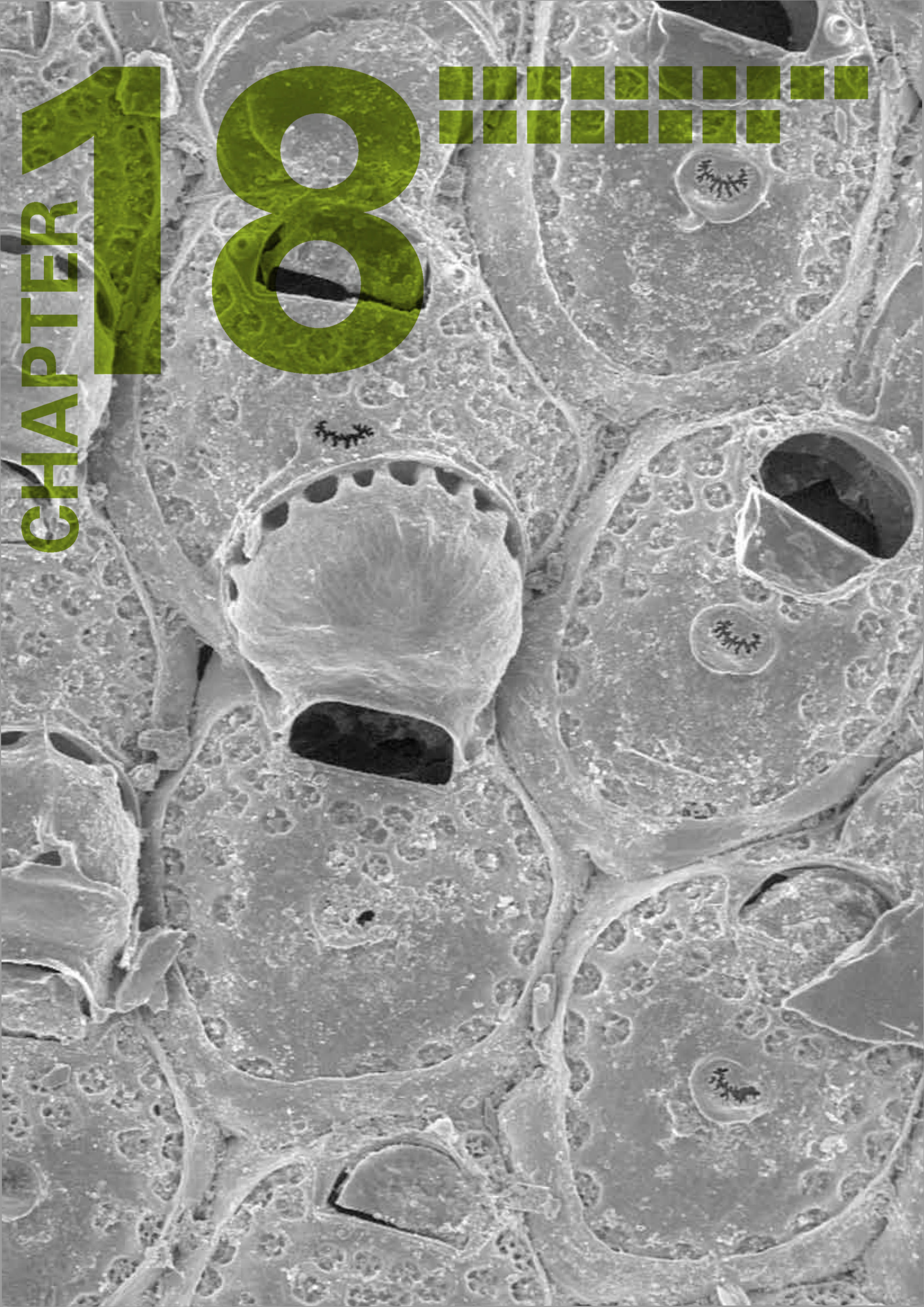
CHAPTER 18



Does it really matter? Changes in species richness and biomass at different spatial scales

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Since the installation of the wind farm foundations and associated scour protection in an area previously characterized by soft bottom sediments, the number of hard substrate associated fish and benthic species has increased markedly. At the level of a single turbine footprint a nearly 4000-fold increase in autumn biomass was observed, whereas at the level of the entire wind farm a 14-fold increase was observed. Further development of the entire Belgian wind energy zone may increase benthic biomass by as much as 3% of the current estimated benthic biomass in the Belgian part of the North Sea.

