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Photo B. Rumes / RBINS / MUMM

Visual inspection of the intertidal hard substrata in the Belwind wind farm
Abstract

There is a world-wide concern of the expansion of non-indigenous species because they alter local biodiversity and sometimes compete with native species, some of which of commercial interest. This is especially the case in shallow coastal waters, subject to a multitude of human activities, including the construction of artificial hard substrata. We took the opportunity of the construction of numerous windmills off the Belgian coast to study the colonisation of non-indigenous species on these new artificial structures. Therefore we monitored the fouling communities of the wind farms on a regular basis from the beginning of their installation. We demonstrated that the new artificial hard substrata of the windmills offer new opportunities for non-indigenous species (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.

4.1. Introduction

In a geological perspective, the North Sea is a very young basin: only after the last glaciation biota could start to move in (colonise) the new water body, either from the north or from the English Channel via the Dover Strait (Wolff, 2005). However, not all species that are capable of living in the new environment did effectively do so. The lack of suitable habitat hampered the spread of several species. As it comes to hard substratum species, especially the lack of hard substrata in the soft sediment dominated Southern North Sea (Cameron & Askew, 2011) should be considered a major obstacle.

Human activities inevitably resulted in changes of the marine biodiversity in historical times (Carlton, 1989). One of the major changes was the introduction of artificial hard substrata all along the coasts of the former predominantly sandy shores of the shallow Southern North Sea. More recently quite some artificial hard substrata was even introduced in the offshore environment. Artificial structures offer opportunities for newcomers that were formerly unable to live in the Southern North Sea. Consequently, the expansion of many rocky shore species living west of the Dover Strait into the North Sea was facilitated by these human-mediated environmental changes (Wolff, 2005).

From the onset of the hardening of the coast, which started in the 16th century (Wolff, 1999), many hard substrata species successfully colonised the new habitat. Through history, shipwrecks further augmented the extent of suitable habitat for many of these hard substrata species (Zintzen & Massin, 2010). With the construction of offshore wind farms finally, a new habitat of artificial hard substratum was introduced in a region mostly characterized by sandy sediments, enhancing the habitat
heterogeneity and biodiversity of the region (Kerckhof et al., 2009, 2010; Reubens et al., 2010), but also interacting with the surrounding natural sandy sediments (Coates et al., 2011). The effect of the introduction of these hard substrata – the so-called reef effect – is regarded as one of the most important changes of the original marine environment caused by the construction of wind farms (Petersen & Malm, 2006).

While the major part of these new artificial hard substrata consists of subtidal habitat, it is the offshore intertidal hard substratum that forms a truly new habitat in the Southern North Sea. Indeed, offshore subtidal hard substratum was already known from the (natural) gravel beds, as well as from (artificial) shipwrecks or oil and gas platforms. Because many subtidal hard substratum species, such as the barnacle *Elminius modestus*, the amphipod *Jassa marmorata*, the Japanese oyster *Crassostrea gigas*, the bryozoan *Bugula stolonifera*, can live on both natural and artificial hard substrata, subtidal non-indigenous species already had plenty of habitat and time to colonise the Southern North Sea, although they were not always recorded (Zintzen and Massin, 2010). This has, however, not been the case for offshore intertidal hard substrata fauna. While coastal (i.e. turbid waters) intertidal habitat was already available in the Southern North Sea, mainly in the English Channel both as (natural) rocky shores and (artificial) hard coastal defence structures, such habitat was largely absent from the clear offshore waters. Abundantly available buoys for example, only represent a splash zone, while a true intertidal zone is missing. The full array of offshore intertidal habitat was yet only to be found on the much scarcer piles of e.g. offshore oil and gas installations.

As such, offshore wind farms facilitate (1) the establishment of intertidal species previously not present in the Southern North Sea, an environment dominated by soft sediment habitats, (2) a strengthening of the strongholds of non-indigenous intertidal rocky shore species, as well as (3) a further spread of the latter from the English Channel into the Southern North Sea.

In this study, we therefore aim at quantifying the importance of offshore intertidal hard substrata, created by the wind farms, to non-indigenous i.e. range expanding and introduced species.

