CHAPTER 8

BLUE MUSSEL *MYTILUS EDULIS* AS HABITAT PROVIDER ON OFFSHORE WIND TURBINE FOUNDATIONS

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Abstract

We compare the species composition of the early (mussels not prevalent) and mature (mussels prevalent) subtidal colonizing communities at offshore wind turbine foundations with special attention to the mobility and habitat preferences of the colonizing species. We identified 47 species belonging to nine different phyla from the samples of the mature community, including 21 species unique to the secondary substratum provided by the mussel shell, all of them are sessile species. Only 17 of the 37 species identified from the early subtidal colonizing community were present in the mature community. The main phyla present in both the early and mature samples were Mollusca, Arthropoda, and Annelida.

Our findings confirm the hypothesis that mussels counteract the impoverishment of total species richness on wind turbines, caused by the abundant presence of *Metridium senile* in mature artificial hard substratum communities by providing secondary substratum for colonization by. sessile and hemi-sessile epifauna. The species assemblage found on these mussels is different from the one previously found on the piles, and only seven-teen species (~36%) present in the mature community were already present in the first year after installation. In 2020, all bryozoan species (7) were exclusively observed on the secondary substratum provided by the shells of the mussels. However, these species were previously encountered on the scour protection or on the shells of other bivalves. This may be due to the fact that the secondary substratum provided by the mussels differs in physical properties (e.g., microhabitat complexity) from the primary (vertical) substratum of the pile.

1. Introduction

Offshore wind turbine foundations, like all submerged man-made structures, are rapidly colonised by fouling organisms (Degraer *et al.* 2020) that successively develop assemblages which may or may not resemble epibioses of natural hard substrata (Kerckhof *et al*. 2017). The effects of the introduction of artificial hard substrata on the surrounding marine environment – the so-called artificial reef effect – is considered as a major effect caused by offshore wind farms (Petersen & Malm 2006). In 2019, we described three succession stages of the

subtidal fouling assemblages at two types of offshore wind turbine foundations (i.e., concrete gravity-based and steel monopile foundation) off the Belgian coast in the first decade after the installation (Kerckhof *et al.* 2019). Installation of the turbine foundations was followed by rapid colonization and a relatively short pioneer stage (~2 years), a more diverse intermediate stage characterised by large numbers of suspension feeders, and a third *Metridium senile*-dominated stage, which was reached after 10 years on the concrete gravity-based foundations, whereas the assemblage on the steel monopiles of the more offshore site was co-dominated by *M. senile* and *Mytilus edulis*.

Metridium senile is a strong competitor for space and can have a strong structuring effect on 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 (Kaplan 1984; Nelson & Craig 2011). On natural reefs in the Dutch North Sea *Metridium*-dominated samples were found to be relatively low in species richness compared to samples with low numbers of *Metridium* (Coolen *et al*. 2015, 2018). At the offshore wind farms, a strong reduction in species richness (> 50% reduction compared to earlier stages) was, however, only observed in the *M. senile*-dominated assemblages on the deep subtidal part of the concrete gravity-based foundations (De Mesel *et al*. 2015; Kerckhof *et al*. 2019). The fact that no such reduction was observed on the steel monopiles studied here, may be due to the presence of large (> 5 cm) *M. edulis*. Mussels are known to increase habitat heterogeneity by providing secondary substratum (Tsuchiya & Nishihira 1985; Albrecht & Reise 1994), creating interstitial cavities (Yager *et al*. 1993) and functioning as a sediment trap (Yager *et al*. 1993). Habitat modification by *M. edulis* has often led to very diverse assemblages on hard substrata (Suchanek 1985; Tsuchiya & Nishihira 1985; Lintas & Seed 1994).

In this study, we focus on the effect of blue mussels *M. edulis* on the epifaunal species diversity at the vertical parts of the turbine foundations in an offshore wind farm located in shallow coastal waters in the southern North Sea. We hypothesize that blue mussels counteract the local impoverishment of species richness caused by the abundant presence of *Metridium senile* in mature artificial hard substratum communities because the living mussels provide secondary substratum for colonization by attached (i.e., sessile and hemi-sessile) epifauna. Secondly, we hypothesize that the species found on these mussels would also be different from those previously found on the piles because mussels do not only provide secondary substratum but also differ in physical properties (e.g., microhabitat complexity) from the primary substratum.

