

CHAPTER 7

ABOUT “MYTILISATION” AND “SLIMEIFICATION”: A DECADE OF SUCCESSION OF THE FOULING ASSEMBLAGES ON WIND TURBINES OFF THE BELGIAN COAST

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Abstract

In this contribution we describe the three succession stages of the subtidal fouling assemblages at two types of offshore wind turbines (*i.e.* gravity-based and monopile foundation) off the Belgian coast in the first decade after the installation. Installation of the turbine foundations was followed by rapid colonisation and a relatively short pioneer stage (~2 years) which differed between locations. At both locations, this was followed by a more diverse intermediate stage characterised by large numbers of suspension feeders. A third, and possibly “climax” *Metridium senile*-dominated stage, was reached after 10 years on the gravity-based foundations, while the assemblage on the steel monopiles of the more offshore site (9 years after construction) was described as an *M. senile*-*Mytilus edulis*-co-dominated assemblage. This study suggests that earlier reports on offshore wind turbines as biodiversity hotspots should be considered with caution as these reports generally refer to the typical species-rich second stage of succession reached after a few years of colonisation but disappearing later (after about 6 years in this study). Our results underline that artificial hard substrata differ greatly from the species-rich natural hard

substrata and hence cannot be considered as an alternative for the quantitatively and qualitatively declining natural hard substrata such as gravel beds.

1. Introduction

Aside from natural hard substrata, there are numerous man-made hard substrata in the North Sea, such as wrecks, oil rigs and wind farms (*e.g.*, Zintzen *et al.* 2008; Coolen 2018). Today, these substrata are ever more prominent features in shelf ecosystems. That evolution, known as the hardening of the coast (Wolff 1999), started in the XVIth century with the construction of coastal defence and harbour structures. Initially, the hardening of the coast remained largely restricted to the coastal zone. That changed with the construction of oil and gas rigs further offshore when semi-permanent man-made structures were installed in the open sea. More recently, the open sea witnessed a further increase in man-made structures due to the proliferation of offshore wind farms (OWFs) and other marine infrastructures in response to the increasing demand of renewable energy (*e.g.*, Mineur *et al.* 2012; Causon & Gill 2018).

All these submerged man-made structures are rapidly colonised by fouling organisms (Horn 1974; Connell & Slatyer 1977; Kerckhof *et al.* 2009, 2010, 2012) that successively develop assemblages which may or may not resemble epibioses of natural hard substrata (Connell 2001; Wilhelmsson & Malm 2008; Svane & Petersen 2011; Kerckhof *et al.* 2017). In the case of OWFs, both the foundations of the turbines and the erosion protection surrounding them form hard permanently submerged substrata on which species can settle. Thus, in the Southern North Sea – a region that is mostly characterised by sandy sediments –, the wind turbines introduced a new habitat of artificial hard substratum that has enhanced the habitat heterogeneity of the region (Kerckhof *et al.* 2009; 2010). The effects of the introduction of these hard substrata – the so-called reef effect – is regarded as one of the most important changes of the marine environment caused by the construction of offshore wind farms (Petersen & Malm 2006).

Like natural hard substrata, also artificial hard substrata are often reported as hosting a lush epifouling community. The creation of new habitats increases the habitat diversity, which in turn increases species diversity, and artificial hard substrata are thus often considered hotspots of biodiversity (Wolff 1999). In fact, artificial hard substrata have recently been put forward as a possible alternative for the loss of natural hard substrata habitat and their installation has been proposed as a measure to strengthen biodiversity *e.g.*, plan Zeehond (Vande Lanotte *et al.* 2012) or to offset the negative environmental impacts of OWF construction (Veraart *et al.* 2017).