4.2. Material and Methods

4.2.1. Study area

Samples were collected in the C-Power and Belwind wind farms, located in a special dedicated zone (see Brabant et al., 2011) of the BPNS. The C-Power wind farm (at present six concrete GBF with 5 MW turbines) is located on the Thornton Bank some 30 km offshore (Figure 1). The Belwind wind farm (at present 56 steel monopiles with 3 MW turbines) is constructed on the Bligh Bank at about 50 km off the coast. Both banks belong to the Zeeland Banks system (Cattrijse & Vincx, 2001). Local water depth within the wind farms ranges from 7 - 30 m and the surrounding soft sediment seabed is composed of medium sand (mean median grain size: between 350 and 500 µm) (Reubens et al., 2009).

We monitored the fouling community of the intertidal part of the foundations of both wind farms as well as the subtidal erosion protection layer from (almost) the beginning of their installation. The concrete C-Power GBF foundations were sampled from autumn 2008, about 3 ½ months after installation (Kerckhof et al., 2009). Later, samples were taken seasonally (starting in spring 2009). At Belwind, sampling of the steel monopile foundations started in February 2010, two months after construction (Kerckhof et al., 2010). In total (from autumn 2008 - spring 2011) *intertidal* samples were collected on 10 and 5 occasions for the C-Power and the Belwind wind farms, respectively.

The samples were collected from a selected set of windmills: windmills D5 and D4 at the C-Power site and windmill BB08 at the Belwind site. The colonisation patterns observed on the sampled foundations were confirmed for the other foundations of both wind parks based on visual inspections and video footage.
4.2.2. Sample collection and processing

Samples were collected by scraping the fouling organisms with a putty knife from the foundation surface. In the subtidal a sampling surface area of 0.25 x 0.25 m was used, whereas the intertidal scrape samples were collected in a non-quantitative manner; this because of practical constraints linked to operating from a detached RIB. In addition, we visually inspected the intertidal of neighbouring piles of the respective wind farms. Video footage collected by the divers and during intertidal sampling was used to determine to what extent the scrape samples represent the actual fauna and to identify a number of rare, large and/or mobile invertebrate species that are otherwise not (adequately) represented in the scrape samples.

All scraped material was collected in plastic bags that were immediately sealed and transported to the laboratory for further processing: fixation using a 5% formaldehyde-seawater solution, sieving through a 1 mm mesh-sized sieve, sample sorting, preservation in 75% ethanol and finally species identification and relative abundance estimation.

The biota (further called species) were identified to species level whenever possible. Identifications were based on the most recent systematic literature and we followed the World Register of Marine Species (WoRMS) for the nomenclature and taxonomy (http://www.marinespecies.org/). We used the SACFOR scale for the estimation of the relative abundance, as developed by the Joint Nature Conservancy Council (JNCC) (Connor & Hiscock 1996). Depending on the growth form and size of the organisms - encrusting, solitary… abundance estimates are made for either percentage cover or numerical abundance. This is then linked to the scale and converted to SACFOR (Table 1).
Table 1. The SACFOR scale and its relation to coverage and density. S, superabundant; A, abundant; C, common; F, frequent; O, occasional; R, rare.

<table>
<thead>
<tr>
<th>Growth form</th>
<th>Size of individuals/colonies</th>
<th>Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>% cover</td>
<td>Crust/meadow</td>
<td>Massive/Turf</td>
</tr>
<tr>
<td>&gt;80%</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>40-79%</td>
<td>A</td>
<td>S</td>
</tr>
<tr>
<td>20-39%</td>
<td>C</td>
<td>A</td>
</tr>
<tr>
<td>10-19%</td>
<td>F</td>
<td>C</td>
</tr>
<tr>
<td>5-9%</td>
<td>O</td>
<td>F</td>
</tr>
<tr>
<td>1-5% or density</td>
<td>R</td>
<td>O</td>
</tr>
<tr>
<td>&lt;1% or density</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>O</td>
</tr>
<tr>
<td></td>
<td>R</td>
<td>&gt;1/10.000 m³ (100 x 100 m)</td>
</tr>
</tbody>
</table>

4.2.3. Intertidal non-indigenous species

This study only focused on the fauna of the eulitoral and splash zone, further referred to as intertidal species. Species were considered as intertidal *sensu stricto* if they inhabit solely or predominantly the eulitoral zone, while species having mainly a sublitoral distribution and only occurring occasionally in the infralitoral fringe (i.e. lower mussel zone) were considered subtidal species (e.g. Hayward & Ryland, 1990; Hiscock *et al.*, 2005; http://www.marlin.ac.uk/).

