CHAPTER 17

Not necessarily all gold that shines: appropriate ecological context setting needed!

Steven Degraer*, Francis Kerckhof*, Jan Reubens*, Nicolas Vanermen*, Ilse De Mesel, Bob Rumes, Eric W.M. Stienen, Sofie Vandendriessche and Magda Vincx.

*shared first authorship

At present, everybody agrees that offshore wind farms do impact the natural environment. Whether or not these impacts should be valued positive or negative, or ecologically and societally acceptable, however remains an open question. While boosting local species richness, the artificial hard substrata may for example also open the door to non-indigenous and even invasive species. Some fish and seabirds are further known to be attracted to wind farms, but fish do not necessarily take profit from these structures and seabirds may suffer from an increased collision risk. The true impact will therefore be valued only if local observations are up scaled to the ecoregion level.

INTRODUCTION

One of the most frequently raised societal questions regarding the impact of offshore wind farms (OWFs) is whether or not the impact should be considered acceptable. As such, the societal relevance of our findings is much linked to a human appreciation of whether the effects are considered positive or negative. Positive or negative, or good or bad, however varies according to different societal points of view, which may not be considered a scientific exercise (Winter et al., 2012). Science may and should however aid assessing the acceptability of impacts. A first and most important step to assess acceptability comprises a scientific context setting as to assess the ecological significance of the observed effects, with the aim of proposing robust sets of criteria and standards.

A series of impacts have been identified in the Belgian OWFs, varying from seemingly negative to seemingly positive impacts as presented in the former chapters. Gannets *Morus bassanus* for example do avoid OWFs, while lesser black-backed gulls *Larus fuscus* seem to be attracted to OWFs (Chapters 4 and 15). Harbour porpoises *Phocoena phocoena* escape from excessive noise levels during piling to a distance of about 20 km, while the same species may want to take profit of the increased food resources once the OWF is fully constructed (Chapters 7 and 16). Soft sediment macrobenthos species richness and biomass seem to increase (Chapters 9 and 13) and some fish species are on average bigger in the OWF, while lesser weever fish *Echiichthys vipera* typically disappears from OWFs (Chapter 10). Hard substratum epifauna finally significantly adds to the biodiversity of the formerly soft sediment environment (Chapter 12). Given the obviously dominant increase in several assets of local biodiversity, many people now seem to have a rather positive general appreciation of the effects (Anonymous, 2012b, c; see also Chapter 18). To holistically evaluate the ecological significance of these positively appreciated effects, a proper context setting is needed. Such context indispensably comprises at least an up scaling of the effects both from effects on local individuals to the level of populations and from single wind turbine effects to Southern North Sea-wide OWF effects. Here, we focus on the potential of ecological traps (in its broadest sense), i.e. the chance of which may seem positive at first sight in fact is negative when interpreted at an appropriate ecological scale. Three examples showcase the need for nuancing effect interpretation, but also to further investigate effects at an ecosystem scale and in a cumulative perspective: (1) the possible facilitation of non-indigenous species by OWFs to further invade the Southern North Sea, (2) the attraction – production dilemma in artificial reef fish and (3) the increased risk of collision of attracted seabirds. The seemingly positive impact of increased benthic richness is tackled in Chapter 18.

CASE 1
ARTIFICIAL HARD SUBSTRATA: BIODIVERSITY HOTSPOT OR STRATEGIC POSITIONING OF INVASIVE SPECIES?

Non-indigenous species: what's in a name?

