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Short-term ecological effects of an offshore wind farm in the Dutch coastal zone; a compilation

H J Lindeboom[1], H J Kouwenhoven[2], M J N Bergman[3], S Bouma[4], S Brasseur[1], R Daan[3], R C Fijn[4], D de Haan[5], S Dirksen[4], R van Hal[5], R Hille Ris Lambers[5], R ter Hofstede[5], K L Krijgsveld[4], M Leopold[1] and M Scheidat[1]

[1] IMARES, PO Box 167, 1790 AD Den Burg, The Netherlands
[2] NoordzeeWind, 2e Havenstraat 5b, 1976 CE IJmuiden, The Netherlands
[3] Royal NIOZ, PO Box 59, 1790 AB Den Burg, The Netherlands
[4] Bureau Waardenburg, PO Box 365, 4100 AJ Culemborg, The Netherlands
[5] IMARES, PO Box 68, 1970 AB IJmuiden, The Netherlands

E-mail: han.lindeboom@wur.nl

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Abstract
The number of offshore wind farms is increasing rapidly, leading to questions about the environmental impact of such farms. In the Netherlands, an extensive monitoring programme is being executed at the first offshore wind farm (Offshore Windfarm Egmond aan Zee, OWEZ). This letter compiles the short-term (two years) results on a large number of faunal groups obtained so far. Impacts were expected from the new hard substratum, the moving rotor blades, possible underwater noise and the exclusion of fisheries. The results indicate no short-term effects on the benthos in the sandy area between the generators, while the new hard substratum of the monopiles and the scouring protection led to the establishment of new species and new fauna communities. Bivalve recruitment was not impacted by the OWEZ wind farm. Species composition of recruits in OWEZ and the surrounding reference areas is correlated with mud content of the sediment and water depth irrespective the presence of OWEZ. Recruit abundances in OWEZ were correlated with mud content, most likely to be attributed not to the presence of the farm but to the absence of fisheries. The fish community was highly dynamic both in time and space. So far, only minor effects upon fish assemblages especially near the monopiles have been observed. Some fish species, such as cod, seem to find shelter inside the farm. More porpoise clicks were recorded inside the farm than in the reference areas outside the farm. Several bird species seem to avoid the park while others are indifferent or are even attracted. The effects of the wind farm on a highly variable ecosystem are described. Overall, the OWEZ wind farm acts as a new type of habitat with a higher biodiversity of benthic organisms, a possibly increased use of the area by the benthos, fish, marine mammals and some bird species and a decreased use by several other bird species.

Keywords: offshore wind farm, ecological effects, marine ecosystems, benthos, fishes, birds, sea mammals

1. Introduction

The pressure for more renewable energy is a strong driver for the construction of offshore wind farms. This also applies to the Dutch North Sea and in 2005 the first offshore wind farm in the Netherlands (offshore wind farm Egmond aan Zee, OWEZ) was commissioned. This farm was built in 2006 and became fully operational at the beginning of 2007. It is the Dutch demonstration project, for gaining knowledge and experience for future large scale wind farms at sea.

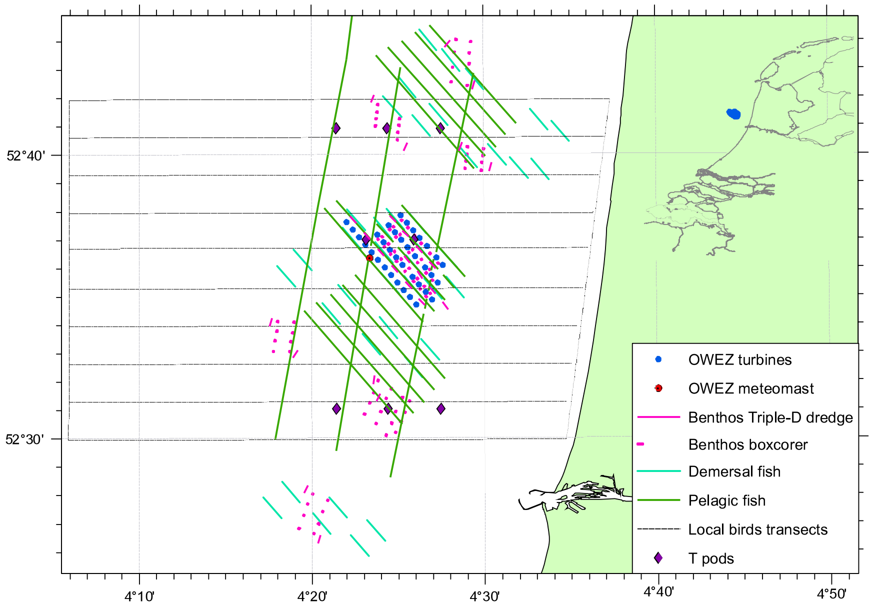

Figure 1. Map of the OWEZ wind farm, showing the locations of the turbines, the meteomast and the sampling sites for the benthos, fish, birds and harbour porpoises both inside and outside the wind farm. The top right shows the position of the wind farm along the Dutch coast.

Part of the project is an extensive environmental monitoring and evaluation programme. This programme aims at determining the possible effects of the wind farm upon benthic organisms, fish, birds and marine mammals. Special attention is paid to sound levels and acoustic effects. The major potential effects of the establishment of a wind farm are disturbance of the area during the building phase, the presence of the farm and exclusion of other uses in the operational phase.

Before the construction phase, an extensive baseline programme was executed in 2003–2004. During the building phase the effects of the construction were studied and they indicated in particular that the hammering of the foundation piles reached sound levels high enough to cause damage to marine mammals. For harbour porpoises (*Phocoena phocoena*) no specific research was conducted. For harbour seals (*Phoca vitulina*), telemetry data indicated that pile driving activities seem to deter the seals. During pile driving, tagged seals avoided the area by up to at least 40 km (Brasseur *et al* 2010).

Research in Danish offshore wind farms indicated avoidance behaviour by marine mammals in the construction phase (Tougaard *et al* 2009). In the operational phase no differences could be detected between harbour porpoise presence inside and outside the Danish wind farms (Diederichs *et al* 2008). The only effect observed was a change in the 24 h cycle of harbour porpoise recordings, with more recordings during the night close to the single turbines. Most likely this is related to differences in fish communities (Diederichs *et al* 2008). Underwater noise recordings showed that audibility of turbine noise was low for harbour porpoises, extending 20–70 m from the foundations, whereas audibility for harbour seals ranged from less than 100 m to several kilometres (Tougaard *et al* 2009). Behavioural reactions of porpoises to the noise appear unlikely unless very close to the turbines. Reactions from seals cannot be excluded up to distances of a few hundred metres (Tougaard *et al* 2009).