INTRODUCTION

The artificial reef effect and the resultant attraction of fish species to wind turbine foundations are often considered the major benefits of offshore wind farm development for the marine environment. The installation of artificial hard substrate in an area previously known for soft bottom sediments will increase local biodiversity due to an influx of hard substrate associated species. In conjunction with the exclusion of commercial fishing in the area (Chapter 8), both this development of the hard substrate epifauna (Chapter 12) and the organic enrichment of the soft substratum benthos associated with the turbine foundations (Chapter 13) will increase local productivity and biomass. By combining the data collected on the various ecosystem components we determine in this chapter how species richness, as a proxy for biodiversity, and biomass, as a proxy for productivity, have changed since the installation of the first offshore wind turbines. These changes are evaluated at different scales ranging from turbine footprint (for the three foundation types present) and a single wind farm concession area to the entire Belgian wind energy zone and the Belgian part of the North Sea.

RESEARCH STRATEGY

In the concession zone of the offshore wind farm at the Thorntonbank (Chapter 2), species richness and biomass and data of the following functional groups are collected: soft sediment epibenthos, soft sediment endobenthos and epifouling macrobenthos. Species richness data are collected for demersal, benthopelagic and hard substrate associated fish and squid. Hard substrate associated fish species are those species known to live predominantly on or near natural or artificial hard substrate. For information on the manner in which these data are collected we refer to their respective previous chapters in this book and earlier reports (Degraer et al., 2010, 2011, 2012).

A comprehensive species list (see also Annex 1) is compiled taking into account those species or taxa observed in the concession area prior to the construction of the first turbine foundations (baseline monitoring: 2005-early 2008) as well as those species or taxa observed in the concession area after to the construction of the first turbine foundations (impact monitoring: autumn 2008-2012). The year of first observance was determined as well as the fact whether this species was observed at multiple occasions, the latter as an indication for continued presence in the area. Species and congeners which could not be identified to the species level had to be combined on higher taxonomic levels to achieve a homogeneous taxonomic resolution among the different functional groups.

Biomass is expressed as ash free dry weight (AFDW) in autumn 2005 (baseline) and 2012 (impact). For the fouling community, data of 2011 are used since meteorologically adverse conditions prevented the autumn 2012 sampling. The first turbine foundations in Belgian waters were colonised by an extensive epifouling community within 3.5 months after installation (Kerckhof et al., 2009). For the purpose of this study, no significant order-of-magnitude differences with the 2012 biomass are expected since the hard substrate epifauna is collected from the concrete gravity based foundations (GBF) installed in 2008 and the colonisation and succession on the structures has stabilised in the last few years (Chapter 12). For endo- and epibenthos no AFDW data of 2009-2011 are used, as the majority of the turbine foundations in the wind farm area was installed only as late as 2011, and as such the data for 2008-2011 are not be considered representative. Total biomass on the turbine foundation and scour protection was calculated by multiplying the average biomass per m² by surface area of the respective depth zone (intertidal, submerged foundation, scour protection) and summing up the values from all depth zones (excluding the splash zone). For the intertidal zone, lacking quantitative samples, biomass data from Krone et al. (2013a) was used, since a similar *Mytilus edulis* dominated epifauna was observed. At the time of writing, no biomass data are available on the autumn fouling community on the more recently installed monopile and jacket foundations and therefore biomass data of the subtidal part of the GBF is used in the extrapolation of this data to monopile foundations. For jacket foundations, where a *Mytilus edulis* dominated subtidal epifauna was observed up to autumn 2013, biomass data from Krone et al. (2013a) was used.

Each of the foundation types (Figure 1) has a different footprint area on the seabed. For a single GBF, the initial type of foundation used on the Thorntonbank, the footprint of the concrete structure comprises 177 m². In addition, there is a scour protection surrounding the GBF comprised of an armour (median diameter of the stones of 350 mm) and filter layer (median diameter of the stones of 50 mm). These add respectively another 1866 m² and 376 m² to the total footprint of the structure (Peire et al., 2009). As such the total footprint area prior to construction is 2419 m². In the absence of a scour protection the footprints of the steel jacket foundations used on the Thorntonbank amount to 357 m² per foundation. One could even argue that during the operational phase the loss of sandy sediment is limited to only the four anchoring point with a total area of ~10 m². Two types of steel monopile foundations were used on the Bligh bank and the Lodewijkbank. We calculated the footprint of the latter since more of these have been installed. A total monopile footprint of 573 m² is comprised of 20 m² footprint of the steel structure and 553 m² of the scour protection.

After construction, distinct communities of epifouling macrobenthos were observed on the foundation in the splash zone, the intertidal zone, the subtidal part of the foundations, and also on the armour layer of the scour protection (Chapter 12). The filter layer of the scour protection was rapidly covered by sand. Due to the complex 3D nature of the armour layer it provides an estimated additional 65 032 m² of artificial hard substrate[1] at the GBF foundation. Per jacket foundation a total submerged substrate surface of 1280 m² is assumed (Krone et al., 2013a). For monopile foundations, the most common type of turbine present in the Belgian part of the North Sea, we used the dimensions of the monopile foundations present on the Lodewijkbank. An overview of the available surfaces is given in table 1.