Contrary to newly exposed landforms where succession may take several hundreds of years, the succession of animals and algae on recently denuded rock walls in the marine subtidal zone takes less time, approximately a decade (Hill *et al.* 2002; Whomersley & Picken 2003). However, few studies of the development of fouling assemblages on large

hard substrata over a longer time period (*i.e.* a decade or more) exist. Much of the information forming the documenting biodiversity at artificial hard substrata in the North Sea hence is derived from one-off sampling events or short-term time series (Vanagt *et al.* 2013, 2014) often providing contradicting views on biodiversity and hence focusing on the high species richness compared to surrounding soft sediments (Leonhard & Pedersen 2006; Lindeboom *et al.* 2011). Short-term time series indeed typically reference the high species richness at *e.g.* OWFs (Kerckhof *et al.* 2009, 2012; De Mesel *et al.* 2015).

The aim of this paper is to study the longer-term dynamics of the macrobenthic fouling assemblage on the first offshore wind turbines that were installed in Belgian waters. This study provides context for one-off sampling events and short-time series results.

2. Material and methods

We investigated the early stage, short-term and longer-term dynamics of the macrobenthic fouling assemblage at two OWFs in the Belgian part of the North Sea (BPNS), focusing on the establishment of new species and the successional trend of those species that, at any stage of the succession, were observed to be superabundant on the Marine Nature Conservation Review SACFOR abundance scale (Hiscock & Connor 1991).

2.1. Study site and sampling locations

We collected hard substrata subtidal macrofauna from the foundations of two OWFs, C-Power and Belwind, both located in the Belgian offshore renewable energy zone (see chapter 1). In the Belwind wind farm, situated on the Bligh Bank at about 50 km offshore and entirely located in the clear English Channel's water (M'harzi *et al.* 1998), wind turbines were installed on steel monopile foundations. The C-Power wind

farm (6 concrete gravity-based foundations (GBFs) and 48 steel jacket foundations) is located on the Thornton Bank, some 30 km off the Belgian coast in waters transitional between the more turbid coastal and clear offshore waters. Both banks belong to the Zeeland Banks system (Cattrijsse & Vincx 2001).

The samples were collected from a selected set of wind turbine foundations: 2 GBFs (D5 and D4; C-Power wind farm, installed respectively on the 30th and 24th of May 2008) and 3 steel monopile foundations (BBB8, BBC8 and BBC2; Belwind wind farm, installed respectively on the 21st and 24th of October and on 14 December 2009), this because access to the same foundation was not always possible due to *e.g.* maintenance works. In this study, the data from both GBF foundations and all three monopile foundations were considered equally representative for location and type of foundation, and were hence pooled in the database to GBF foundation and monopile foundation.

2.2. Sampling and sample processing

Sampling started shortly after the installation of the turbines *i.e.* first sampling in September 2008 for the GBFs (start: 164 days after installation; 10 years' time series) and in February 2010 for the monopiles (start: 181 days after installation; 9 years' time series). The last sampling event included in this analysis took place in August 2018. Samples are missing for 2012, 2016 and 2017.

Scuba divers collected the subtidal scrape samples from the foundations by scraping three replicas of the fouling organisms from a square sampling surface area of 6.3 dm² (Kerckhof *et al.* 2010, fig. 1). Samples were collected at -15 m, which is considered representative for the assemblages in most of the subtidal part of the foundations (Kerckhof *et al.* 2010). In order to exclude seasonal variability in the data and hence focus on the year-to-year variability in the fouling assemblages, only samples

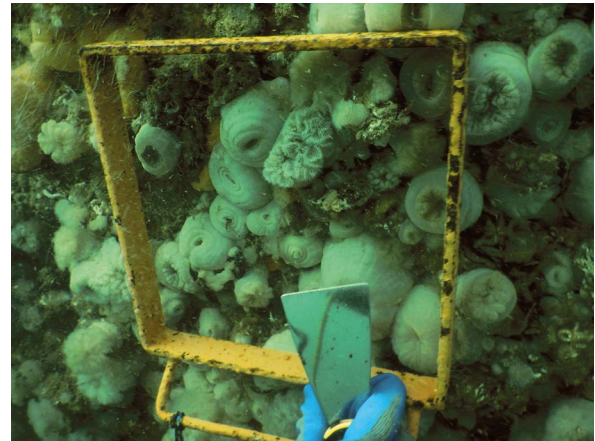


Figure 1. Sampling square and scraper at the BBC02 monopile (August 2019). Note the presence of *Mytilus edulis* clumps in between and under *Metridium senile*.

that were collected in late summer and autumn (August–November) were included in the analysis.