2. Material and methods

2.1. Research strategy

We compared the species composition of the early (mussels not prevalent) and mature (mussels prevalent) subtidal colonizing communities at offshore wind turbine foundations with special attention to the mobility and habitat preferences of the colonizing species.

2.2. Study site and data collection

We collected subtidal hard substrata macrofauna from the Belwind offshore wind farm, located at about 50 km offshore in the Belgian offshore renewable energy zone (see Chapter 1). The Belwind wind farm is situated on the Bligh Bank and is entirely located in clear English Channel water (M'harzi *et al*. 1998; Lacroix *et al.* 2004).

As part of the long-term environmental monitoring, on 12 October 2020, Scuba divers collected four scrape samples from the steel monopile foundation of the BBB8 turbine (originally installed on the 21st of October 2009) by scraping fouling organisms from a square sampling surface area of

6.3 dm² (Kerckhof *et al.* 2010). Samples were collected at -15 m which is considered representative for the assemblages of most of the subtidal part of the foundations (Fig. 1; Kerckhof *et al.* 2010).

The scraped material was collected in plastic bags that were sealed, subsequently preserved in buffered formalin 10% and transported to the laboratory for sieving over a 1 mm sieve. Individual organisms were sorted and identified to the lowest taxonomic level possible (mostly species level; further called "species"). Density was determined for non-colonial species, while percentage cover was assessed for the crust forming and erect (bushy) colonial epifaunal species such as hydrozoans, bryozoans and sponges. We assigned the observed species to be mobile, hemi-sessile or sessile based on the mobility of the life stage observed in the samples. Hemi-sessile organisms are organisms that usually remain attached in the same place (e.g., *Jassa herdmani*, *Mytilus edulis*), but have limited mobility, whereas sessile organisms, such as adult barnacles, live permanently attached to the substratum and are unable move. All data were transformed

to the SACFOR scale to allow for integrating relative abundances of colonial and non-colonial species (Connor & Hiscock 1996). Specimens of *M. edulis* were separated during sorting, lightly rinsed, measured (lengthwise) and classified according to their length (small: < 30 mm, medium: 31-60 mm, large: > 61 mm). Associated organisms were sorted and identified to the lowest taxonomic level possible, and the percentage cover of the mussel shells (medium and large as the few smaller mussels present in the samples were devoid of epifauna) by fouling organisms was estimated for all species in four broad categories (1:-1-4%, 2: 5-19%, 3: 20-40%, 4: >40%). The commensal species *Pinnotheres pisum* was excluded from further analysis.

To compare the epifaunal composition on the mussel shells (= secondary habitat) with that of the initial epifauna that settled directly on the turbine foundations (= primary habitat), we used the dataset on epifauna observed in 2010 on the Belwind monopiles (i.e., three scrape samples collected on 18 August 2010, i.e., nine months after installation of the turbine foundation) as compiled by Kerckhof *et al.* (2019).

Figure 1. Sampling square and scraper at a Belwind monopile. Note the presence of *Mytilus edulis* clumps in between and under *Metridium senile* (left). Example of a mussel fully covered by fouling organisms (right).

2.3. Statistical methods

We applied the Spearman rank correlation coefficient to relate mussel length and, both the number of associated species and cumulative percentage cover. However, because multiple mussels had the same length, exact p-values could not be computed. Species accumulation curves (SAC; or species-richness curves) and extrapolated species richness (Chao 1987) were used to estimate the total number of species associated with these mussels and visualized using the R package vegan (Oksanen *et al*. 2019). All data analyses were performed in R (R Core Team 2020).