The wind farm concession area on the Thorntonbank covers 19.83 km². The wind farm consists of 55 foundations: six GBF with scour protection, 48 jacket foundations without scour protection and one jacket foundation of the OHVS with scour protection (Bolle et al., 2012). The wind farm on the Bligh bank has used 56 monopile foundations and one jacket foundation in its phase 1, with up to 55 turbines yet to be installed during phase 2. In the wind farm on the Lodewijkbank 73 monopile foundations have been installed. In addition to these already constructed wind farms, four more were licensed with up to 315 additional turbines of which the foundation types are as yet uncertain.

[1] A volume of 1306 m³ of rocks was deposited with a layer thickness of 0.7 m. The top half of the layer (653 m³) is found to be consistently above the level of siltation throughout the monitoring period and as a result is colonized by hard substrate epifauna. Using the average surface to volume ratio as based on the recovered rocks (N=14) and an average interstitial space between the rocks of 40%, an area of 65032 m² of armour layer hard substrate is calculated.

Table 1. Overview of the newly available hard substrate surface area per structure for the three foundation types present in the BPNS. For the GBF the dimensions of the D5 foundation were used, for monopile dimensions of the structures installed at the Lodewijkbank were used. n.d. means not determined.

Foundation type	Vertical zonation				
	splash zone	intertidal zone	subtidal zone	scour protection	
				armour layer	filter layer
	Surface area in m²				
GBF (CP-D5)	62	76	671	1866	376
Jacket	n.d.	51	1280	0	0
Monopile (NW)	39	58	518	471	82

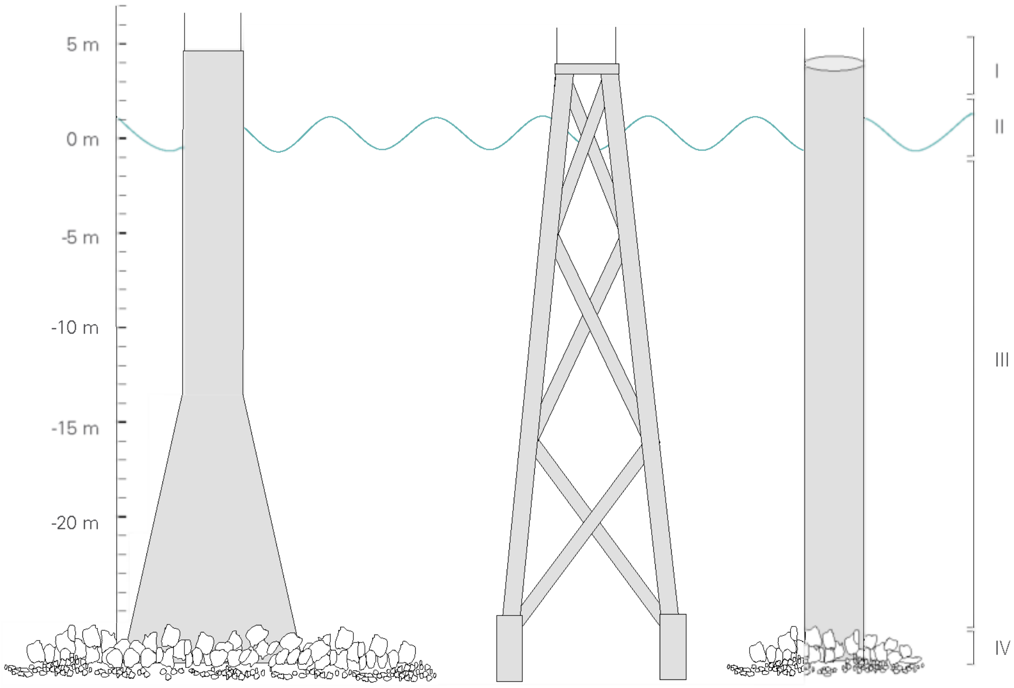


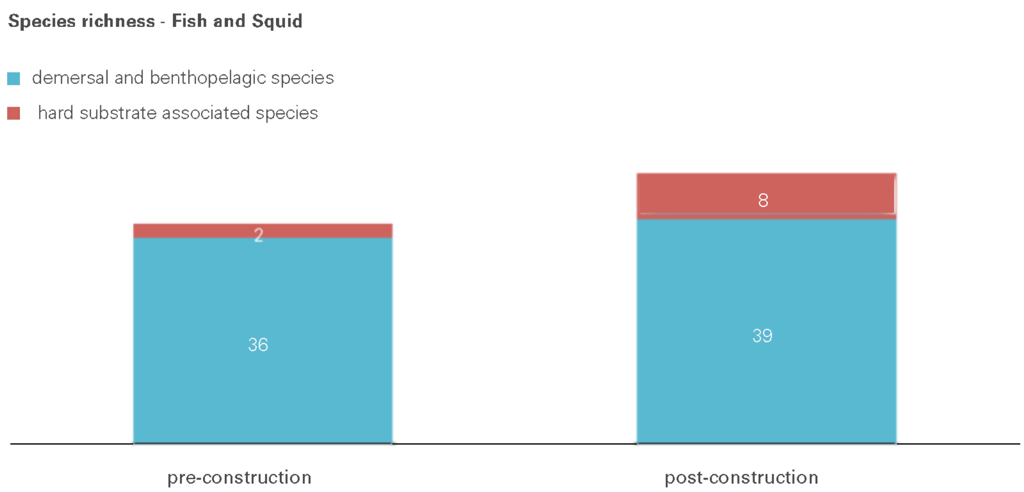
Figure1. Foundation types present in the Belgian part of the North Sea (from left to right: Gravity based, Jacket and Monopile foundation) with indication of the different fouling depth zones: I splash zone, II intertidal zone, III submerged foundation, and IV scour protection (if present).