In Denmark, research was also executed to see whether birds show reactions to the turbines once erected. Comparison of pre-construction and post-construction aerial surveys of waterbird abundance and distribution in and around two offshore farms generally showed that waterbirds avoided the turbines, at least during the three years following construction (Petersen *et al* 2006). In the same farms an increase in benthic organisms and fish on and around hard substrata was established (Leonhard and Pedersen 2006).

In this letter we focus on the ecological effects of the OWEZ wind farm in the operational phase. Possible impacts are expected from:

- the new hard substrate;
- underwater noise;
- the moving rotor blades;
- the absence of other human uses, such as fisheries.

The effects on the different faunal groups and on the local ecosystem will be discussed.

1.1. The Offshore Windfarm Egmond aan Zee (OWEZ)

OWEZ is situated between 10 and 18 km off the Dutch coast near Egmond aan Zee (northwest of Amsterdam) in water depths between 17 and 21 m. It consists of 36 Vestas V90 wind turbines with a total installed capacity of 108 MW placed on 70 m high steel towers with a diameter of 4.6 m (figure 1). The total height of the turbines, including the rotor, is 115 m. The wind farm consists of four rows of turbines at a distance of approximately 1 km with a minimum distance of 650 m between the turbines. The total surface area of the wind farm is approximately 40 km^2. The foundation of each turbine consists of a steel monopile hammered into the sea floor to a penetration depth of about 30 m. To prevent scouring, a layer of stones, with a diameter of approximately 25 m, consisting of a filter layer of small sized rock and a top layer of heavier rocks, has been installed around each pile.

A 116 m meteorological measurement mast (meteomast) was also installed, suited to support scientific equipment or observers.

The farm was constructed in 2006 and became fully operational on 1 January 2007. The farm and a surrounding safety zone of 500 m are closed to all shipping activities with the exception of vessels for maintenance or research. All fishing is prohibited in the wind farm and the safety zone.

2. Methods

Here we will briefly describe the different methods used. For details we refer the reader to the reports on the various faunal groups that are available or will be made available soon at http://www.noordzeewind.nl/reports_data_65.html.

2.1. The benthos

2.1.1. The impact on the local macrobenthos community. Before the wind farm was constructed, a baseline study (T0) was conducted in 2003 by the Institute of Estuarine and Coastal Studies (IECS) of the University of Hull. The results of this baseline study have been presented in a report (Jarvis *et al* 2004), which describes in detail the sampling design chosen, the methods used and the distribution of the macrobenthic fauna before the construction of the wind farm started. During this T0 study the fauna in the area was sampled in three subareas: OWEZ itself and two reference areas. We carried out a power analysis on the T0 data to assess whether the T0 sampling design was adequate for detecting possible effects after construction (T1) with statistical significance (Daan *et al* 2009). The outcome of the power analysis showed that continuance of the original sampling design would imply that only extremely large differences would be detectable with any statistical significance and that, from a statistical point of view, the number of reference areas was too low. It was decided therefore to spread the sampling effort at T1 over more and smaller control areas. This implies that possible effects within the area of the wind farm should be detected on the basis of instantaneous differences between the macrobenthos in the wind farm and in the reference areas at T1, rather than by mutually comparing the T0 and T1 data.

The T1 benthic survey was carried out in spring 2007, a few months after completion of the wind farm, to study the possible short-term effects of the presence of OWEZ upon the composition of the local benthic fauna living in or on the sediment. The benthic fauna were sampled in the sandy area inside the farm and in six reference areas lying north and south of it. Sampling took place with a 0.078 m^2 boxcorer, taking 30 samples inside the farm and 15 samples in each of the reference areas (see figure 1). Additionally there was also a limited sampling programme with a Triple-D dredge (cutting plate width 20 cm, digging depth 18 cm), taking 14 samples inside the farm and 2 samples in each of the reference areas. The dredge programme was aimed at getting an impression of possible short-term changes in the larger fauna in the wind farm, where fishery is not permitted and where the bottom fauna could develop in an environment without disturbance of trawling gear. The programme was limited, however, since it was anticipated that a measurable change among larger benthic species can be expected only after at least several years without fisheries.

Boxcore samples were sieved on board through a 1 mm mesh sieve and the residue was preserved in a 6% neutralized formaldehyde solution for later analysis in the laboratory. The dredge catches were sorted and counted on board. The occurrence of possible effects was analysed by comparing characteristics of the macrobenthos within the wind farm with those in the reference areas. For a detailed description of all methods used see Daan *et al* (2009).

2.1.2. The impact on bivalve recruitment. To measure the possible difference in densities of juvenile bivalves (settlers in 2007) inside and outside OWEZ, 20 stations inside the fishery-closed wind farm and 10 stations in each of the 5 regularly trawled reference areas were sampled with a circular boxcorer (depth 20 cm, diameter 30 cm) in October 2007 (Bergman *et al* 2010). Per boxcorer, three subsamples (diameter 10 cm, height 5 cm) were collected and stored with 4% buffered formalin. The number of juvenile bivalve species >0.2 mm and >0.5 mm was counted after a decanting and sieving procedure (for details see Bergman *et al* 2010). Grain size and mud content of the upper 10 cm of the sediment was analysed from the same boxcore samples. To study the settling response of larval bivalves to a range of sediment types conceivably developing in the fishery-free OWEZ wind farm, *in situ* mesocosm experiments were carried out. Submerged benthic landers with trays with three different fractions of defaunated sandy sediment (fine (200–500 μm), medium (500–1000 μm) and coarse (>1000 μm)) were deployed for two three-week periods in 2007 both inside and outside the wind farm. The number of bivalve recruits was determined per sediment fraction as described by Bergman *et al* (2010).

2.1.3. The hard substrate. The development of flora and fauna on the hard substrates of the monopiles and rocks of the scour protection layers was recorded using video footage and samples collected by divers. The samples were collected around three monopiles and the species composition, covering percentages and numbers and biomass of species present, was established. For details see Bouma and Lengkeek (2009).

2.2. Underwater acoustic measurements

In 2007, during three wind turbine operations, acoustic measurement sessions were conducted using a 12 m sport fishing vessel which was passively drifting with all equipment switched off (de Haan *et al* 2007a, 2007b). The measurements involve series of 7–10 files per session; file records covered a time length of 38 s. Acoustic emissions were measured in a range of distances varying between 10 and 3000 m using a calibrated certificated RESON 4032 (sn 2005017) hydrophone suspended over the side of the vessel at a depth of 7 m. The RESON 4032 has a 10 dB built-in preamplifier, and sensitivity of -170 dB for 1 V μPa^{-1}. The hydrophone signal is conditioned by using an ETEC preamplifier with high and low pass filtering to a frequency band of 10 Hz–20 kHz. The analogue conditioned signal is digitized by using an Avisoft analogue to digital converter at a sampling frequency of 50 kHz. This converter is connected to the USB gate through which the continuous digital sound files are logged in WAV format.