In this study a non-indigenous species is 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. Range expanding species are a 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. Introduced species are another 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).

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 status – native or not – in a certain geographical area cannot sufficiently be proved are termed cryptogenic (Carlton, 1996).

4.3. Results

During the considered period – late 2008-mid 2011 – we identified 26 species in the intertidal samples at the windmills. Of these species we considered 17 species as intertidal (Table 1). The non-indigenous species form an important part of the intertidal fouling community. We found eight non-indigenous species. These include six introduced species: the oyster *Crassostrea gigas*, the barnacles *Elminius modestus* and *Megabalanus coccopoma*, the amphipod *Jassa marmorata*, the crab
Hemigrapsus sanguineus and the midge Telmatogoton japonicus, and two range expanding species: the barnacle Balanus perforatus and the limpet Patella vulgata. The ratio for non-indigenous to introduced species is high 1/3. Their relative abundance, as estimated from the SACFOR scale, is in most cases high almost from the beginning (Table 2).

Table 2.
Overview of recorded intertidal species at the C-Power and Belwind site with indication of their abundance as indicated by the SACFOR scale. S, superabundant; A, abundant; C, common; F, frequent; O, occasional; R, rare. Non-indigenous species are indicated in bold.

<table>
<thead>
<tr>
<th>Species</th>
<th>C-POWER</th>
<th>BELWIND</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Year One</td>
<td>Year Two</td>
</tr>
<tr>
<td>Megabalanus coccopoma (Darwin, 1854)</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>Balanus perforatus Bruguière, 1789</td>
<td></td>
<td>S</td>
</tr>
<tr>
<td>Telmatogoton japonicus Tokunaga, 1933</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Elminius modestus Darwin, 1854</td>
<td>A</td>
<td>A</td>
</tr>
<tr>
<td>Jassa marmorata (Holmes, 1903)</td>
<td>C</td>
<td>C</td>
</tr>
<tr>
<td>Mytilus edulis (Linneaus, 1758)</td>
<td>F</td>
<td>S</td>
</tr>
<tr>
<td>Semibalanus balanoides (Linneaus, 1758)</td>
<td>S</td>
<td>S</td>
</tr>
<tr>
<td>Balanus crenatus Bruguière, 1789</td>
<td>F</td>
<td></td>
</tr>
<tr>
<td>Patella vulgata Linneaus, 1758</td>
<td></td>
<td>F</td>
</tr>
<tr>
<td>Hemigrapsus sanguineus (De Haan, 1835)</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Crassostrea gigas (Thunberg, 1793)</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Littorina littorea (Linneaus, 1758)</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>Balanus improvisus Darwin, 1854</td>
<td>O</td>
<td>O</td>
</tr>
<tr>
<td>Emplectonema gracile (Johnston, 1873)</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Emplectonema neesii (Orsted, 1843)</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Pleioplana atomata (OF Müller, 1776)</td>
<td>O</td>
<td></td>
</tr>
<tr>
<td>Eulalia viridis (Johnston, 1829)</td>
<td>O</td>
<td></td>
</tr>
</tbody>
</table>

During the first two years the number of non-indigenous species was the same for both windmill farms and encompassed the same species: M. coccopoma, B. perforatus, E. modestus, T. japonicus and J. marmorata. An additional three species, the limpet P. vulgata (Figure 2), the crab H. sanguineus and the Japanese oyster C. gigas (Figure 2) were found during the third and fourth year on the C-Power wind farm.

