EXECUTIVE SUMMARY

ASSESSING AND MANAGING THE EFFECT SPHERE OF INFLUENCE

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Today, environmental monitoring of offshore wind farms is ever more targeting an impact assessment at the larger spatial scales at which ecosystems are functioning. Observing increased densities of cod *Gadus morhua* at the erosion protection layer of wind turbines for example needs to be put into the wider perspective of a rapidly increasing number of offshore wind farms within the geographic distribution of the species to assess the impacts onto the population dynamics of the species. Similarly, the threat of invasive non-indigenous species present in the intertidal zone of wind turbines or the possible impact on the status of harbour porpoise *Phocoena phocoena* populations can only be assessed in the same cumulative perspective. With 238 km² reserved for offshore wind farms in Belgium (*i.e.*, by the end of 2018: 274 offshore wind turbines representing an installed capacity of 1152 MW, Chapter 1), 344 km² in the adjacent Dutch Borssele zone and 122 km² in the French Dunkerque zone, cumulative ecological impacts are likely to form a major concern in the coming years.
While the importance of an upscaling of locally observed effects hence is widely recognised, the key to such upscaling still is based on an understanding in depth of what happens at the wind turbine or wind farm scale. Local scale effects indeed are at the basis of possible knock-on impacts onto the wider ecosystem. Furthermore, an eventual mitigation of unwanted impacts through management measures will also most likely take place at this local scale. At-source mitigation generally is considered a better option than *e.g.* compensation of eventual ecological damage.

When considering the local scale effects, knowledge about the extent of the sphere of influence is indispensable. The sphere of influence comprises four dimensions, *i.e.*, the two horizontal dimensions (distance from source of disturbance), the vertical spatial dimension (throughout the water column and in the air) and time (seasonal and yearly variation). In this report, new findings with regards to the extent of sphere of influence and its possible management are presented. These findings can roughly be allocated to (1) assessing the effect sphere of the wind turbines, (2) assessing the effect sphere of the wind farm and (3) managing the sphere of influence of offshore wind turbine construction.

Assessing the sphere of influence of offshore wind turbines

At the smallest spatial scale, the sphere of influence of an individual wind turbine is expected to comprise the biofouling and direct hard substrate-associated communities, and the surrounding (often soft sediment and less mobile) communities that are affected by the presence of the structure and its biofouling communities. This sphere of influence could actually be called the first-order artificial reef effect.

Artificial hard substrates are known to be attractive to many hard substrate-associated species, among which several fish species. For the latter, these offshore structures provide shelter, suitable habitat and a source of food. In Belgium, a total of 25 fish species were observed in the immediate vicinity of the wind turbines, 15 of which are also known to dwell around wrecks (Chapter 6). In contrast to that of the surrounding sandbanks, the fish community around wind turbines may hence be considered relatively unique. Four species, the tadpole fish *Raniceps raninus*, the tompot blenny *Parablennius gattorugine* and the longspined bullhead *Taurulus bulbalis* were previously rarely or, in the case of the ballan wrasse *Labrys bergylta*, only once reported from Belgian waters. This, however, does not necessarily mean that they are rare. Most of the obligate hard substrate fish species that were observed are frequently recorded in the oyster beds and boulder fields of the nearby Eastern Scheldt estuary. Sampling efforts, designs and techniques all co-determine the perceived rarity of a species. We show that, in order to obtain a good insight into the fish fauna dwelling hard substrates, the use of a suite of varied sampling techniques is necessary. We expect that hard substrate-frequenting fish species will increasingly benefit from the continued expansion of offshore wind farms in the Southern North Sea. Because these communities primarily consist of hard substrate-associated species, the immediate sphere of influence is limited to the spatial extent of artificial hard substrate.