2.3. Fish

The abundance of pelagic fish was estimated by both trawl and acoustic surveys. Observations were made in the OWEZ area and two reference areas, one north and one south of the park (figure 1). The surveys were executed in April and October 2003, and after the construction of the farm in April 2007. The whole area was observed with the acoustic equipment, and when schools of fish were observed trawls with a semi-pelagic net were made. For further details see Grift *et al* (2004) and Ybema *et al* (2009).

Demersal fish were sampled with two 6 m beam trawls, one equipped with a 40 mm net and the other with a 20 mm net. The trawls were made in the OWEZ area (13 hauls) and in three reference areas (figure 1), one to the north (13 hauls) and two to the south (6 and 8 hauls). The demersal surveys were executed in summer 2003 and winter 2004 and after the construction in the summer of 2007 and winter 2008. For further details see Hille Ris Lambers and Ter Hofstede (2009), Ter Hofstede (2008) and Tien *et al* (2004).

2.4. Harbour porpoises

Harbour porpoise activity and presence was measured with eight stationary acoustic porpoise detectors (T-PODs) (Scheidat *et al* 2009). Two T-PODs were placed in the wind farm and three T-PODs were placed in each of the reference areas north and south of the wind farm (figure 1). Porpoise acoustic activity (expressed in four indicators: porpoise positive minutes, percentage porpoise positive minutes per day, encounter duration and waiting time) was measured during the baseline study before the construction of the wind farm (June 2003–May 2004) as well as in the period for which the farm was fully operational (June 2007–April 2009). To investigate the potential effect of the wind farm a statistical before–after control–impact (BACI) analysis (Green 1979) was carried out; for details see Scheidat *et al* (2009) and Scheidat *et al* (2011).

2.5. Harbour seals

To study the effect of the wind farm on harbour seals, 34 seals were tagged with satellite tags (Brasseur *et al* 2010). Twelve seals were tagged before the farm was built and 22 after the construction phase; half of these seals were tagged south of the farm, the other half north of the farm. Seals were caught on haul-out areas with a large seine net and tagged directly on location. Satellite relayed data recorders transmitting through the ARGOS system and later GPS phone tags were used to track the seals. Both the ARGOS and GPS tags were constructed by the Sea Mammal Research Unit (St Andrews, UK). The data were retrieved and the swimming patterns of both individual seals and the release groups were mapped in relation to the site of the wind farm (figure 1). For details see Brasseur *et al* (2010).

2.6. Local seabirds

Distribution patterns of local seabirds were established during bimonthly ship counts along 10 transects in and around the OWEZ wind farm. Data on densities were collected using strip-census techniques (Leopold *et al* 2004). The densities obtained during 6 surveys in the T0 (September 2002–February 2004) period were compared with the densities during 12 surveys executed during T1 (April 2007–January 2009). During the T0 surveys, distribution patterns were found to be influenced by location within the study area. Both distance to the 20 m isobath and location along the north–south axis of the study area were found to be important. In order to determine whether or not the three impact areas (two wind farms and one anchorage area) have an effect on the distribution of different bird species, their natural distribution patterns must be taken into account. Because these cannot necessarily be described using linear relationships, generalized additive modelling (GAM), which uses smoothing functions to model nonlinear relationships (Wood 2006, Zuur *et al* 2007), was applied to the data. Bird distributions were modelled in the ‘R’ statistical and programming environment (v2.9.2; R Development Core Team 2009), using packages ‘mgcv’ (Wood 2009) and ‘nlme’ (Pinheiro *et al* 2006) and using distance to coast and northing as smoothers and the wind farm as an additional factor. The data were analysed at the level of individual surveys; for details see Leopold *et al* (2004, 2009).

2.7. Flying birds

To assess the flight paths of birds flying through the wind farm, both visual observations and fully automated radar observations were conducted from the meteomast (figure 1) at the wind farm (Krijgsveld *et al* 2010). Visual observations were carried out during daylight periods by panoramic scanning using a standard pair of 10 × 42 binoculars fixed on a tripod. Flight paths of individual birds or groups of birds were recorded. To detect flight patterns continuously during both day and night and at a wider scale two kinds of radar observations were combined: horizontal and vertical. The observations of flight paths were done using a horizontal marine surveillance radar (S-band). The observations of fluxes and altitude were done with a similar radar (X-band) which was tilted to rotate vertically. Together these radars formed a Merlin Avian Radar system (DeTect Inc.). For details see Krijgsveld *et al* (2010).

It was also intended to record bird collisions with wind turbines and several techniques that use some type of sensor, which triggers the saving of pictures from cameras filming the area of the rotor blades, have been considered. However, so far no reliable technique was found that could be applied in the OWEZ wind farm.

3. Results

3.1. The benthos

3.1.1. The impact on the local macrobenthos community. As stated in the methods section, it was decided to execute a different programme in the T1 as compared to the T0. Therefore, no T0–T1 comparison was made and results are based on the data from the wind farm and the reference areas. The comparison of macrofauna characteristics inside OWEZ with six reference areas leads to the conclusion that there were no major differences a few months after completion of the wind farm (Daan *et al* 2009). This conclusion was based on the following results.

The Bray–Curtis index for percentage similarity showed a great to very great similarity (60–85%) in the fauna composition of OWEZ and the majority of reference areas. Overall fauna densities, overall biomass values and diversity, expressed in terms of species richness, evenness and dominance in OWEZ, were well within the range found in the reference areas. The relative fauna abundance within OWEZ was not statistically different from that in the reference areas.

Statistical analyses of differences in mean densities of 22 individual species caught with the boxcorer in the seven areas showed a significant difference in 6 cases. But for all species tested the density found in OWEZ was within the density range of at least 5 of the 6 reference areas. The same was done for 10 species collected with a Triple-D dredge, showing that for none of these species was there a significant difference between samples collected in OWEZ and outside OWEZ.

All analyses indicated that there are no short-term effects of the construction and presence of the wind farm on the local benthic fauna composition in the sandy areas between the monopiles (Daan *et al* 2009). More sampling at a later stage is needed to establish possible long-term effects.

3.1.2. The impact on bivalve recruitment. In the field survey no differences were found between the densities of bivalve recruits (>0.2 and >0.5 mm) settled in OWEZ and in the five reference areas during the first nine months of 2007. For the larger (older) recruits >0.5 mm differences in densities were found only between two of the reference areas: 383 m^{-2} in Ref 3 and 113 m^{-2} in Ref 5. Of the recruits >0.5 mm that could be identified to species level, only *Ensis spp.* showed a significant difference in density between (reference) areas: 154 m^{-2} in Ref 3 and none in Ref 4 (Bergman *et al* 2010).