The scraped material was collected in plastic bags that were sealed, preserved in buffered formalin 10% and transported to the laboratory for further processing: sieving over a 1 mm sieve and sorting. Individual organisms were sorted and identified to the lowest taxonomic level possible (mostly species level; further called “species”) using a stereoscopic binocular microscope. Density was determined for countable species, while percentage cover was assessed for the uncountable colonial crust forming and erect (bushy) epifaunal species such as hydrozoans, bryozoans and sponges. All data were transformed to the SACFOR scale to allow for integrating relative abundances of countable and uncountable species (Connor & Hiscock 1996).

2.3. Data analysis

For the sake of investigating trends in successful coloniser arrival, we considered a new species established (*i.e.* successful new colonisation) when the species was first detected in year *x* and also found in subsequent years. As such, we maximally exclude bias caused by the erratic and hence less reliable

observations of rare species. Both countable and uncountable species were included.

To investigate species turnover in the assemblages, we focused on the most numerically abundant species, being those that have been scored superabundant (cf. SACFOR scale) at least once in the time series; this either for GBFs and monopile foundations. This resulted in a list of 13 species, eleven of which being countable, and only two being uncountable. Among the countable species, the Echinodermata dominated with four species (*Asterias rubens*, *Amphipholis squamatus*, *Ophiothrix fragilis*, *Psammechinus miliaris*) followed by three Amphipoda (*Jassa herdmani*, *Stenothoe* sp., *Monocorophium acherusicum*), two Polychaeta (*Phyllodoce mucosa*, *Spirobranchus triqueter*) and finally, one bivalve mollusc (*Mytilus edulis*) and one hydrozoan (*Metridium senile*). The uncountable species were *Electra pilosa*, a bryozoan, and *Tubularia indivisa*, a hydrozoan. Per countable species and per type of foundation, absolute densities were relativised to the maximum density recorded for that species in any of the samples (*i.e.* normalised density); this to be able to visualise the successional patterns of the different species irrespective of their absolute densities. The succession of uncountable species was presented using the SACFOR scale.

3. Results

On both GBFs and monopiles, successful new colonisers clearly dominated over non-successful newcomers only in the first 3-4 years (fig. 2), with year 5 being a transition year, because successful new arrivals did not (or hardly) occurred in years 6 and beyond. For both foundation types, overall species numbers declined after the fifth year. After the fifth year, the number of species per sample was higher on the monopiles than on the GBFs, where the increasingly dominating presence of *M. senile* coincided with a species-poor assemblage. On the monopiles, large clumps of *M. edulis* and a few other species coexisted with *M. senile*.

The colonisation of the most numerically abundant countable species shows a similar pattern on both foundation types, with a similar suite of species involved. Looking at those species that were observed to be superabundant, we can distinguish three stages in the succession, each characterised by certain specific species (figs 3 & 4, table 1). A pioneer stage of about two years was characterised by a number of opportunistic species and differed markedly between foundation types. In the intermediate stage between years 3 and 6, several types of suspension feeders became superabundant including