Except for M. coccopoma, the presence of all other non-indigenous species seems permanent. Juveniles of all species considered have been found during subsequent years. From the Japanese oyster C. gigas, only juveniles have been found so far.
4.4. Discussion

4.4.1. Non-indigenous species

From the very beginning the newly available substrata were colonised by non-indigenous species. Both introduced species and range expanding took advantage of the increased availability of hard substrata of the windmills to settle and further spread into the North Sea and, if already present in the region, to expand their overall population size.

We found the greatest number of non-indigenous species in the intertidal, whereas subtidally we so far only found one: the introduced slipper limpet *Crepidula fornicata*, present on both wind farms (Kerckhof et al., 2010; Kerckhof unpublished)

Approximately 1/3rd of the intertidal species were introduced, which is somewhat higher than the numbers reported for coastal habitats such as estuaries or lagoons (1/4th in Reise et al., 2006). All introduced species were known opportunists and early colonisers, taking advantage of man-made structures and disturbed conditions for settlement (Kerckhof et al., 2007).

Most introduced species 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. Since juveniles of all species considered have been found during subsequent years, they must reproduce either on site or have a regular influx of larvae. All non-indigenous species found in our study were already known to occur in the Southern North Sea and that several of them such as *E. modestus*, *C. gigas*, *M. coccopoma*, *T. japonicus*, *J. marmorata* and *B. perforatus* were already detected in the vicinity of the wind parks e.g. on buoys (Kerckhof et al., 2007; Kerckhof unpublished). These buoys do 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. Other species such as *Littorina littorea* and *Patella vulgata* were never (or only rarely) found on buoys.

Illustrative for the fast expansion of some non-indigenous species is the presence of the crab *Hemigrapsus sanguineus*, one of the latest reported introductions in the region. This species originates from the northwest Pacific and was first recorded in Europe in the late 1990s (d’Udekem d’Acoz and Faasse, 2002) and in Belgian waters in 2006 (d’Udekem d’Acoz, 2006). This species is now very
common in intertidal coastal areas and our findings prove that *H. sanguineus* is not limited to coastal areas, but can thrive in offshore areas too, provided that a suitable habitat available, more specifically the intertidal zone, is available.

For some species a suitable habitat had previously been available, but other factors had prevented them from establishing themselves. This is the case for the Lusitanian barnacle *B. perforatus*, which used to have its northern boundary in the eastern English Channel, but started a range expansion into the western English Channel from the 1990s onward (Herbert *et al.*, 2003). Here we recorded its presence in large numbers on the windmill pilings. This is thus a further range expansion and subsequent establishment in the Southern North Sea of this species. This expansion is likely favoured by the current warming of the coastal waters of the Southern North Sea (MacKenzie & Schiedek, 2007).

Finally, some introduced species can become invasive and may become a threat to the native biodiversity and even affect commercially important species. One example is the non native Japanese oyster *C. gigas*, which 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 wild *Crassostrea*, itself without any commercial value. If *Crassostrea* 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; possibly to the detriment of the commercially valuable coastal mussel banks, which are already under severe pressure (OSPAR, 2010).

The intertidal habitat on the windmill pilings could be attributed to the LR.HLR.MusB biotope of the JNCC Marine Habitat Classification (Connor *et al.*, 2004) a biotope that also has been identified on the pilings of other wind farms in the North Sea (e.g. EMU, 2008; Bouma & Lengkeek, 2009; Leonhard & Pedersen, 2006). This is typically a biotope for very exposed to moderately exposed eulitoral bedrock. For the characteristic high intertidal splash zone, often with a conspicuous *Telmatogeton* zone, and also present elsewhere on wind farms in the Southern North Sea e.g. on the Danish Horns Rev wind farm (Leonhard & Pedersen, 2006) no such biotope code is available. A similar habitat and zonation pattern in the intertidal (Kerckhof *et al.* 2010) have been reported on artificial hard substrata in the intertidal zone and on other wind farms in the North Sea (e.g. EMU, 2008; Whomersley & Picken, 2003; Joschko *et al.*, 2008; Bouma & Lengkeek, 2009; Leonhard & Pedersen, 2006).