Non-indigenous species (NIS) are here defined as any species that occurs outside its natural range (past or present) and that has become established in a certain region in the wild with self-sustaining populations. As such, non-indigenous can be synonymised with non-native and allochthonous. This means that the occurrence of such species derives from an intervention by man either through deliberate/ intentional (e.g. import for aquaculture) or non-deliberate/ non-intentional (e.g. climate change, habitat creation, accidental propagule introduction) human action. We further make a distinction between introduced species and range expanding species. Introduced species are a subset of non-indigenous species that are introduced in a certain region – in this case the North Sea – by historical human intentional or unintentional activities (e.g. Carlton, 1996) across natural dispersal barriers. This means that they came from remote areas elsewhere around the globe including the Mediterranean, the Black and Caspian Sea (Wolff, 2005). Range expanding species are another subset of non-indigenous species that are spreading from adjacent regions by natural means. For the Southern North Sea, this encompasses Atlantic species with a Northeast Atlantic origin.
For a number of species, now with a cosmopolitan occurrence in harbour and coastal habitats and therefore possibly non-indigenous, it is often difficult to unravel whether or not they are native in the North Sea especially in the absence of fossil evidence. Such species of which the indigenous or non-indigenous status in a certain geographical area cannot sufficiently be proved are termed cryptogenic (Carlton, 1996).

Human interventions have a major impact on local marine biodiversity. A striking example is the ongoing hardening of the coast by the construction, in historical times, of many coastal defence works, harbours and other artificial structures. More recently, artificial hard substrata are even introduced in the offshore environment and wind farms will in the future occupy large areas of the shallow waters of the North Sea.

In Belgian waters, these new artificial structures attract hard substratum species that were formerly unable to live in the sandy environment of the Southern North Sea and they will facilitate the expansion of rocky shore species, living west of the Dover Strait, into the North Sea. Additionally, introduced species from all over the world may now find a suitable place to survive. At first sight, this increase of local species richness may seem a positive effect, that may however be countered by the fact that these non-indigenous species (NIS) may harm the (local) ecosystem when becoming invasive (Reise et al., 2006). The increased risk of invasiveness may as such be considered an ecological trap linked to the introduction of hard substrata in an originally soft sediment environment.

Here, we address the possible effects of the presence of NIS on the local biodiversity, and, on a broader scale and time frame, on the fauna of the Southern North Sea. Contrary to Chapter 12, where the subtidal colonisation process on the wind turbines is analysed, this section focuses on the intertidal zone, where a high number of NIS are currently thriving.

Patella vulgata, Elminius modestus and *Littorina littorea*

Megabalanus coccopoma and *Balanus perforatus*

Hemigrapsus sanguineus

The colonisation of the structures was fast (Kerckhof et al., 2012) and NIS were present shortly after turbine installation. Their presence was most striking in the intertidal zone, where we identified 17 obligate intertidal species, of which no less than one out of two species appeared to be non-indigenous (Table 1). These NIS include six introduced species, i.e. the Pacific oyster *Crassostrea gigas*, the barnacles *Elminius modestus* and *Megabalanus coccopoma*, the amphipod *Jassa marmorata*, the Asian crab *Hemigrapsus sanguineus* and the midge *Telmatogeton japonicus*, and two range expanding species, i.e. the barnacle *Balanus perforatus* and the limpet *Patella vulgata*. Except for *M. coccopoma*, the presence of NIS seems permanent and juveniles of all species considered have been found during subsequent years. Most of these species were already detected in the vicinity of the wind farms, particularly on buoys (Kerckhof et al., 2007; F. Kerckhof, unpublished data). These buoys form a somewhat comparable habitat, but lack a real intertidal zone as they move up and down with the tides. As such, only the uppermost and lowermost intertidal zones, i.e. splash zone and infralittoral fringe, are present on buoys. Only *P. vulgata* was not yet discovered on buoys.

Most NIS colonised the wind turbines during the first two years after installation and are common both on the monopile turbines at the Bligh Bank and the concrete gravity based wind turbines (GBFs) at the Thorntonbank. *Patella vulgata, H. sanguineus* and *C. gigas* however only arrived after three to four years and are currently restricted to the GBFs. The larger, more massive concrete GBF's can indeed be regarded as small rocky outcrops, offering a suitable place to settle for certain rocky shore species, including NIS. We however anticipate that some of these species will also be able to colonise the smaller sized monopiles in the future. Some of these species have already been detected on navigational buoys in the region (F. Kerckhof, unpublished data).