Area-based differences in species composition of bivalve recruits >0.5 mm were not found. Cluster analysis of the stations revealed two significant clusters attributed to density differences of mainly *Ensis spp.*, *Montacuta ferruginosa*, *Tellina spp.* and *Abra alba*. The position of the clusters did not coincide with survey areas but suggested an offshore–coast gradient in species composition. The cluster of stations near the coast harboured a much denser bivalve population than the more offshore cluster; species composition in the coastal cluster was correlated with higher mud content and water depths exceeding 18–20 m. Within the wind farm significant correlations were found between environmental variables and both total abundance and single-species abundances of bivalve recruits >0.5 mm. Mud content scored the highest correlation coefficient. In the reference areas no such correlations were found. Here the coupling between sediment characteristics and bivalve recruits may be diminished by resuspension like that caused by trawling and/or strong wind events (Bergman *et al* 2010).

The mesocosm experiments revealed that settling bivalves did not show a preference for any of the sand fractions that we used in the deployments in OWEZ and Ref L. In the second deployment, in coarse sediment only, settlement was remarkably higher in Ref L than in OWEZ. Since the numbers of settlers in the fine and in medium fractions were not significantly different in OWEZ and Ref L, the result may point at coarse sediments being more attractive to certain bivalve species in zones near the coast like Ref L. Competent bivalve larvae arrived in patches in the coastal zone causing a temporal pattern in settlement. Differences in length of the settlers were not found in the deployments in OWEZ and Ref L (Bergman *et al* 2010).

Average net settlement of bivalves in the mesocosms in OWEZ varied from 1565 m^{-2}/day in July to 324 m^{-2}/day in August, whereas 816 m^{-2}/day successfully settled in Ref L in August. In October 2007, several months after initial settlement, densities of bivalve recruits (>0.2 mm) varied from 4312 to 1558 m^{-2} in OWEZ and Ref L, respectively, while densities of recruits >0.5 mm varied from 429 to 121 m^{-2}. These data suggest a considerable loss of bivalve recruits during the first months of settlement in the field situation (Bergman *et al* 2010).

Indirect effects of the fishery cessation in OWEZ such as a less turbid water column allowing better growth of bivalves, and finer sediments allowing higher species richness are unlikely. Turbidity and median grain size in OWEZ are primarily governed by tidal and wind (wave) regimes, and local mud deposits.

3.1.3. Colonization of hard substrates. In 2008, a total of 33 different species were identified in the video footage and/or collected samples taken from three different monopiles (Bouma and Lengkeek 2009). Along the monopiles two clear zones of two hard substrate communities could be distinguished.

- An upper zone (7–10 m depth) dominated by fast growing common mussels (*Mytilus edulis*) with associated fauna of barnacles (*Balanus crenatus* and *Balanus balanoides*), the common starfish (*Asterias rubens*), several species of worms and crabs and the encrusting sea mat (*Conopeum reticulum*). The mussels covered the surface area between 80 and 100%, where bare patches were colonized by anemones (mainly *Metridium senile* and *Sargartia spp.*) and (tubes of) the small crustacean *Jassa spp.*
- A deeper zone (10 m–bottom) dominated by a community of (tubes of) *Jassa spp.*, several species of anemones (*Metridium senile*, *Sargartia spp.* and *Diadumene cincta*) and patches of *Tubularia larynx*, which covered 100% of the monopiles below the mussel zone.

Other less common species included the pullet carpet shell (*Venerupis senegalensis*), the North Sea or edible crab (*Cancer pagurus*), the skeleton shrimp (*Caprella linearis*), the common brittle star (*Ophiotrix fragilis*) and exotic species like the Japanese oyster (*Crassostrea gigas*) and the Titan acorn barnacle (*Megabalanus coccopoma*).

In September 2008, the common mussels in the top zone reached an average of 6725 individuals m^{-2} with a biomass of 1257 g ash-free dry weight (afdw)/m^2. The total biomass of mussels within OWEZ was estimated at 11 500 kg afdw.

On the scour protection rocks around three monopiles, 11, 14 and 17 species were detected, respectively. The most dominant species are the sea mat *Conopeum reticulum*, the anemones *Metridium senile* and *Sargartia spp.*, (tubes of) the crustacean *Jassa spp.* and the ringed tubularia *Tubularia larynx*. Other species include the common starfish, North Sea crab, Japanese oyster, slipper limpet (*Crepidula fornicate),* barnacles, the hydroid *Obelia spp.* and orange crust (*Crypstosula pallasiana*). The video footage indicated that the new hard substrate also provides shelter and food for fish species like North Sea cod (*Gadus morhua*) and pouting (*Trisopterus lucus*). Recently a pair of common eiders (*Somateria mollissima*) were seen foraging on the molluscs in OWEZ.

3.2. Underwater acoustics

The measurements of the underwater acoustic characteristics of the wind farm in operation were hampered by the measurement method and the lack of availability of suitable measurement vessels (de Haan *et al* 2007b, 2007a). A new system of separate drifting buoys with hydrophones was developed and will be deployed in the future subject to approval by the commissioning authorities. The preliminary measurements with the old measurement set-up using a small boat as platform and one hydrophone suspended over the side of the vessel gave the following indications.

At relatively low wind speeds (between 1.8 and 9.7 m s^{-1}) the energy of turbine noise peaked in the low frequency band between 875 and 1500 Hz with broadband equivalent noise levels (Leq) varying between 125 and 130 dB for 1 μPa^2 s (time averages of 10 s) and was only detectable in a range up to 300 m. Below this distance range the Leq levels increased with 4–5 dB. In one instance a raised noise level was detected which was identified as hydraulic noise from the mechanical system to set the rotor direction to changing wind conditions. This noise peaked at 1500 Hz and 32 kHz and raised the noise levels in these particular bands by 8 and 10 dB. All results indicate low noise levels at lower wind speeds. However, more measurements with a more elaborate system and at higher wind speeds need to be executed before more conclusions can be drawn (de Haan *et al* 2007a).

3.3. Fish

The baseline study executed in April and October 2003 showed a highly dynamic pelagic fish community consisting of nine species. In biomass terms, mackerel (*Scomber scombrus*) was the most important species in April and October, while other surveys in the same year showed that herring (*Clupea harengus*) and sprat (*Sprattus sprattus*) dominated in November and sandeel (*Ammodytes marinus* and *Ammodytes tobianus*) in June (Grift *et al* 2004). That the community is highly dynamic was confirmed by the T1 April survey in 2007. The species composition of the catches in the entire coastal zone (so both inside and outside the farm) was different from the one found four years earlier (Ybema *et al* 2009). In 2007, large quantities of sandeel dominated the catches and acoustic output, whereas in 2003 schools of herring were most dominant. The sandeel in 2007 were migrating daily in and around the wind farm and no indications of any avoidance of the farm were detected. The overall environmental conditions in both years were quite comparable; however the average temperature in 2007 was around 2 °C higher. The higher temperature is considered the main explanation for the observed change. In colder water sandeel are buried in the sand (Van Deurs *et al* 2009) making them invisible as regards the acoustic signal. They appear when the temperature reaches a certain level.