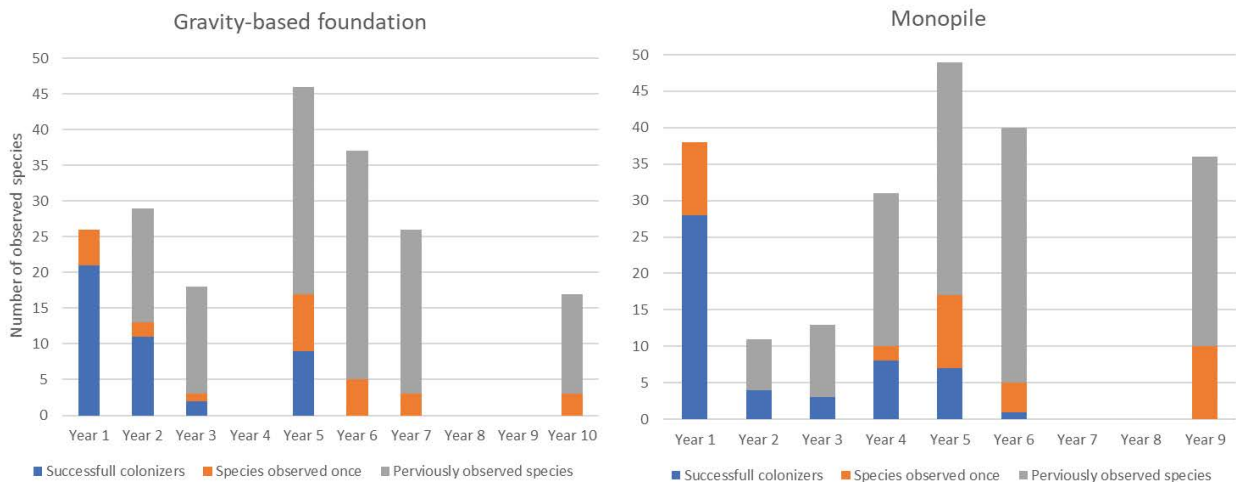


Figure 2. Total number of species observed per year, distinguishing between successful new coloniser arrivals (*i.e.* species first detected in year x and also found the subsequent years: blue), non-successful new arrivals (*i.e.* species first detected in year x and not found in subsequent years: orange), and previously observed species (*i.e.* species detected in year x and also found in a previous year: grey).