We expect that other NIS will pop up within the wind farms, since more NIS have been observed in the area of the wind farms and also on ships operating in the area, including the research vessel Belgica (Kerckhof et al., 2007; F. Kerckhof, unpublished data). The non-indigenous barnacle *Balanus* (*Amphibalanus*) *amphitrite* for example, is common in Belgian marinas and is occasionally recorded on offshore buoys of which one close

Table 1. Overview of recorded intertidal species at the Thorntonbank and Bligh Bank offshore wind farms with indication of their abundance as indicated by the SACFOR scale, as developed by the Joint Nature Conservancy Council (JNCC) (Connor and Hiscock, 1996). S, superabundant; A, abundant; C, common; F, frequent; O, occasional; R, rare. Bold: non-indigenous species.

	Thorntonbank gravity based foundations						Bligh Bank monopiles			
	years						years			
	1	2	3	4	5	6	1	2	3	4
Emplectonema gracile (Johnston, 1873)			O							
Emplectonema neesii (Örsted, 1843)			O			O				
Pleioplana atomata (OF Müller, 1776)			O							
Eulalia viridis (Johnston, 1829)				O						
***Patella vulgata* Linnaeus, 1758**			F	F	F	F				
Littorina littorea (Linnaeus, 1758)			F	F	F					
***Crassostrea gigas* (Thunberg, 1793)**			O	O	O	O				
Mytilus edulis (Linneaus, 1758)	F	S	S	S	S	S	C	C	A	A
***Elminius modestus* Darwin, 1854**	A	A	A	A	A	A	C	C	C	C
Balanus crenatus Bruguiére, 1789		F					C	R		
***Balanus perforatus* Bruguiére, 1789**	S	A	A	C	C	C		C	F	F
Balanus improvisus Darwin, 1854			O				O	R		
***Megabalanus coccopoma* (Darwin, 1854)**	C						F			
Semibalanus balanoides (Linnaeus, 1758)		S	S	S	S	S	C	C	C	C
***Jassa marmorata* (Holmes, 1903)**	C	C	C	C	C	C	C	S	C	C
***Hemigrapsus sanguineus* (De Haan, 1835)**			F	F	F	F				
***Telmatogeton japonicus* Tokunaga, 1933**	S	S	S	S	S	S	S	S	S	S

to the wind farm on the Thorntonbank (Kerckhof et al., 2007; Kerckhof and Cattrijsse, 2001). *Megabalanus tintinnabulum* is common in the fouling community of ships and has been noted before on e.g. buoys (Kerckhof et al., 2007; Kerckhof and Cattrijsse, 2001). Both species should hence have the capacity to colonise the Belgian wind farms.

Successfully introduced species are often opportunists that can now be found all over the world in habitats altered or influenced by human activities. Some of them may occur in such large numbers so that they change the habitat and alter local biodiversity. They are called invasive. Such species are a threat to the native biodiversity and may even affect commercially important species. Especially shallow coastal waters, subject to a multitude of human activities including the construction of artificial hard substrata, seem vulnerable to bio-invasions (Ruiz et al., 2009; Mineur et al., 2012). Most NIS found in this study, are known from coastal habitats, but our findings illustrate that they are very well capable to live in offshore conditions, provided that suitable habitat is available. The introduced Pacific oyster *C. gigas* for example, is thriving and spreading along the coasts of the Southern North Sea (Troost, 2010). The species is competing with native biota, especially the blue mussel *Mytilus edulis*. In certain regions, such as the Wadden Sea, mussel banks have even been replaced by Crassostrea reefs (Markert et al., 2009; Kochmann et al., 2008; Diederich, 2006).

Although both species may co-exist (Diederich, 2005), it is clear that commercial exploitation becomes difficult if mussel beds are infested with *C. gigas*, without any commercial value. If *C. gigas* were able to establish (semi-)permanent offshore populations in the Southern North Sea, it would be able to further strengthen its competitive position in the Southern North Sea; this possibly to the detriment of the commercially valuable coastal mussel banks, which are already under severe pressure (OSPAR, 2010). Most probably, *C. gigas* has already firmly established populations and the species may be considered here to stay, regardless what will happen. Other species such as the non-indigenous barnacles, also compete for space and resources with indigenous species, but are of less concern since none of the indigenous species are actually outcompeted and their competitors do not have a commercial value. *Telmatogeton japonicus* finally seems to occupy an empty niche, i.e. steep vertical walls in the intertidal, a feature that is seldomly encountered naturally in the North Sea. Competition with indigenous species may as such be excluded.