SPECIES RICHNESS

A total of 44 fish species and four species of squid were observed in the wind farm area from 2005 to 2012 (Figure 2). Prior to the installation of the turbine foundations, 38 species were recorded including two hard substrate associated species: sea bass (*Dicentrarchus labrax*) and pouting (*Trisopterus luscus*). After the installation of the foundations the number of hard substrate associated fish species increased to eight with the addition of combtooth blennies (Blenniidae sp.), wrasses (Labridae sp.), lemon sole (*Microstomus kitt*), Atlantic pollock *(Pollachius pollachius)*, saithe (*Pollachius virens*), and black seabream (*Spondyliosoma cantharus)*.

Our results suggest that the species pool of fish and squid present in the wind farm area on the Thorntonbank has not undergone drastic changes. With a single exception (painted goby – *Pomatoschistus pictus*) all species observed prior to the installation of the turbine foundations are still present after the installation. The main difference observed is an increase in the number of hard substrate associated fish species (from 2 to 8). At Horns Rev, a Danish offshore wind farm located on a sandy seabed, a similar increase in reef habitat fish species was observed (Leonhard et al., 2013). It is unlikely that the limited increase in species richness of demersal and benthopelagic fish and squid species (from 40 to 43 species) is due to the exclusion of commercial fishing in the area since most of these species will not stay within a single wind farm concession area for longer periods (Lindeboom et al., 2011).

Figure 2. Species richness of fish and squid in the wind farm area prior and post construction of the (first) turbine foundations with distinction between demersal and benthopelagic species and hard substrate associated species.



A total of 285 benthic species were observed in the wind farm area from 2005 to 2012. Prior to the installation of the turbine foundations, 91 species were recorded, including ten hard substrate associated species (~11%). These hard substrate associated species were probably recovered from either shell fragments or coarser sediments. After the installation of the turbine foundations the number of hard substrate associated species increased to 100 out of 264 species observed in total (~38%). 83 species are recorded only once, of which respectively 21 and 62 were observed only before and after construction of the first turbine foundations.

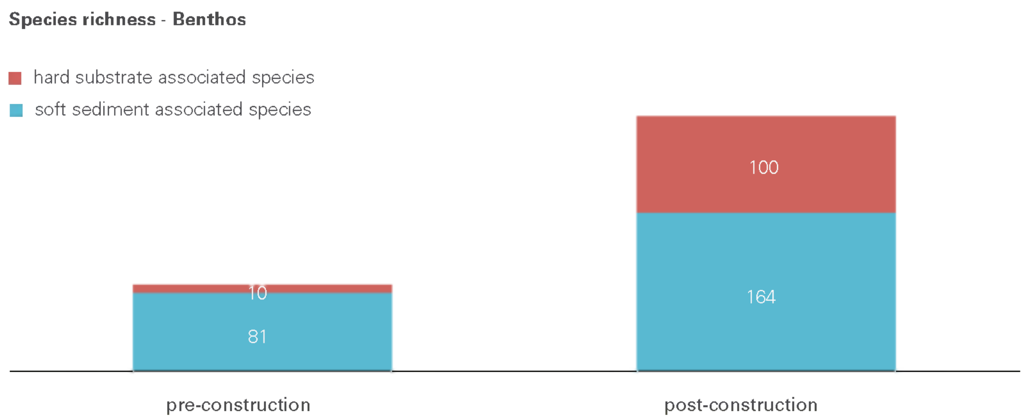
In contrast to the species of fish and squid, the number of benthic species observed in the concession area has more than doubled since the installation of the first turbine foundations (from 91 to 264, Figure 3). The number of hard substrate associated species has increased from 10 to 100. The large majority of the latter (90) were observed for the first time in the concession area after the installation of the foundations. These include both the dominant intertidal species, such as *Telmatogeton japonicus*, *Mytilus edulis* and, *Semibalanus balanoides*, as well as the dominant subtidal species, such as *Jassa herdmani*, *Tubularia* spp. and *Electra pilosa*. Prior to the installation of the turbine foundations, only shells and coarser sediments were available as substrate for such species.