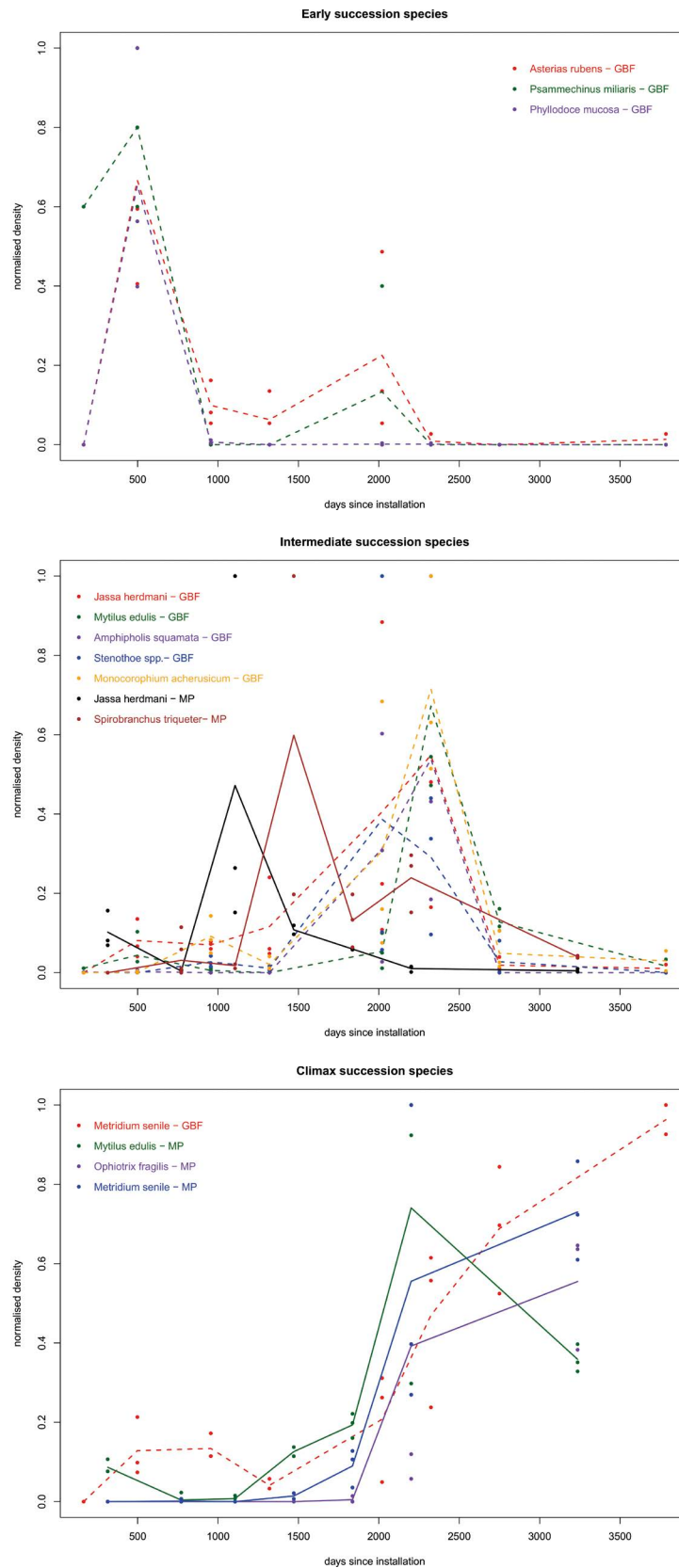


Figure 3. Succession stages and species turnover on the gravity-based foundations (GBF; dashed lines, ~ 10 years) and the monopile foundations (MP; full lines, ~ 9 years). Normalised density: per species and per type of foundation, absolute densities were relativised to the maximum density recorded for that species in our time series.

Table 1. List of superabundant epifouling species per foundation type with an indication of when these epifouling species were superabundant on the turbine foundations

Succession stage	Monopile	GBF
Stage 1: Pioneer (y 1 & 2)		
	<i>Jassa herdmani</i>	<i>Jassa herdmani</i>
		<i>Electra pilosa</i>
		<i>Psammechinus miliaris</i>
		<i>Asterias rubens</i>
		<i>Phyllodoce mucosa</i>
Stage 2: Intermediate (y 3-5)		
	<i>Jassa herdmani</i>	<i>Jassa herdmani</i>
	<i>Tubularia indivisa</i>	<i>Tubularia indivisa</i>
	<i>Spirobranchus triqueter</i>	<i>Mytilus edulis</i>
		<i>Monocorophium acherusicum</i>
		<i>Amphipholis squamata</i>
		<i>Stenothoe sp.</i>
Stage 3: "Climax" (from y 6 onwards)		
	<i>Metridium senile</i>	<i>Metridium senile</i>
	<i>Mytilus edulis</i>	
	<i>Ophiothrix fragilis</i>	

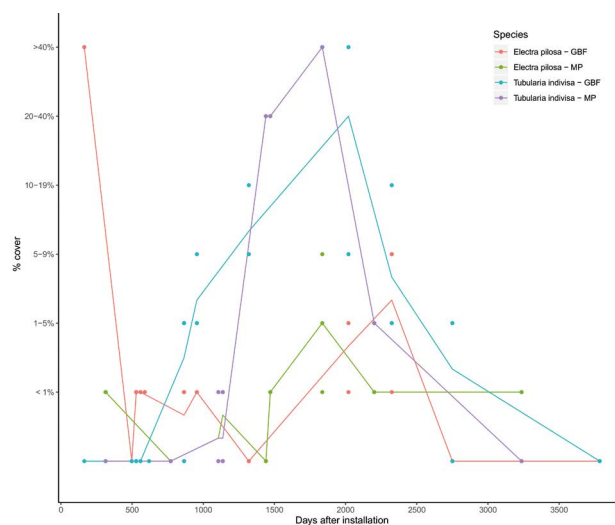
amphipods, bivalves, hydrozoans and polychaetes. From approximately the 6th year onwards, there is a third stage in which only a few species dominate (table 1).

4. Discussion

4.1. Successional stages

The establishment of a biofouling community follows a clear successional development, as

the newly available structures are gradually colonised by several species. These organisms will each influence the environment in a species-specific way, as such preventing other organisms to get established (*i.e.* inhibition, *e.g.* *M. senile*) or creating the right circumstances for other species to settle (*i.e.* facilitation, *e.g.* *Tubularia* sp., *M. edulis*; Connell & Slatyer 1977). During our survey, new species arrivals and the disappearance of other species continuously modified the

**Figure 4.** Percentage cover per sample of *Electra pilosa*, a bryozoan, and *Tubularia indivisa*, a hydrozoan, on the gravity-based foundations (GBF; ~ 10 years) and the monopile foundations (MP; ~ 9 years).

assemblage, as suggested by Underwood and Chapman (2006). Three stages could be identified: an early colonisation stage, a species-rich intermediate stage and a *M. senile*-dominated or *M. senile*-*M. edulis*-co-dominated mature stage here called "climax" stage.