The sphere of the first-order artificial reef effect also comprises the surrounding (often soft sediment) communities that are impacted by *e.g.* the deposition of faecal pellets from the biofouling communities, altered hydro- and hence morphodynamics, and/or increased predation pressure by attracted fish. The extent of this sphere of influence still is under investigation by the scientific community and depends on *e.g.* the communities under consideration and, the size and age of the artificial structure. We compared the soft sediment macrobenthos (*i.e.*, the fauna retained on a 1 mm mesh-sized sieve and inhabiting the soft sediments) at 350-500 m away from the artificial structures with that close by (37.5 m) (Chapter 5). Turbine-related effects were detected at close distances from jacket-based foundations at the Thornton Bank with fining (median grain size: 343 ± 22 µm *vs* 378 ± 49 µm) and organic enrichment (total organic matter content: 0.72 ± 0.39% *vs* 0.53 ± 0.17%) of the sediment together with higher macrofaunal densities (934 ± 1112 *vs* 343 ± 329 ind. m^{-2}), diversity (number of species: 18 ± 9 *vs* 8 ± 4, diversity: 1.92 ± 0.46 *vs* 1.57 ± 0.44) and shifts in communities at close distance and not further off. The sphere of influence hence stretches out to at least some 40 m, but less than 350 m, from the jacket-based turbines (*i.e.*, ~5000 m^2). In contrast, effects around monopile foundations at the Bligh Bank were significantly different between close by and further off sampling locations for community composition only. These contrasting results might be due to a combination of structural differences (*in casu* jacket *vs* monopile foundations) but also site-specific (*in casu* transitional *vs* offshore waters), justifying further research into the subject of the sphere of influence onto soft sediment macrobenthos. Site specific differences are exemplified by a clear north-south gradient within the wider offshore wind farm area for both soft sediment epibenthos and demersal-benthopelagic fish assemblages (*i.e.*, larger fauna living on the soft sediments) (Chapter 4). The concession area closest to shore (ca. 23 km) exhibited much higher densities (1200 *vs* ca. 80 ind. 1000 m^{-2} for epibenthos and 120 *vs* 25 ind. 1000 m^{-2} for fish) and biomass (3900 *vs* 180 g WW 1000 m^{-2} for epibenthos) and also community structure differed from the more offshore concession areas. The area close to the shore is inhabited by an assemblage most related to a typical coastal community, while further offshore a typical offshore assemblage prevails.

When further considering the epibenthos and demersal-benthopelagic fish trends, remarkable was that two epifaunal animals, *i.e.*, blue mussels *Mytilus edulis* and anemones Anthozoa spp. known to be fouling on the foundations, were quite abundant in soft sediment samples collected in one of the investigated wind farms (resp. 5 and 3 ind. 1000 m^{-2}). Both were totally absent or present in much lower densities (resp. 0.04 and 0.3 ind. 1000 m^{-2}) in the reference locations outside the offshore wind farms (Chapter 3). This could indicate that the 'reef' effect is starting to expand beyond the direct vicinity of the turbines, as such expanding the sphere of influence with time. However, a detailed follow-up would be needed to validate whether this is a one-off observation or a persistent wind farm effect reflecting the effect of time after construction. Overall, no direct wind farm effect, nor indirect fisheries exclusion effect was yet observed for the soft-bottom epibenthos and demersal-benthopelagic fish assemblage in 2017. Aside from the difference for blue mussels and anemones, species composition, species number, density and biomass (for epibenthos only) of the soft-bottom assemblage inside the offshore wind farms remained very similar compared to the assemblage in reference locations. The epibenthic and demersal-benthopelagic fish species originally inhabiting the soft sediments of both offshore wind farm areas remain dominant.

Another example of the sphere of influence of individual turbines is given by bats exploring and migrating across the marine environment. Several bat species known to migrate long distances between summer and winter roosts also cross the North Sea and may hence encounter offshore wind farms. The developments of offshore wind farms in the North Sea therefore represents a potential risk for migrating bats. To investigate the altitude-specific activity of bats at sea and as such the risk of collision, we installed eight acoustic bat detectors at four turbines in the wind farm on the Thornton Bank (Chapter 9). Four were installed on the platform of the transition piece (17 m above mean sea level, amsl) and four were installed on the nacelle of the turbines in the centre of the rotor swept area (94 m amsl). A total of 98 recordings of bats were made by all eight Batcorders during 19 different nights during the entire study period (from the end of August 2017 until the end of November 2017). The detections at nacelle height were only ~10% of the detections made at low altitude. The observations made by the detectors at nacelle height give a first indication of the activity of bats at that altitude. Given the limited detection range of the detectors, this does not yet allow to make sound conclusions about the collision risk for bats, especially not in the lower part of the rotor swept zone. Therefore, there is a need for studies assessing bat activity at the entire rotor swept zone.