Many of the species found in the area for the first time, had already been reported from elsewhere in the Belgian Part of the North Sea, for instance on shipwrecks. Both wrecks and turbine foundations provide patches of hard substrata in sea beds dominated by soft sediments. On these wrecks a total of 224 hard substrate associated species has been observed (Zintzen, 2007). As such it can be expected that the number of species typically associated with hard substrate will continue to increase in the wind farm zone in the coming years due to colonisation by additional species, a continuing increase in available habitat, expansion of this wind farm zone e.g. to include the gullies between the sand banks, and the ongoing sampling effort.

In addition to this, the number of soft sediment benthic species observed more than doubled, from 81 to 164. While the exclusion of commercial fishing in the area and the organic enrichment of the soft bottom sediments may account for part of this increase in species richness, it is likely that a post-construction increase in sampling effort plays a significant roll (number of epibenthic samples 2005-2008: 16 /2009-2012: 28, number of macrobenthic samples: 2005-2008: 60/ 2009-2012: 66). A clear shift in the benthic species composition of the soft sediments was only observed in the immediate vicinity of the foundations, where an accumulation of juvenile starfish (Asteriidae juv.) and opportunistic polychaetes such as *Spio* sp. and *Spiophanes bombyx* was observed (Coates et al., 2012). In the rest of the concession area the soft bottom benthic communities are still dominated by the same taxa as before (Chapters 9 & 10). 83 species out of a total of 285 benthic species ever registered in the area, were recorded only once. This indicates the low probability of encountering these species and may partly also be due to difference in taxonomic keys used by different reseachers. It is likely that this number will decrease as long-term monitoring continues and overall sampling effort increases.

Of the 333 taxa recorded including 44 fish and four squid species and 285 benthic species, only four were new for the Belgian part of the North Sea: *Fenestrulina delicia*, *Harmothoe antilopes*, *Molgula complanata* and *Polydora caulleryi* (Figure 4). All four hard substrate associated species are present in the surrounding UK, French and/or Dutch marine waters and the absence of records of these species in previous Belgian datasets may be indicative of the relatively poor knowledge of the fauna of the natural hard substrate rather than an extension of their geographical range. Additionally, four previously only once or rarely observed taxa were noted: *Thelepus setosus*, *Iphimedia nexa*, *Maja squinado* (spider crab) and *Homarus gammarus* (European lobster) (Figure 8).

Figure 3. Species richness of benthos in the wind farm area prior and post construction of the (first) turbine foundations with distinction between soft sediment and hard substrata associated benthos taxa.



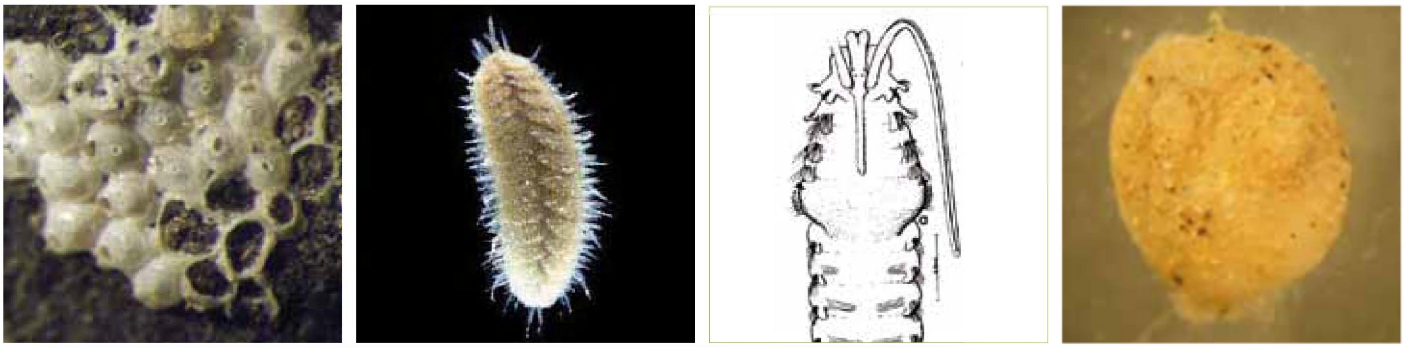
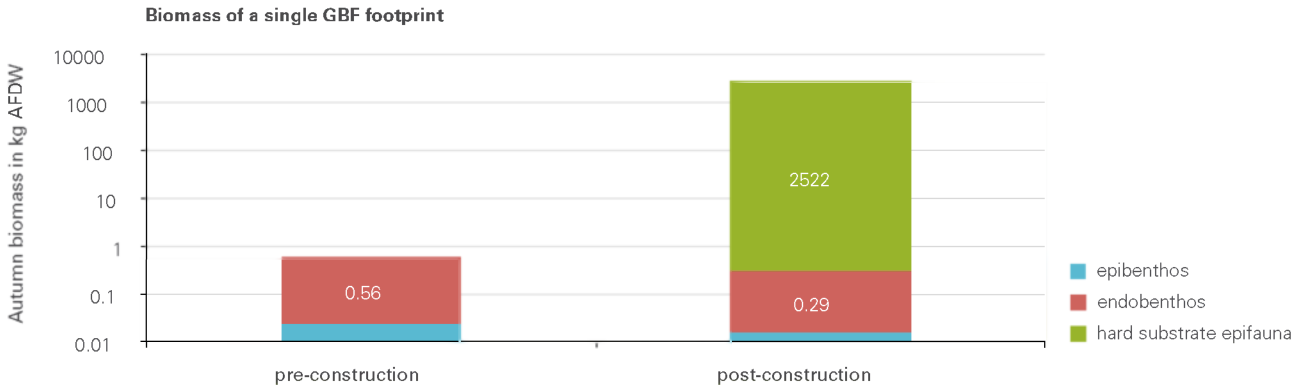