Succession started with a swift colonisation by early colonisers (first stage of succession). As previously discussed by Kerckhof *et al.* (2010, 2012), this pioneer stage, of about two years, was characterised by a number of opportunistic species. Its species composition differed markedly between foundation types which may be explained by both the difference in timing of installation (GBF: late spring; monopile: autumn-winter) and geographical location of the foundations (with the GBF located in coastal waters and the monopiles located in more clear Channel waters) resulting in a different species pool of spores and larvae available for colonisation.

Despite initial differences in the intermediate stage, a convergence towards a common assemblage dominated by the same suspension feeders was achieved. This conforms with the results of Pacheco *et al.* (2011) who studied succession of sessile biota in sublittoral rocky shore communities and demonstrated that, although seasonality generates high variability during early colonisation process, this effect diminishing as succession proceeds.

Most of the first colonisers persisted during the subsequent years, but with a decreasing trend in their abundance as succession proceeded. However, several of these *e.g.* *Spirobanchus*, *Jassa herdmani*, *Electra pilosa* showed a second peak (figs 3 & 4), likely related to the presence of keystone habitat modifiers species *sensu* Coolen *et al.* (2018), *in casu* *M. edulis* and *Tubularia* sp. *Jassa herdmani* could indeed have been facilitated by the presence of *Tubularia* sp. offering complex 3-dimensional structures, home to many associated species by offering addition

substrata to settle (Zintzen 2007; De Mesel *et al.* 2015; Coolen *et al.* 2018). This facilitation effect could also apply to *Stenothoe* sp. and, to a lesser extent, *Monocorophium acherusicum*.

In the last stage, and especially apparent during the latest sampling event, the plumose anemone *M. senile* dominated the species assemblage on both GBF and monopiles; this at the expense of most other fouling species. Because the prominent presence of *M. senile* on the GBFs was already apparent in the earlier stage of the GBF succession series, the development towards a species-poor *M. senile*-dominated biotope was already suggested before (De Mesel *et al.* 2015).

4.2. *Metridium senile* effect

Due to its large body size, the plumose anemone constitutes a conspicuous part of the subtidal community everywhere in the Southern North Sea where it appears, which is especially noticeable on artificial hard substrata such as wrecks (Van Moorsel *et al.* 1991; Zintzen 2007) and buoys, but also on (disturbed) natural hard substrata (*e.g.* Coolen *et al.* 2015; own observations).

Metridium senile is a strong competitor for space that can have a strong structuring effect onto the fouling community by rapidly colonising new substrata, covering large areas, preventing other species' propagules to settle, consuming free-living larvae and smothering new recruits (Nelson & Craig 2011; Kaplan 1984). With other predators lacking or occurring in low numbers (such as the sea spider *Pycnogonum littorale* (Wilhelm *et al.* 1997) or *Epitonium clathratulum*, respectively), *M. senile* can be seen as both a keystone predator and a keystone modifier on artificial hard substrates in the North Sea (Coolen *et al.* 2018).

The establishment of a species-poor assemblage dominated by Actiniaria, as it was the case on the GBFs, is a common feature on man-made substrata in the North Sea.

The *M. senile* biotope, *sensu* Connor *et al.* (2004), is often the characteristic final state for this type of substrata in the North Sea.

4.3. The *Metridium* – *Mytilus* stage

There was a difference in the “climax” assemblages between GBFs and monopiles. When the samples came on board during the last sampling event, we observed that the sea anemones all lived attached to adult blue mussels *M. edulis*, often occupying both valves of the shells. They were not directly attached to the surface of the monopiles, while on the GBFs the sea anemones lived directly attached to the concrete surface of the piles. The association of mussels with *M. senile*, although not commonly observed in the North Sea (see above), is also known from areas beyond the North Sea, *e.g.* from Shark River along the New Jersey US East coast (Kaplan 1984).