Assessing the sphere of influence of offshore wind farms

The sphere of influence for other, often more mobile species is less likely to be concentrated at the scale of a single wind turbine, as was observed for macrobenthos, epibenthos and demersal-benthopelagic fish, but rather at the spatial scale of a wind farm or a multitude of wind farms. This second-order artificial reef effect particularly holds true for marine mammals but also seabirds that may be attracted to the offshore wind farms because of *e.g.* improved foraging conditions and availability of roosts.

With regards to seabirds, we analysed GPS data of lesser black-backed gulls *Larus fuscus* caught and tagged in the colonies at Ostend and Zeebrugge (Chapter 7). Three modelling exercises were performed to study the response of lesser black-backed gulls to a Belgian offshore wind farm at a fine spatial scale. These exercises confirmed that much more time was spent roosting on outer than on inner turbines located 500 m from the wind farm edge (2.5 *vs* 0.5 h per turbine). Next, we found a significant and gradual increase in the number of logs of flying birds going from the centre of the wind farm (~0.6 logs) up to 2000 m from the wind farm edge (~1.4 logs), beyond which the response seemed to stabilise. For non-flying birds too, the model showed a minimum number of logs (~0.5) in the centre of the wind farm and a flattening of the smoother at about 2000 m (~3.5 logs), yet with a spike of increased presence right at the wind farm's edge, representing birds roosting on the outer turbine foundations. The last model aiming to assess temporal variation in the presence of lesser black-backed gulls in and around the Thornton Bank offshore wind farm showed that the birds were increasingly wary entering the wind farm during times of strong winds (> 14 m/s) with fast moving rotor blades. The results of this study illustrate that the sphere of influence of offshore wind farms to lesser black-backed gulls is subject to both temporal and (within-offshore wind farm) spatial variation, which can be used to further refine collision risk models.

Managing the sphere of influence of offshore wind turbine construction

With a proper understanding of the (negative) effects, mitigation measures to directly manage the sphere of influence can be designed. For offshore wind farms, the production of high levels of impulsive underwater sound, when large steel turbine foundations are hammered into the seabed, is one of the most pertinent stressors for *e.g.* marine mammals. Sound mitigation measures recently became mandatory for such pile driving activities in Belgian waters.

In 2017, during construction of the Rentel wind farm, a single big bubble curtain (BBC) was used as sound mitigation measure. With BBC deployed, the zero to peak sound level (L_{z-p}) normalized to 750 m distance from the source and ranged from 185 to 194 dB re 1µ Pa (for 7.8 m diameter steel monopiles, 4000 kJ max. hydraulic hammer) (Chapter 2). L_{z-p} was estimated to have been reduced with maximum 11-13 dB re 1 µPa by the BBC compared to the extrapolated values of L_{z-p} that would have been produced in case of absence of sound mitigation. Therefore, the efficiency of the BBC was assessed to be in the lower range of the values that can be found in literature. More than one mitigation measure will thus be needed for future projects to comply with the Belgian Marine Strategy Framework Directive requirements (L_{z-p}: max. 185 dB re 1µ Pa) and hence reduce the effects of underwater impulsive sound to ecologically acceptable levels.

Although not enough to comply with the Belgian standards, current sound mitigation measures will have reduced the extent of the effect sphere of influence. Ecological damage can further be limited by a careful timing and preparation (*e.g.*, acoustic deterring device, ADD) of piling activities. We therefore tested seventeen 'mitigation' scenarios for the effects of the likely construction schedules for three future Belgian wind farms onto the harbour porpoise; this with and without various mitigating measures (Chapter 8). The interim Population Consequences of Disturbance (iPCOD) model was used to quantify how differences in regulatory regimes with regards to offshore wind farm construction impact a simulated harbour porpoise population. The impact of pile driving on the harbour porpoise population proved to be strongly influenced by the timing of the activities, because of the seasonal changes in spatial distribution of the species. Regardless of timing however, the impulsive sound effect sphere of influence is reduced (by up to 90%) when noise mitigation measures such as BBC and/or a noise mitigation screen are in place. The combination of a seasonal pile driving restriction and an ADD alone was not enough to lower the additional risk of a 5% decline of the porpoise population to less than 10%. Our results further suggest that building a wind farm every year would negatively affect the harbour porpoise population more than constructing two wind farms at the same time.