In conclusion, the newly introduced hard substrata within OWFs play an important role in the establishment and the expansion of the population size of NIS and we argue that these new artificial hard substrata offer new opportunities for NIS (introduced and southern Northeast Atlantic range-expanding species) to enter the Southern North Sea, or, if already present, to expand their population size and hence strengthen their strategic position in the Southern North Sea. This is particularly important for the obligate intertidal hard substrata species, for which other offshore habitat is rare to non-existing. We however also recognise that not all species have the same capacity to truly invade a habitat, but plead for a continued monitoring of this phenomenon as OWF development continues in the Southern North Sea.

CASE 2
WIND TURBINE ARTIFICIAL REEFS AS AN ECOLOGICAL TRAP FOR POUTING?

Each habitat in the marine environment has a specific carrying capacity, influenced by environmental parameters (e.g. currents, heterogeneity, temperature, sediment type, organic enrichment, etc.). As a result, habitat selectivity will influence the fitness, survival chance and reproductive capacity of fishes. Fish aggregation devices have the potential to act both as ecological traps (Hallier and Gaertner, 2008) and as productive sites (Dempster et al., 2011), depending on the species, the ecology and the environment. Pouting *Trisopterus luscus* is known to be attracted to wind turbine artificial reefs and high catch rates are observed during summer and autumn (Reubens et al., 2013a; Reubens et al., 2011). However, whether the wind turbines are poorer (ecological trap) or richer (productive site) in habitat quality than the surrounding soft-bottom sediments remains unknown. Therefore, we investigated length-at-age, condition and diet (as proxies for fitness) of pouting at different sites in the Belgian part of the North Sea. Pouting was sampled from January 2009 until December 2012 at a GBF wind turbine and at two sandy reference areas (i.e. the Gootebank and the Belgian part of the North Sea, BPNS). At the OWF and the Gootebank pouting were collected by standardised line fishing. At the BPNS, fish were caught with an 8-metre beam trawl with a fine-meshed shrimp net and a bolder-chain.

At the OWF, 0-group pouting were significantly larger compared to the Gootebank and the BPNS (Figure 1). In autumn, average length was 18.8 ± 1.5 cm at the OWF, while it was 15.6 ± 2.3 cm and 17.6 ± 1.7 at the BPNS and Gootebank respectively. Comparison between the OWF and the BPNS confirmed this pattern, with average lengths of 18.8 ± 1.5 cm at the OWF compared to 15.6 ± 2.3 cm in the BPNS in autumn, and 20.5 ± 1.4 cm at the OWF compared to 17.6 ± 2.4 cm at the BPNS in winter.

The Fulton's condition index, indicative for the general condition of the fish, was calculated as $(W/TL^3)*100$, with W = total weight (g) and TL = total length (cm). No significant differences in condition index were detected between the wind turbines and the Gootebank (Figure 2), as fish had a similar condition index (1.4 ± 0.26 g/cm³ and 1.4 ± 0.16 g/cm³ for the wind turbines and Gootebank respectively) for the period September-November.

Figure 1. Comparison of average total length (cm; + standard deviation) of pouting *Trisopterus luscus* at an offshore wind farm (OWF, green bars) and Gootebank (red bars).

