass in the BPNS. Future monitoring will focus on a validation of the fouling biomass estimates for jacket and monopile foundations.

#### **Reflections for an optimisation of future monitoring programmes**

Six years of monitoring triggered a reflection on how to best continue the monitoring programme, building on both basic and targeted monitoring contexts. The basic monitoring should be rationalised at the level of the likelihood of impact detection, related to research effort and impact size. The meaningfulness of impact size deserves our attention and should be aligned with the current implementation of European Directives, such as the Marine Strategy Framework Directive. Future basic monitoring finally needs to consider the representativeness of the current findings, so far largely focused on GBFs. Within a targeted monitoring context, the artificial reef effect will undoubtedly play a key role in the future monitoring programme. It already received a lot of attention in the monitoring so far, but various cause-effect relationships, mainly linked to the attraction-production hypothesis, remain yet to be tackled, preferably through international scientific collaboration. A major challenge however is to achieve a reliable assessment of cumulative impacts and to upscale locally observed impacts to the larger scale at which ecological processes take place. This will require a close collaboration between scientists, industry stakeholders and administrators, preferably across countries bordering the North Sea.