The demersal fish catches also showed large variations. Both in the T0 and T1, plaice (*Pleuronectes platessa*), dab (*Limanda limanda*) and solenette (*Buglossidium luteum*) were the most common species (Ter Hofstede 2008). Considering species richness, the total number of species caught was significantly higher during the T1 survey than during the baseline, both in summer and in winter. During summer also the mean species richness was significantly higher. However, since this rise was found both in the wind farm and in all three reference areas, it is unlikely to be caused by the construction of the wind farm. The same was found for the catch per unit effort for all fish combined. Benthivore fish (Greenstreet *et al* 1997), that feed on benthos species, dominated the catch in summer and in the winter of 2003. During the winter in 2008 the catch composition changed significantly, to having many more piscivore fish. This change also occurred both in the wind farm and in the reference areas and therefore the cause could not directly be attributed to the construction of the farm.

More detailed analyses for individual demersal fish species indicated a possible effect of the wind farm. An exclusive significant increase inside the wind farm was found for sole (*Solea solea*), whiting (*Merlangius merlangus*) and striped red mullet (*Mullus surmuletus*) during the summer, whereas a significant decrease was found for lesser weever (*Echiichthys vipera*), both in summer and in winter. No clear explanation for why these species reacted this way can so far be given.

3.4. Harbour porpoises

The acoustic results from the T-POD measurements show a strong seasonal variation in harbour porpoise occurrence (Scheidat *et al* 2009, 2011). Echolocation activity was generally high during the winter months and low during summer months. The number of harbour porpoises recorded in T1 both in the wind farm and in the reference areas increased in comparison with the numbers in T0. Both this seasonal variation and the overall increase in porpoise abundance have also been found in land-based observations of porpoises (Camphuysen 2008).

Echolocation activity was similar in all areas during the baseline period, but increased significantly more during the operation period in the wind farm area. Free-swimming porpoises in the wild have been shown to vocalize almost constantly (Akamatsu *et al* 2005, 2007), meaning that the chosen measurements of acoustic activity can be used as an indicator of the number of porpoises present. The results showed that relatively more porpoises are found in the wind farm area compared to the two reference areas (Scheidat *et al* 2011). It was established that this effect is genuinely linked to the presence of the wind farm. The most likely explanations are increased food availability due to the attached fauna on and in the hard substrates (reef effect) as well as the exclusion of fisheries and reduced vessel traffic in the wind farm (shelter effect).

3.5. Harbour seals

The satellite telemetry data indicate that seals tend to avoid shipping activity at least in the direct proximity of the large shipping routes. Because of the large distance between the wind farm and the haul-out areas the analyses were less conclusive for the possible effects of wind farms upon seal distribution. But both in the periods before and after construction, tagged seals extend their distribution towards the study area, which they avoided during construction (Brasseur *et al* 2010). Untagged seals were observed inside the operational wind farm (Verdaat 2007) and in late 2010, two seals tagged in another programme were recorded in OWEZ. Although seals have been observed in the wind farm, minor effects on behaviour cannot be ruled out, as was also stated for Danish farms (Tougaard *et al* 2009).

3.6. Local birds

The comparison of the bird surveys before and after the construction of the wind farm do not suggest large effects on many of the bird species studied (Leopold *et al* 2009). Topographic factors like depth and northing seem of overriding importance, as was the influence of fishing vessels on some of the bird species. The data showed considerable noise, year to year variation and patchiness, hampering the attempts to find effects of the wind farm upon local birds. When the influence of gross topography is removed, few indications of avoidance become apparent. Common scoters (*Melanitta nigra*) seem to avoid the wind farm, but their densities have become very low in the area in general in recent years. The highest peak was observed in 1991–3 after which numbers declined, especially after 2004. Small groups heading towards the farm always reacted strongly when noticing the farm and changed course to avoid the farm (Leopold *et al* 2009). Northern gannets (*Morus bassanus*) and possibly little gulls (*Larus minutus*) seem to avoid the wind farm, but numbers of observations are still low and modelling power is low. In contrast to findings in Denmark (Petersen *et al* 2006), divers (*Gadidae*), guillemots (*Uria aalge*) and razorbills (*Alca torda*) did not show a marked avoidance. One seabird species, the great cormorant (*Phalacrocorax carbo*), was attracted to the wind farm and uses the site as a new platform for offshore foraging. These cormorants are birds from two colonies nearby (in the dunes on the mainland), including sub-adult non-breeders. They commute between these colonies and the wind farm. They feed in and around the wind farm and use the monopiles and meteomast (figure 1) for drying their feathers, resting, and socializing. The wind farm is thus an offshore outpost of the two colonies on the mainland. With the possible exception of the little gulls, most gulls seemed largely indifferent to the presence of the wind farm.

3.7. Flying birds

The collecting of visual and radar data on flying birds continued until May 2011, and only preliminary basic results are presented here (Krijgsveld *et al* 2010). These results indicate that bird fluxes after the construction of the wind farm were considerably lower than those measured during the baseline study. This was not related to the presence of the wind farm, but seems in part related to the specific offshore location of the wind farm and in part to the significantly lower numbers of fishing vessels in the T1 study as compared to the T0 study. Gulls were by far the most common species observed in the wind farm area. Both in spring and autumn the fluxes increased due to migration. The peak measured in autumn was much higher than the numbers measured in spring, which might be due to higher flying altitudes in spring, that are above the detection range of the radar (Krijgsveld *et al* 2010). Visual observations showed a lower bird density within the wind farm than outside it.

Preliminary results indicate that deflection occurred during day in most species flying in the wind farm area. The distance at which deflection occurs varies from 200 m to several km. First results indicate that birds tend to deflect more during the night. Gulls, cormorants and terns did not show much avoidance and were regularly seen foraging in the wind farm. Pelagic seabirds, like gannets, scoters, auks, guillemots and divers showed the strongest avoidance of the wind farm, and the gannets changed their flying patterns closer to the farm (down to 500 m) as compared to the other seabird species (>2–4 km). Migrating landbirds sometimes showed strong avoidance but not always. Geese flying at rotor height showed very strong reactions to the turbines. When flying above rotor height, no avoidance was recorded in any species. Flocks of passerines, probably the majority of the migrating birds in the area, showed both deflection around the entire wind farm and flying through, avoiding individual turbines. Often birds of the avoiding species entered the wind farm at a turbine that was standing still—densities were higher where spacing was larger and at stationary turbines.