Figure 4. Species newly observed for the Belgian part of the North Sea. From left to right: the bryozoan *Fenestrulina delicia* (see also S.E.M. picture at the front of this chapter), the annelid worms *Harmothoe antilopes* and *Polydora caulleryi* (anterior end, drawing adapted from Blake, 1971) and the tunicate *Molgula complanata*

BIOMASS

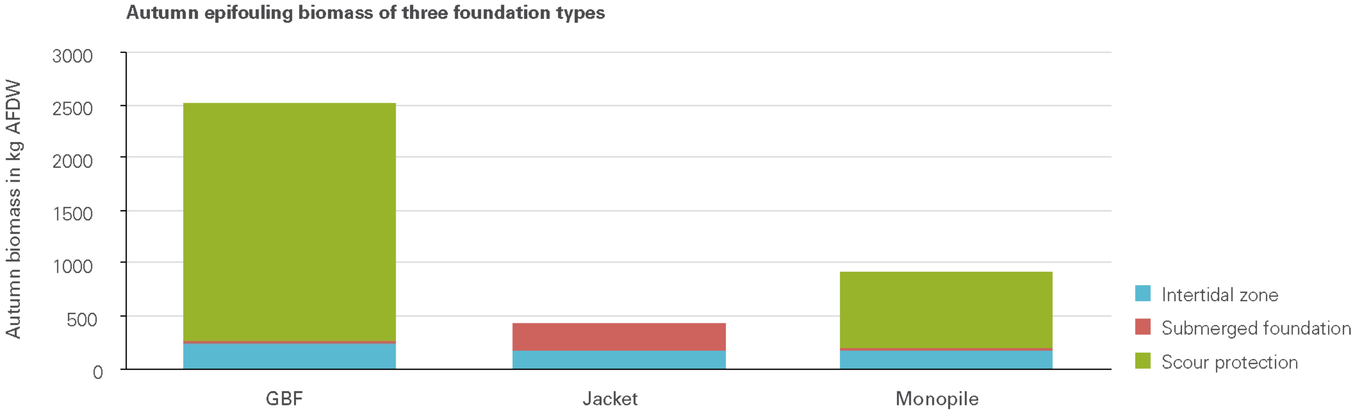
Autumn benthic biomass for a single GBF footprint increased ~4000 fold from 0.6 kg AFDW in 2005 (pre-construction) to ~2500 kg (post-construction) (Figure 5). For this particular foundation structure, the majority of the hard substrate epifaunal biomass was situated at the scour protection (89%) followed by the intertidal *Mytilus* zone (10%), with only the remaining (1%) located on the submerged part of the foundation. Epibenthos and endobenthos are assumed to have recolonized the silted filter layer (376.4 m²).

Figure 5. Autumn biomass prior (2005) and post (2012) construction of the offshore wind farm for the footprint of a single GBF.



Comparison of the calculated total autumn biomass for the three foundation types used in the BPNS shows that, despite a much higher subtidal area and a different fouling community, jacket foundations will have a lower epifouling biomass (Figure 6). The highest epifouling biomass is expected at the GBF, which has a sizable scour protection.

Figure 6. Calculated total autumn biomass (in AFDW) for a single concrete gravity based foundation (GBF), steel jacket foundation and steel monopile foundation present in the Belgian part of the North Sea.



For the entire Thorntonbank wind farm concession, with six GBF and 49 jacket foundations, the autumn biomass increased about 14 fold from 4.8 to 69.6 ton AFDW (Figure 7). Epibenthic and endobenthic biomass increased by 311 and 230% respectively. In contrast, epibenthic biomass in the reference area increased only by 1.3%. For endobenthos the increase falls within the boundaries of the inter-annual variation. In this wind farm the six GBF (with scour protection) account for a biomass comparable to that of 35 jacket foundations without scour protection (see also Figure 6).