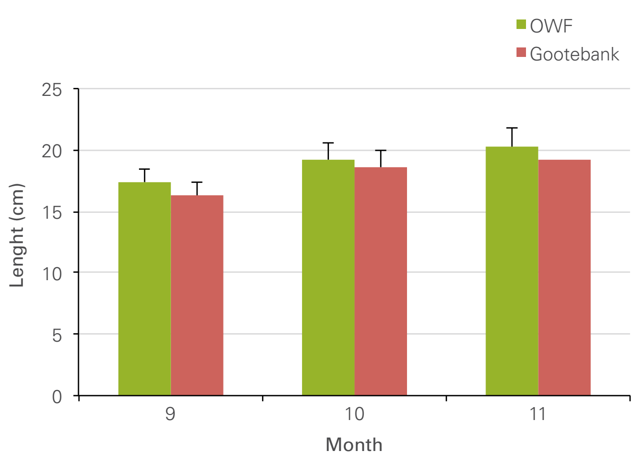
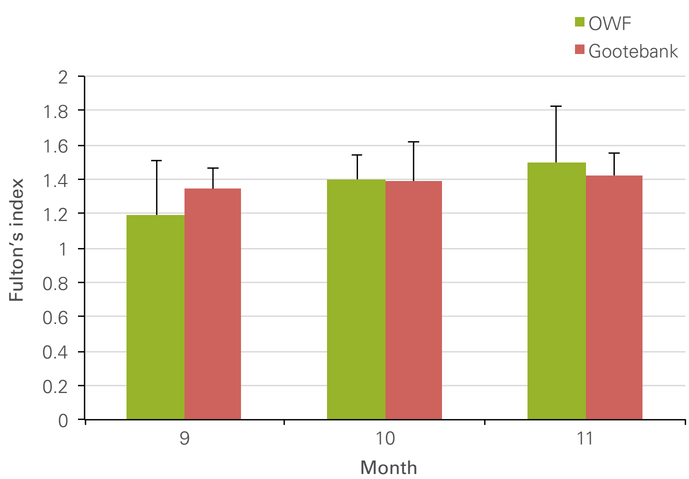


Figure 2. Average Fulton's condition index (+ standard deviation) of pouting *Trisopterus luscus* at the offshore wind farm (OWF, green bars) and the Gootebank (red bars).



Stomach content analyses revealed that large differences in diet were present between pouting from the OWF and the Gootebank (see also chapter 14). At the OWF, the diet was dominated by Amphipoda, followed by Reptantia, while the pouting at the Gootebank had more diverse diets with fish, Reptantia, Anthozoa and Amphipoda as the most dominant prey groups (Table 1). A more detailed analysis of the individual prey species showed that pouting at the OWF mainly fed upon hard substratum-associated prey species (i.e. *Jassa herdmani*, *Pisidia longicornis* and *Liocarcinus holsatus*), while at the sandy area they mainly fed both on hard and soft substratum-associated prey species (i.e. *Callionymus* sp., Actiniaria sp., *Polychaeta* sp. and *L. holsatus*). In addition, the stomach fullness (IF) was significantly higher at the OWF (1.5 ± 1.4 IF) compared to the Gootebank (0.6 ± 0.8 IF), which signifies a high food availability at the former.

Based on the information of the current study, no evidence was obtained to assume that OWFs act as an ecological trap for pouting, related to habitat quality. Length of pouting at the OWF was slightly larger compared to individuals at the sandy areas, while no significant differences in condition were observed between sites. In addition, no restrictions related to food availability were encountered at the OWF. Based on the measured proxies, fitness of pouting was even slightly better compared to the sandy areas (increased length and enhanced fullness index). This might be a first indication towards production (in terms of biomass) of pouting at the OWF. It should be noted however, that the current results do not exclude the OWF to potentially act as an ecological trap via increased fishing mortality in the future. Fish aggregations are particularly vulnerable to fishing pressure (Rose and Kulka, 1999). Concentration of both fish and fisheries activities can lead to local overfishing. If (uncontrolled) fisheries would be allowed at the OWF, which is not the case in Belgian waters, fish aggregating in this habitat would experience enhanced fishing mortality and may thus be caught in an ecological trap. Further details may be found in Reubens et al. (2013b).

Some of the most dominant prey species of pouting *Trisopterus luscus*.

CASE 3
SEABIRD ATTRACTION AND INCREASED COLLISION RISK

In January 2013, 1,662 offshore turbines were present in European waters. The European Union aims at an offshore capacity of 43 GW in the near future, which is equivalent to more than 14,000 3 MW turbines (EWEA, 2013). The number of offshore turbines still to be installed is thus enormous and their distribution will no longer be limited to the near shore zone, illustrated by the fact that at the Doggerbank in the central part of the North Sea, plans were licensed to build a 9 GW wind farm. As such, all North Sea seabirds will be confronted with the presence of offshore turbines. Considering the future large-scale exploitation, it is interesting to extrapolate the results as found at the BPNS and frame them into an international context. The numbers of estimated collision victims presented in Chapter 5, are without any doubt highly site-specific, largely reflecting the local seabird community, and the results based on this extrapolation should thus be interpreted with care.