Due to the presence of aggregates of large mussels, the species diversity on the monopiles was higher in the “climax” stage than the species-poor *M. senile*-dominated GBFs. Mussels *M. edulis* create complex aggregates that increase habitat heterogeneity resulting in increased species richness (Drent & Dekker 2013; Coolen *et al.* 2018). Indeed, many *Ophiothrix fragilis* lived between the mussels on the monopiles while the shells on their turn added additional hard substratum surface suitable for other species to settle and live, such as *M. acherusicum*, *J. herdmani* and *S. triqueter*, but also *M. senile*. *Mytilus edulis* can therefore be considered as another keystone habitat modifier (Coolen *et al.* 2018).

During the initial succession stages, mussels were almost absent from the subtidal (Kerckhof *et al.* 2009, 2010). In contrast, a conspicuous blue mussel *M. edulis* belt had developed in the intertidal and shallow subtidal zone already during the early stages of colonisation (*e.g.* De Mesel *et al.* 2015). Observations of blue mussels in subtidal samples gradually increased throughout the

years, not as spat nor young mussels but already as adults (Kerckhof, unpublished data). Likely, the adult mussels – being semi-mobile organisms – had moved down from the intertidal mussel belt. Subsequently, this mussel belt gradually expanded to greater depths and extended to the deepest subtidal as individuals moved downwards in a natural thinning process (*e.g.* Hughes & Griffiths 1988).

A similar situation of co-dominance of *M. edulis* and *M. senile* was seen at the monopile foundation after about nine years of colonisation and was also detected in GBF samples collected in the years prior to the *M. senile*-dominated stage, which corresponds to about nine years of colonisation at the GBFs. We argue that the co-dominance of *M. edulis* and *M. senile* may hence represent a transitional stage that will ultimately lead to a pure *M. senile*-dominated assemblage. Once these large mussels die off, *M. senile* may be able to fully occupy the free space and hence block further colonisation opportunities for adult mussels and propagules of other organisms. The mytilisation *sensu* Krone *et al.* (2013) and observed in other studies might hence represent only a transitional stage towards a pure *M. senile*-dominated stage common in the deeper waters on man-made structures. In the short-term, however, the presence of *M. senile* could be considered beneficial to *M. edulis* as the presence of *M. senile* on the valves of *M. edulis* has been shown to significantly reduce mussel predation by starfish (Kaplan 1984).

Why artificial hard substrate epifaunal communities tend to evolve towards a species-poor anemone-dominated community is yet to be proven. As for shipwrecks, specific features of the wind turbines such as verticality, spatial patchiness, unnatural substratum composition and/or the lack of microhabitats may explain the specific community structure typified by an impoverished epifauna compared to the surrounding natural hard substrata (Svane & Petersen 2001; Chapman 2003).

5. Conclusion

We revealed that, as suggested by De Mesel *et al.* (2015), the subtidal community on the wind turbine foundations in the BPNS develops towards a species-poor *M. senile*-dominated biotope *sensu* Connor *et al.* (2004). In our study, a relatively short pioneer stage (~ 2 years) was followed by a more diverse intermediate stage characterised by large numbers of suspension feeders. A third and possibly "climax" stage has been reached after about 10 years on the GBFs of the C-Power site, while the assemblage on the monopiles of the Belwind site after only 9 years of colonisation may be seen as a transient *M. senile*-*M. edulis*-co-dominated assemblage that may ultimately evolve to the same species-poor *M. senile*-dominated biotope as on the GBFs. This study suggests that earlier reports on offshore wind turbines as biodiversity hotspots may be considered premature; this because the reports generally refer to the typical species-rich intermediate stage of succession reached after a few years of colonisation but disappearing later on (about 6 years in this study). Our results underline that artificial hard substrata strongly differ

from the species-rich natural hard substrata and hence cannot be considered an alternative for the quantitatively and qualitatively declining natural hard substrata such as the gravel beds in Belgian waters.

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