The results from the vertical radar recorded flight activity at all altitudes with most flight activities in the lowest altitude band (up to 70 m) especially during winter when most activity was from local seabirds. Migrating passerines flew both at very low altitudes (concentrated at less than 300 m) and at a wide range of altitudes up to the highest altitude measured (1500 m). There was a clear difference between daylight and darkness: fluxes were higher and birds flew higher during darkness. Numbers of bird collisions were not recorded, but based upon visual observations and model calculations are estimated as being low.

4. Discussion

The major anticipated impacts of the establishment of a wind farm are disturbance of the area in the construction phase, the presence of the farm and exclusion of other uses in the operational phase. In this letter we have focused upon the operational phase. During this phase, possible impacts are expected from the presence of hard substrate in the form of the monopiles and scour protection rocks, noise from the gearboxes, generators and hydraulic systems, the turning rotor blades and the absence of fisheries and major shipping movements. First we will describe the effects upon the major faunal groups followed by the overall effects upon the (local) ecosystem as a whole.

4.1. The benthos

The absence of fisheries and the presence of the new hard substratum were expected to have the most impact on the benthos. A few months after the construction of the park, the local benthos community in the sandy area between the monopiles showed no major differences, in composition, densities, overall biomass and diversity, inside the farm as compared to in six reference areas (Daan *et al* 2009). This indicates no clear short-term measurable effects of the construction of the farm. This is comparable to the conclusions for Danish wind farms, where only negligible impacts on the native communities were found (Leonhard and Pedersen 2006).

On the monopiles, however, 33 different species were observed and on the scour protection rock 11–17 hard substratum benthos species were detected in 2008. This is a significant change and if no hard substrates were present in the wind farm area before the construction, these hard substratum species count as an increase in the number of species, increasing biodiversity in the farm area, similar to what was found for the Danish farms (Leonhard and Pedersen 2006), where an increased local food availability arose.

The species on the monopiles were observed in two clearly distinguishable zones: an upper zone dominated by mussels and a lower zone dominated by tubeworms and anemones (Bouma and Lengkeek 2009). Mussel larvae attach easily to the monopiles and grow very fast in this area. This feature might be used in the future to stimulate multiple use in the form of aquaculture in the wind farms.

The species on the scour protection rocks include both native and introduced species, such as the Japanese oyster. One may argue that hard substratum is not natural along the Dutch sandy coast. But the bottom map in the Piscatorial Atlas published by Olsen in 1883 shows the presence of a so called moorlog area. Coarse peat was found in this area with exposed remnants of trees and branches. Although we have no further data, it is likely that many animals lived on and in the hard substratum of this moorlog. So hard substratum is not new to this area, and apart from the newly introduced species, a hard substratum fauna being present may be considered rather natural.

The field study at the end of the first year of the wind farm's operational phase does not indicate a rapid increase of bivalve populations in OWEZ through enhanced recruitment. Since the mesocosm experiments revealed that settling bivalves did not show a preference for any of the sand fractions offered, no indications were found that bivalve settlement will be impacted if OWEZ, being closed for fishery, were to develop more variation in sediment grain size. The recruitment study concludes that OWEZ does not have an overriding effect upon soft-bottom bivalve recruitment during the first year of being closed to trawling (Bergman *et al* 2010). Other factors, e.g. natural post-settlement mortality or a low supply of larvae, especially in the case of *Spisula subtruncata*, may play a more important role in the relatively limited numbers of recruits resulting from the spring/summer settlement in OWEZ. Since adult survival is expected to benefit from the closure to trawling, benthos population increase depends upon accumulation of older individuals (Leonhard and Pedersen 2006), which has not been measured as yet in OWEZ.

Cluster analyses of recruit composition suggested an offshore–coast gradient but no clear correlation with the location of OWEZ. However inside the farm there was a significant correlation between bivalve abundances and especially mud content. No such correlation was found outside the farm and Bergman *et al* (2010) suggested that this might be an effect of fisheries outside the farm. Therefore, if an effect on the benthic ecosystem was observed, this was not to be attributed to the presence of the farm but to the absence of bottom trawling.

For the benthos, there are indications that the absence of fisheries resulted in a more explicit correlation between mud and bivalve recruitment and that hard substratum leads to a higher biodiversity inside the wind farm.

4.2. Fish

The presence of the monopiles and scour protection stones, and the absence of fisheries, are expected to have the most impact upon fish species. Noise and vibrations from the turbine generators and electromagnetic fields from cabling do not seem to have a major impact upon fish and other mobile organisms attracted to the hard bottom substrates for foraging, shelter and protection (Leonhard and Pedersen 2006). The data collected by the pelagic and demersal surveys indicate a highly dynamic fish community with large differences between the catches before the wind farm was built and the catches in the operational phase. The dominance in pelagic species switched from herring to sandeel (Ybema *et al* 2009) and the species richness of demersal fish was significantly higher in the first year after construction (Ter Hofstede 2008). However, since these changes were found both in the wind farm and in the reference areas it is unlikely to be caused by the presence of the farm. There are indications that the large temporal variability has a relationship with observed differences in temperatures.

At species level there was an increase of sole, whiting and striped red mullet and a decrease of lesser weever in the wind farm in comparison to the reference areas. The results are based on observation from the sandy area at least 200 m away from the monopiles. For Danish wind farms, Leonhard and Pedersen (2006) estimated that the availability of food for fish directly around the turbine sites increased by a factor of approximately 50 after the introduction of hard substratum, in comparison with the former sandy area. Taking the whole wind farm area into account they estimated an increase of about 7% of the total biomass in the area, making an increase in fish production related to the presence of the hard substratum possible. On the basis of the T1 data this anticipated increase cannot be shown from the survey data. Video footage, however, showed that the new hard substratum provides shelter for cod and pouting, comparable to the observations in Danish wind farms, where pouting together with schools of cod were observed presumably feeding on crustaceans on the scour protection (Leonhard and Pedersen 2006). These observations indicate a possible refuge function of the farm for certain fish species. For cod this was further confirmed by results of a side project within the wind farm. This project, to study the behaviour of individual fish types, has been conducted with sole and cod. It indicated that sole do not stay in the farm for longer periods, whereas some cod stayed near a single wind turbine for the whole nine-month measuring period (Winter *et al* 2010).

4.3. Marine mammals

Possible effects upon marine mammals are expected from the noise generated by the turbines, as well as the presence of additional food sources due to a lack of fisheries and the new hard substratum with associated fauna. For porpoises, the acoustic recordings show that significantly more activity was recorded in the operational wind farm as compared to the reference areas outside the farm. Scheidat *et al* (2009, 2011) indicated that this may be linked to increased food availability or that wind parks could provide areas of relative quiet in comparison to the surrounding waters with high vessel activity (the so called shelter effect).