3. Results

We identified 47 species belonging to nine different phyla in the 2020 samples (Fig. 2): 24 sessile species, 5 hemi-sessile species and 18 mobile species (Table 1). The main phyla present in the samples were Mollusca (11 species), Arthropoda (11 species), Annelida (8 species), and Bryozoa (7 species) (Fig. 2). Twenty species were exclusively found on the pile, i.e., the primary substratum (17 mobile, 1 hemi-sessile and 2 sessile species). On the

mussels, i.e., the secondary substratum, we found 21 unique species all of them sessile species. Six species were found on both the primary and secondary substratum (3 sessile, 2 hemi-sessile and 1 mobile species). The three species most frequently observed on the mussels were the encrusting annelid *Spirobranchus triqueter* (present on 34 out of 38 mussels), hemi-sessile anemones (mostly *Metridium*, on 29 out of 38 mussels) and the encrusting barnacle *Verruca stroemia* (on 25 out of 38 mussels, Table 1). The species observed on the mussels have all been found previously, e.g., on the stones of the scour protection or on shells of other bivalves (dataset Kerckhof *et al*. 2019). All bryozoan species were exclusively observed on the secondary substratum.

The 37 species observed in the August 2010 samples comprised 26 mobile, 2 hemi-sessile and 9 sessile species (dataset Kerckhof *et al*. 2019). The main phyla present in the samples were Arthropoda (12 species), Mollusca (8 species), Annelida (8 species), and Echinodermata (3 species). Most of the sessile (7/9) and half of the hemi-sessile species (1/2) observed on the primary
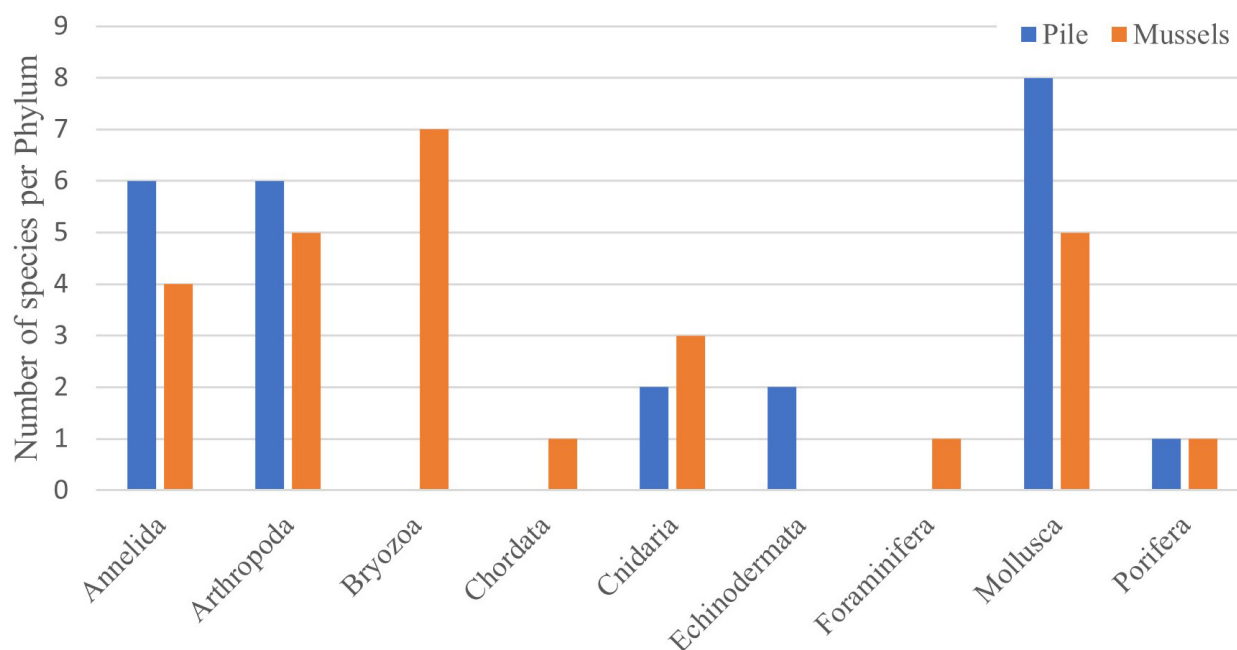
Figure 2. Number of taxa per phylum present on the primary substratum -pile - (blue) or on the secondary substratum – mussels - (orange) in 2020 (pooled samples).