In their research on wind farm-induced mortality in German waters, Dierschke et al. (2003) regard an increase of the existing mortality rate by less than 5% as acceptable. For Flanders, Everaert (2013) also sets the acceptable level at 5%, but with a more stringent threshold of 1% for vulnerable species and species facing population decline. When extrapolating the expected number of victims per turbine at the Bligh Bank wind farm (Table 2, see also chapter 4) to a scenario of 10,000 turbines, we exceed the 5% limit for lesser and great black-backed gull (*Larus fuscus, L. marinus*). Black-legged kittiwake (*Rissa tridactyla*) too shows a relevant increase of the existing adult mortality by 1.5%. The other three species regarded here (northern gannet *Morus bassanus*, common gull *Larus canus* and herring gull *Larus argentatus*) are at the safe side of the mortality threshold value.

Importantly, the applied threshold values are indicative, set to function as an 'early warning system', and the true critical threshold will depend on the species and its population dynamics (Dierschke et al., 2003). Nevertheless, the results presented here show that the cumulative impact of large scale wind farm development might potentially cause significant increases in bird mortality levels, putting specific seabird populations under pressure.

Table 2. Estimation of the additional mortality per 10,000 offshore turbines and a micro-avoidance of 97.6%, based on an extrapolation of the CRM results found for the Bligh Bank study area ([a] Mitchell et al., 2004; [b] Wetlands International, 2013; [c] BTO, 2013; [d] Poot et al., 2011).

Species	Biogeographical population	Population level	Yearly mortality	Number of collisions per year	Additional mortality per year
northern gannet	NE Atlantic	310,000 [a]	8.1% [c]	182	0.7%
common gull	NW and C Europe	1,640,000 [b]	14.0% [c]	545	0.2%
lesser black-backed gull	ssp. *graellsii* + *intermedius*	930,000 [b]	8.7% [c]	11,818	14.6%
herring gull	ssp. *argenteus* + *argentatus*	3,030,000 [b]	12.0% [c]	1,091	0.3%
great black-backed gull	N and W Europe	420,000 [b]	16.5% [d]	5,091	7.3%
black-legged kittiwake	NE Atlantic	6,600,000 [b]	5.9% [c]	5,818	1.5%

FUTURE MONITORING

All three examples demonstrate that the current data do not allow us to equivocally demonstrate ecological traps to occur at OWFs. NIS are present, but so far neither bio-invasions nor its ecological effects were detected. Fish are attracted to the OWFs, but seem to have found a suitable habitat at the OWFs. Birds may also be attracted, but only few species seem to be at risk due to potential collision with the wind turbines. The same data may however also be interpreted from a different point of view: we were only able to reject the ecological trap hypothesis for pouting, while for all other ecosystem components the question is yet to be answered. Further attention is hence needed here.

Future monitoring should take account of two considerations, i.e. the need for up scaling to species population levels and to the expansion of OWFs in the Southern North Sea. At the level of seabird populations, there is an urgent need for scientifically sound thresholds for acceptable additional mortality, which are societally accepted and politically defined, ensuring coherence at a North Sea scale. Further, while pouting seems to take profit from OWFs, we do not know whether or not this is the case for other fish species, some of which with commercial interest such as cod *Gadus morhua*. When finally the population size of e.g. NIS would become too large, bio-invasions with unwanted ecological consequences may still occur. A focus on population size rather than local densities is hence advised for future monitoring. When focusing at species population size, an up scaling of local wind turbine effects to the effects of Southern North Sea wide wind farms becomes indispensable. The extent of OWF is indeed inherently linked to habitat extent and hence population size potential. To properly deal with both aspects of up scaling a cross-wind farm and international collaboration will be needed.

Hemigrapsus sanguineus