Although some of the above listed studies on wind farms in the North Sea do mention the presence of non-indigenous species, the number is always lower than in our study and the presence of *H. sanguineus*, *C. gigas*, *B. perforatus*, *M. coccopoma* and *P. vulgata* has not been mentioned elsewhere. Part of this difference can be attributed to a less intensive monitoring, decreasing the chance of encountering species (initially) occurring in low numbers (e.g. *C. gigas*, *M. coccopoma*), but also to problematic taxonomic issues hampering a proper distinction between morphologically similar species resulting in a lower taxonomic resolution. This was the case for difficult taxa such as *Jassa* or *Balanus* (e.g. Bouwma & Lengkeek, 2009). The following three non-indigenous species are mostly mentioned: *E. modestus*, *T. japonicus* and *Jassa* spec. For example, in a report on the Kentish Flats wind farm in the Thames estuary off the UK east coast only the presence of the barnacle *E. modestus* (EMU, 2008) was observed. *Jassa* is present in all cases but only *J. marmorata* was identified in the Danish Horns Rev wind farm (Leonhard & Pedersen, 2006) then as a new and introduced species. A conspicuous *Telmatogeton* zone, as we have found, was also present on the Horns Rev wind farm (Leonhard & Pedersen, 2006), but initially not on the windmills off the Dutch coast (Bouwma & Lengkeek, 2009). However, in a later survey, the species was detected (Lengkeek, pers. communication).

### 4.4.2. Colonisation and succession of offshore intertidal hard substrata

The colonisation of the intertidal zone of the foundation structures in both wind farms was rapid and non-indigenous species constituted a major part of the colonists. However, some clear differences
in colonisation rate and subsequent succession could be found between both wind farms, of which part could be attributed to the construction time of the windmills. The foundations of the C-Power wind farm for example were available for colonisation in late summer, favouring species that are reproducing late in the season such as *B. perforatus* and *M. coccopoma* (Bassindale, 1964; Kerckhof unpublished data). After these species hence abundantly colonised the windmills shortly after installation, their numbers gradually declined as a result of an increased competition with other species.

Within both wind farms, we further witnessed a gradual increase of the species richness. This has been most clearly demonstrated at the C-Power site, where colonisation could have taken place during three consequent recruitment periods, and was less obvious at the Belwind site, where colonisation only took place during one recruitment period. We hence expect that the number of species will continue to increase on the pilings of the Belwind wind farm too, including the arrival and subsequent establishment of new non-indigenous species. We also expect that other non-indigenous species might pop up within the wind farms, since more non-indigenous species have been observed in the area of the wind farms and also on ships operating in the area (Kerckhof et al., 2007; Kerckhof unpublished data). For example, the barnacle *Balanus (Amphibalanus) amphitrite* was present in the fouling community on the research vessel Belgica and on a buoy marking the Thornton Bank and an empty specimen of the large barnacle *Megabalanus rosa* has been found on a buoy marking the Belwind wind farm, together with specimens of another Megabalanus, *M. tintinnabulum*. At least *B. amphitrite* and *M. tintinnabulum*, have the capacity to colonise the Belgian wind farms. The former is a spreading species, already common in Belgian marinas and occasionally recorded on offshore buoys (Kerckhof et al., 2007; Kerckhof & Cattrijsse, 2001), whereas the latter is common in the fouling community of ships and has been noted before, e.g. on buoys (Kerckhof et al., 2007; Kerckhof & Cattrijsse, 2001). *Megabalanus rosa*, on the other hand, is also an introduction through shipping but has never been found before in the North Sea. In conclusion, we expect the intertidal (non-indigenous) fauna of the Belwind and the C-Power sites to become richer in species number over the course of the next few years and more similar. However, some differences in the composition of the intertidal fauna may remain since different foundation types were used large concrete GBF versus smaller steel monopiles (see also Brabant et al., 2011).

4.5. Conclusion

This study demonstrated that the newly introduced hard substrata within offshore wind farms play an important role in the establishment and the expansion of the population size of non-indigenous species, thus strengthening their strategic position in the Southern North Sea. This is particularly important for the obligate intertidal hard substrata species, for which offshore habitat is rare to non-existing.

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