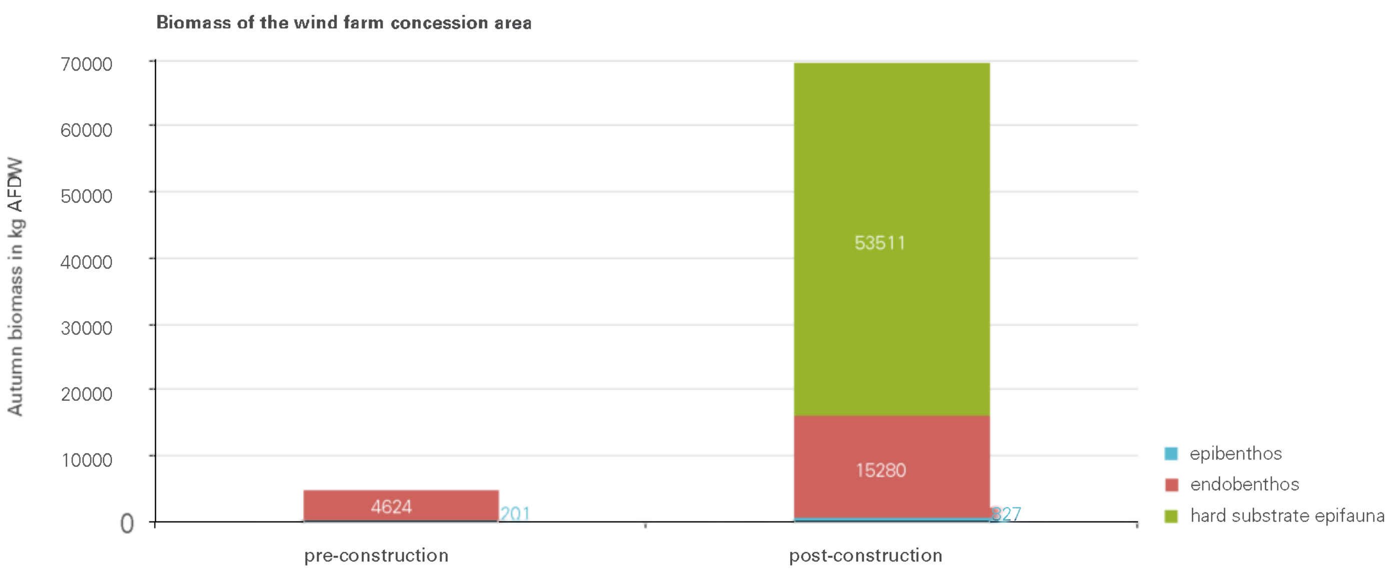
Zintzen et al. (2008b) estimated a mean epifauna biomass of 288 g AFDW m^{-2} for nine Belgian shipwrecks, with higher values for coastal sites with *Metridium senile* assemblages. In a Dutch study by Leewis et al. (2000) the average biomass of the *Metridium senile* assemblage was 1072 g AFDW m^{-2}. These values are higher than what we observed for epifauna biomass on the foundations (48 g AFDW m^{-2} for the submerged part of the GBF foundations. and 35 g AFDW m^{-2}. for the scour protection), with exception for the intertidal zone (3298 g AFDW m^{-2}). While these differences in values may in part reflect the difference in epifauna of a recently colonized offshore substrate and a coastal mature hard substrate community, we should also take into account the strong seasonal and interannual variations as we used data from autumn 2012 and both Zintzen et al. and Leewis et al used late spring to summer data.

Using the size of the seabed footprint of the different foundation types and the available surface of the respective structures, we calculated an epifauna biomass m^{-2} footprintof 1132 g AFDW m^{-2} for GBF,1230 g AFDW m^{-2} for jacket foundations, and 1603 g AFDW m^{-2} for steel monopile foundations. This is much higher than the soft sediment biomass of 0.8 g AFDW m^{-2} as measured in the concession zone. In general soft sediment macrobenthos biomass values for the southern North Sea are around 10 g AFDW m^{-2} (Duineveld et al., 1991, Heip et al., 1992), with higher values in the coastal *Abra alba* community (30-50 g AFDW m^{-2}, Prygiel et al., 1988).

Our results show that for the entire Thorntonbank wind farm concession area autumn biomass increased about 14 fold. While this biomass estimate is based on an extrapolation of a limited number of samples, and as such can be considered a very rough estimate, it remains valid to conclude that there is an order of magnitude increase in biomass for the entire concession area – as is observed in other countries (Lindeboom et al., 2011, Krone et al., 2013a, Birklund, 2006). This increased biomass serves as a food resource for the fish species and -indirectly - bird species found to aggregate or forage near the artificial hard substrate. This is illustrated by the large numbers of *Trisopterus luscus* (pouting) and *Gadus morhua* (Atlantic cod) observed near these structures both of which are known to feed on *Jassa* spp.(Reubens et al., 2011 and 2013d). Preliminary results also suggest that several bird species are attracted to the Thorntonbank area, including species with high protection status such as *Sterna sandvicensis* (Sandwich Tern), *Sterna hirundo* (Common Tern) and *Hydrocoloeus minutus* (Little Gull) (Vanermen et al., 2012, Chapter 15). As yet no attraction for marine mammals can be observed (Chapter 16) but this may be the result of ongoing construction activities in nearby concession areas, a type of disturbance that is expected to go on intermittently up to 2018.