Table 1. Overview of the species encountered in the 2020 scrape samples, the mobility of the life stage observed (M = mobile; H = hemi-sessile; S = sessile), location where they were encountered (P = on primary substratum; M = on mussels), the frequency with which they were encountered on individual mussels, and whether they were previously observed in 2010.

Species	Phylum	Mobility of observed life stage	Location encountered	Frequency on mussels	Previously observed in August 2010
Eulalia aurea	Annelida	M	P		
Eulalia sp.	Annelida	M	P & M	1/38	X
Eunereis longissima	Annelida	M	P		X
Lanice conchilega	Annelida	S	M	1/38	X
Lepidonotus squamatus	Annelida	M	P		X
Sabellaria spinulosa	Annelida	H	M	10/38	
Spirobranchus triqueter	Annelida	S	P & M	34/38	
Subadyte pellucida	Annelida	M	P		
Balanus crenatus	Arthropoda	S	M	19/38	X
Balanus perforatus	Arthropoda	S	M	5/38	X
Corophium sextonae	Arthropoda	H	M	19/38	
Gitana sarsi	Arthropoda	M	P		
Harmothoe extenuata	Arthropoda	M	P		X
Jassa herdmani	Arthropoda	S	P & M	19/38	X
Phtisica marina	Arthropoda	M	P		X
Pilumnus hirtellus	Arthropoda	M	P		X
Pisidia longicornis	Arthropoda	M	P		X
Stenothoe monoculoides	Arthropoda	M	P		
Verruca stroemia	Arthropoda	S	M	25/38	X
Alcyonidium mytilii	Bryozoa	S	M	2/38	
Callopora dumerilii	Bryozoa	S	M	7/38	
Celleporella hyalina	Bryozoa	S	M	8/38	
Conopeum reticulum	Bryozoa	S	M	7/38	
Electra pilosa	Bryozoa	S	M	8/38	
Membranipora tenuis	Bryozoa	S	M	3/38	X
Microporella ciliata	Bryozoa	S	M	6/38	
Diplosoma listerianum	Chordata	S	M	23/38	
Actiniaria	Cnidaria	H	P & M	29/38	
Alcyonium digitatum	Cnidaria	S	M	2/38	
Clytia hemisphaerica	Cnidaria	S	M	5/38	
Obelia bidentata	Cnidaria	S	P		
Ophiothrix fragilis	Echinodermata	M	P		
Psammechinus miliaris	Echinodermata	M	P		X
Planorbulina mediterranensis	Foraminifera	S	M	1/38	
Aequipecten opercularis	Mollusca	H	P		X
Crepidula fornicata	Mollusca	S	P & M	1/38	X
Doto sp.	Mollusca	M	P		
Epitonium clathratulum	Mollusca	M	P		
Euspira nitida	Mollusca	M	P		
Heteranomia squamula	Mollusca	S	M	14/38	X
Hiatella arctica	Mollusca	S	M	1/38	
Mytilus edulis	Mollusca	H	P & M	18/38	X
Odostomia turrita	Mollusca	M	P		
Ostrea edulis	Mollusca	S	M	1/38	
Trivia monacha	Mollusca	M	P		
Cliona celata	Porifera	S	M	1/38	
Dysidea fragilis	Porifera	S	P		

substratum in 2010 were present on the secondary substratum in 2020. In contrast, only two sessile species (*Crepidula fornicata* and *Jassa herdmani*) present in 2010, were also observed on the primary substratum in 2020. Only a single mobile species (*Eulalia* sp.) observed in 2010 was recovered from the secondary substratum in 2020.

We found no correlation between the length of the mussels and the number of species on the mussel (Fig. 3; correlation coefficient: 0.08) and only a weak correlation between the length of the mussels and their cumulative percentage of cover by epifauna (Fig. 4, correlation coefficient: 0.39). No species were found on small mussels (< 30 mm), and maximally one species was associated with medium mussels (31-60 mm). It would appear that the mussels have to be of a certain size or age before they can be colonized by epifauna. Nearly all large mussels were covered, often entirely (Fig. 4), by fouling fauna.