During the studies on the Danish wind farms (Diederichs *et al* 2008), no differences could be detected in the presence of harbour porpoises between inside and outside the wind farm. The only effect of the turbines that was observed on harbour porpoises was a difference in the 24 h cycle of harbour porpoise recordings. Especially in 2005, a pronounced diurnal rhythm with most recordings during the night occurred at T-PODs deployed close to single turbines. Diederichs *et al* (2008) suggest that this difference in diurnal cycle of harbour porpoise activity could be related to diurnal differences in the fish community close to the monopiles. This is an indication of increased foraging behaviour of harbour porpoises in wind farms. Both Dutch and Danish research studies indicate that operational wind farms are frequently visited by harbour porpoises and most likely used for foraging. It appears that these relatively small wind farms do not induce aversive responses from these protected animals. Another Danish wind farm in the Baltic Sea, Nysted, showed that porpoises left the area after construction and did not return during the operational phase (Tougaard *et al* 2009). Therefore these results cannot easily be extrapolated to any wind farm.

During pile driving, tracked harbour seals seemed to avoid the area up to at least 40 km away. The effect of the wind farm in operation upon seals could not clearly be defined. In the period after construction tagged seals extended their distribution towards the wind farm area (Brasseur *et al* 2010). However, many more data are required before definite conclusions concerning possible reactions of seals to wind farms can be established. Danish studies (Tougaard *et al* 2006) also indicated that the use of satellite transmitters does not supply sufficient accurate data for establishing effects upon seals. However, some tagged seals seem to have visited the wind farm, while visual observations from ship surveys indicated no difference between numbers inside and outside the farm. This is in contrast to the construction period situation, where very few seals were observed in and around the area due to the very high levels of underwater noise generated by the pile driving operations. Tougaard *et al* (2006) conclude that underwater noise from the turbines seems to be the only potential negative source of impact for seals—but based on measurements of emitted noise, that the scale of this impact can be considered as marginal. In addition, they believe that seals may also benefit from the increased food availability on the foundations and scour protection. Thomsen *et al* (2006) estimate that the operational noise of wind turbines will be audible to harbour porpoises at around 100 m, and to harbour seals at over 1 km. So far, only a few sound measurements have been conducted in the OWEZ farm at relatively low wind velocities, indicating low noise levels which are not expected to significantly influence marine mammals (de Haan *et al* 2007b). More measurements at other wind and sea states are, however, required before more definite conclusions can be drawn.

4.4. Birds

For the distribution of local birds in the wind farm area, topographic factors such as depth and latitude as well as the influence of fishing vessels on some of the bird species seem to be extremely important (Leopold *et al* 2009). Ship-based bird counts in and around the wind farm indicated avoidance behaviour of common scoters and northern gannets, no marked avoidance by divers, guillemots, razorbills and most gulls and attraction for cormorants. Visual and radar observations from the meteomast (Krijgsveld *et al* 2010) indicated that the bird fluxes through the wind farm area were lower compared to counts before construction. They also found lower bird densities inside the farm. This was however not related to the presence of the wind farm, but seems in part related to the specific offshore location of the wind farm and in part to the significantly lower numbers of fishing vessels in the T1 study as compared to the T0 study. Gulls, cormorants and terns did not avoid the farm and used it for foraging. But gannets, scoters, auks, guillemots and divers showed strong avoidance behaviour in their flight pattern in the vicinity of the farm. Inger *et al* (2009) also concluded that generally wind farms have a negative impact on local bird abundance.

In general, the flight altitudes of migrating birds were higher inside the farm as compared to outside, most likely demonstrating avoidance in the vertical direction. So far, collisions could not be measured in a reliable way but on the other hand, many hours of visual observations did not record any collisions. When visibility is good, both for birds and observers, there seems to be no problem. But better techniques need to be applied for periods of poor visibility, such as dark foggy nights.

Danish studies found similar effects (Blew *et al* 2008). High proportions of aquatic birds (pelagic species, sea ducks, swans, geese and others) avoid the wind farms at large scales. Others like the common scoters, common eiders, migrating great cormorants and terns show a clear, yet not total avoidance of the offshore wind farms. Resident species such as gulls and non-migrating cormorants regularly enter the wind farm, where they potentially take advantage of a new food source. Petersen and Fox (2007) reported that during three out of four surveys in 2007, more common scoters were recorded within the food print of the wind farm than during any previous survey. And although earlier reports indicated that common scoters were adversely affected by the presence of the wind turbines at Horns Rev, habituation could take place after several years.

In conclusion, several bird species seem to avoid the wind farm, while others are indifferent or even attracted. All results indicate a change in habitat utilization by birds when an operational wind farm with turning rotor blades is present. Some may benefit while others avoid the area. Depending on the location and scale of future wind farms the adverse effects may increase. Therefore, large scale monitoring programmes are required to establish effects on population levels.

4.5. The ecosystem in general

Although the impact of the offshore wind farm Egmond aan Zee in the operational phase seems relatively small, it does influence the local biodiversity and behaviour of local and migrating animals. The presence of a new hard substratum and operating wind turbines creates a different habitat in comparison with the original situation before construction as well as with the surrounding area in the operational phase. The piles and scouring stones act as artificial reefs, thus increasing the amount of available habitat for some taxa (Inger *et al* 2009).

Depending on the former absence or presence of other hard substratum in the area where the wind farm was constructed, the presence of the farm can lead to settlement of new organisms in the area, and thus to a higher biodiversity. If other hard substratum was present before construction, e.g. shipwrecks, platforms, (artificial) reefs, etc, it can hardly be expected that new organisms will be introduced to the area, but their numbers will increase. The same is true for invading species.

When assessing the effects of wind farms, the temporal and spatial variability of the marine ecosystem has to be taken into account. The temporal variability of the marine ecosystem is large and there are continuous changes in production, biomass and species composition (Lindeboom *et al* 1994). These changes can be gradual but there are also indications of very abrupt changes or regime shifts (Beaugrand 2004, van Nes *et al* 2007, Weijerman *et al* 2005). These regime shifts appear to be common features and different causes such as large scale hydrometeorological forcing, severe winters, high storm frequencies, ecological feedbacks, nutrient loads and fisheries have been suggested in the literature. The causes can be natural or anthropogenic. These regime shifts also occur in the Dutch coastal zone, where major changes were observed in 1979 and 1988 (Weijerman *et al* 2005). Regime shifts seem to occur at intervals of years to decades and it is likely that shifts will be observed during the lifetime of a wind farm. Possibly the shift in the dominance of pelagic fish species in the samples between before and after construction (Ybema *et al* 2009) is the result of a shift in temperature. Thus the effects of a wind farm are additions to an already very variable system, and both analyses of long-term data sets and comparisons between the impact area and reference areas are needed when interpreting the possible effects of wind farms.