In contrast to Dutch (Lindeboom et al., 2011), Danish (Birklund, 2006) and German (Krone et al., 2013*a)* offshore foundations as well as the Belgian jacket foundations, only a fairly thin portion of the GBF and monopile foundations is covered by *Mytilus edulis* (blue mussel), resulting in a lower epifaunal biomass for the submerged part of the foundation compared to the intertidal zone and scour protection. On the foundations of the Horns Rev wind farm, *Asterias rubens* (common starfish) played a role as key predator in preventing a "mussel monoculture" from developing (Leonhard & Birklund, 2006). This may also be the case here as seasonally high densities of *A. rubens* have been observed from the GBF (Kerckhof et al., 2010b) and surrounding soft sediments (Coates et al., 2012).

Figure 7. Calculated autumn biomass (in AFDW) prior (2005) and post (2012) construction for the entire Thornton-bank wind farm concession area.



FUTURE MONITORING

We expect that, due to the further development of the Belgian wind energy zone, the number of hard substrate associated species present in an area previously characterised by soft sediments will increase. Furthermore, the exclusion of fisheries activities in the area is expected to allow a number of benthic species sensitive to disturbance to recover or recolonize. However, these artificial hard substrate do not provide a long term solution for the preservation or restoration of the fauna of the threatened natural boulder fields and oyster banks since they harbour a different epifaunal community (Kerckhof et al., 2012) and have a relatively short expected lifetime (~20-30 years).

Our results demonstrate that there is a spectacular increase in biomass as a result of the development of fouling on the foundations and associated scour protection. Since the largest part of this fouling biomass is situated on the scour protection and the presence and extent of the scour protection is largely related to the type of foundation, the impact of the further development of the entire Belgian wind energy zone (with seven wind farms with a total of 446-530 turbines licensed) will be largely dependent of the foundation types chosen. Depending on the type of foundation chosen, roughly between 1078 (all new foundations GBF – total footprint 0.93 km²) and 272 (all new foundation jacket – total footprint 0.20 km²) ton of fouling AFDW could be added to the Belgian part of the North Sea[2] resulting in the maximal addition of circa 3% of the total biomass from the BPNS[3].In comparison, all shipwrecks on the BPNS together represent a footprint between 0.85 km² and 1.49 km² and were calculated by Zintzen (2007) to increase the soft sediment biomass of the BPNS by a maximum of 4%. Future monitoring will determine whether our assumptions with regards to the fouling biomass on the jacket and monopile foundations are valid.

If the objective is to preserve the soft sediment fauna characteristic of the area, than licensing should focus on minimising the amount of artificial hard substrate introduced to zone i.e. allowing only jacket type foundations. If, on the other hand, the objective is to combine renewable energy development with the promotion of a number of hard substrate associated commercial species such as Atlantic cod (Reubens et al., 2013a), European lobster and edible crab, than introduction of sizable artificial hard substrates may be beneficial although this will need to be confirmed by studies on their residence periods, food and shelter requirements.

[2] Simplified extrapolation taking into account the already installed foundations and assuming similar foundation dimensions and fouling development for the entire wind energy zone. While both assumptions are clearly false (see e.g. Zintzen et al., 2008b) they do allow for a rough order-of-magnitude estimate.

[3] Assuming an average value of 10 g AFDW m $^{-2}$ for the BPNS (as in Duineveld et al., 1991; Heip et al., 1992)

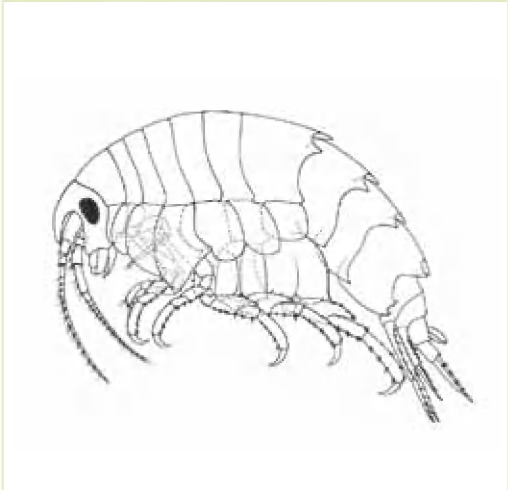


Figure 8. Species only once or rarely encountered in the Belgian part of the North Sea prior to the construction of the offshore wind farm: *Thelepus setosus*, *Iphimedia nexa*, *Maja squinado* (spider crab) and *Homarus gammarus* (European lobster).