In the Dutch coastal zone where the wind farm was constructed, depth is a major driver for the spatial distribution of fish, birds and seals. The bird distribution shows an especially distinct relationship with depth (Leopold *et al* 2009). OWEZ was constructed between the densely used coastal area and the more open sea. Fish and seals have a distinct distribution parallel to the coast (Lindeboom *et al* 2005) and for many species the 20 m depth contour appears to be a clear division between coastal distribution and the more open sea distribution. OWEZ is situated around this depth contour and possible effects may be typical for this distinct zone. Since so far all other marine wind farms are planned outside the zone of 12 nautical miles, care must be taken when extrapolating results to other areas.

The major effects of a wind farm itself are due to the new hard substrate enhancing biodiversity and the rotating rotor blades possibly scaring certain bird species. However, other major effects could come from the absence of other user functions. Apart from the presence of a certain driver, in an already adapted ecosystem, the new absence of a driver with a large impact could create the most important changes.

Before construction, the OWEZ area belonged to the heavily fished Dutch coastal area (Piet *et al* 2007), where beam trawlers (‘eurocutters’) with less than 221 kW or 300 HP engines regularly plough or rake the sea floor with their tickler chains and nets. Most likely this led to lower biodiversity, different fauna composition and different age structure of populations (Lindeboom and de Groot 1998, Bergman and van Santbrink 2000, Duineveld *et al* 2007, Lindeboom *et al* 2009). Exclusion of fisheries may lead to restoration of the original fauna or parts thereof. In the first year after construction there were some observations of fish supporting this hypothesis, but more observations, which are planned in the fifth year (2011), are needed for more firm conclusions.

During the first operational year, OWEZ wind park did not have an effect upon soft-bottom bivalve recruitment, indicating that a rapid increase of bivalve populations through enhanced recruitment cannot be expected. There are also no indications from the mesocosm experiments that more variation in sediment characteristics generated by the presence of a fishery-closed OWEZ will lead to enhanced settlement. Results, however, suggest that the coupling between sediment (mud) and abundances of bivalve recruits could be better maintained in the absence of trawling in OWEZ. Since absence to trawling is expected to favour adult survival, increase in benthos abundances and in biodiversity will most likely be caused by accumulation of older individuals. Future field studies planned in 2011 will give answers as regards this hypothesis.

The OWEZ area is situated near IJmuiden harbour, the entrance to Amsterdam harbour and near busy shipping routes. It is very likely that prior to construction, underwater noise from ships, including fishing vessels, affected the use of the area by animals susceptible to these noises, while after construction the noise levels were reduced in comparison to former levels or present surrounding levels. The possible presence of higher numbers of porpoises in the farm could also be the result of shifting noise levels. To test this hypothesis, acoustic maps before and after construction are needed.

The actual impact that a wind farm in operation will have on the marine ecosystem greatly depends upon the local features of that ecosystem before and after construction. In areas where hard substratum is already present, the piles or stones will lead to far fewer effects than in areas with almost purely sandy sediments. Furthermore, depending on the former use of the area and the intensity of other human activities and its effects, the local impact of wind farms can differ significantly. Results in one area are not necessarily valid for other areas. The background conditions will be different. And the absence of one user function may lead to more effects than the presence of another. In areas with a high fishing pressure, such as the Dutch coastal zone, the exclusion of fisheries will have clearer effects than in areas less fished, further offshore.

Effects accumulate, and what we observe is always the result of many influences or the changed intensity of such influences. The results of this study indicate that the presence of the OWEZ wind farm leads to an increase in local biodiversity, may give shelter to benthic organisms and fish, and slightly changes the bird use of the area. Whether one considers this positive or negative depends upon the ecological targets set for the area. In Marine Protected Areas with targets for the presence of specific bird species, the effects of turning generators could be considered negative. In other already heavily influenced areas, a wind farm could lead to habitat enhancement or even environmental recovery (Inger *et al* 2009).

Crutzen (2002) introduced the term Anthropocene for our present era. There are no areas on Earth were human influences cannot be measured and many aspects of the Earth's system and her functioning are influenced or even dominated by human actions. The same holds for the North Sea, where extensive fishing pressure, pollution, sand, oil and gas extraction, and shipping have already resulted in a changed ecosystem (Lindeboom *et al* 2009). Now wind farms are being constructed, adding hard substratum and turning rotor blades into a sandy and open marine area: a new addition in the Anthropocene. Inger *et al* (2009) state that marine renewable energy installations have the potential to produce significant anthropogenic influence on marine ecosystems, and the positive and negative impacts on the marine environment will certainly interact in complex and unpredictable ways. These impacts may also be cumulative both in time and with increasing numbers of wind farms. Hence it is critical that we consider a wider marine ecosystem rather than focusing on the effects of individual farms.

For the future, it could be helpful to designate specific energy areas in the sea. Here we consider the impact of wind farms as part of the unavoidable effects of human presence and energy demands. We can set clear targets for the desired energy production and limits for potential ecosystem impacts, reflected in the location and design of the wind farm. This also offers possibilities for planning the future of the area when decommissioning the wind farm.

5. Conclusions

The effects of the operational OWEZ wind farm on biota have been collated in this letter. The soft-bottom benthos community is not affected by the wind farm, and nor is the bivalve recruitment during the first year of operation. Recruit abundances in the farm are correlated with mud content. Species composition of recruits in OWEZ and the surrounding reference areas is correlated with mud content of the sediment and water depth irrespective of the presence of OWEZ. There is an increase in biodiversity due to the newly introduced hard substrata of the piles and stones. The temporal variability of the fish community is large, both inside and outside the wind farm, and not due to its presence. Some fish species, such as cod, seem to find shelter in the wind farm.

Some bird species appear to avoid the farm while others are indifferent or even attracted. There are clear indications of the influence of the turbines on the flight pattern of both local and migratory birds, where several bird species tend to avoid the turbines or the entire farm. It has not proved possible to collect data on bird collisions so far.

For seals, the data density is insufficient for definite conclusions but before and after the pile driving seals used the study area. Harbour porpoises showed no aversion to operational wind farms. In contrast, there are indications that, at least during the study period, animals used the area in the wind park more frequently than the reference areas.

Overall, the OWEZ acts as a new type of habitat with a higher biodiversity of benthic organisms, a possibly increased use of the area by fish, marine mammals and some bird species, and a decreased use by several other bird species.

Furthermore, the construction of wind farms will also have an impact on other local human uses like fisheries or shipping. A decrease in impacts of these uses may also lead to changes in the ecosystem.

The results of this research programme so far do not indicate a need for major changes in the development of more wind farms in the open sea, although care should be taken to avoid sensitive bird areas. On the other hand, these findings are based on two years of research and only apply to a relatively small wind farm at a distance from the coast between 10 and 18 km. If more or larger wind farms are constructed in other places, more data on the vulnerable species need to be collected.

A large scale monitoring programme, coupled with an adaptive development of future wind farms, is recommended. Such a monitoring programme, which should run before, during and after construction, should not only address the amounts and behaviour of vulnerable organisms, but also the intensity and effects of human uses other than wind farm operation.

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