The four replicates each contained between 5 and 17 medium to large-sized mussels with 12 up to 18 mussel-associated species per replicate. A single replicate thus contained less than half to up to 2/3rd of the observed number of species associated with the mussels (27 spp.). Each individual medium to large-sized mussel was associated with 0 to 11 species (mean: 6.6 spp., SD: 3.0, Fig. 5). The extrapolated maximum number of species associated with mussels on the turbine foundation was estimated to be 35.

4. Discussion

Out of the 47 species in the 2020 samples, 21 species were only observed on the shells of mussels, all of them sessile species. This suggests that ten years after initial colonisation, shells of large mussels
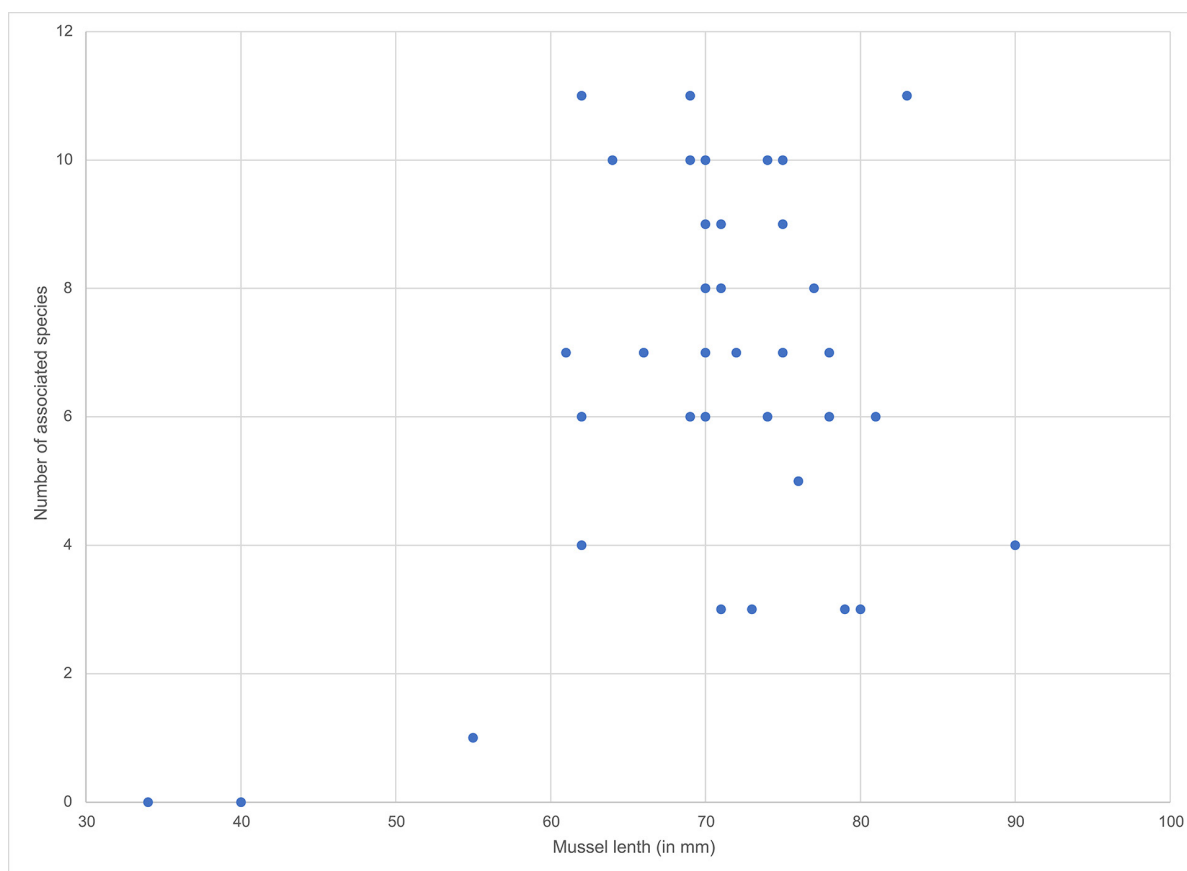
Figure 3. Number of associated species as a function of *Mytilus edulis* length (n = 38). Note that the ~55 mm mussel was colonized exclusively by *Metridium senile*.
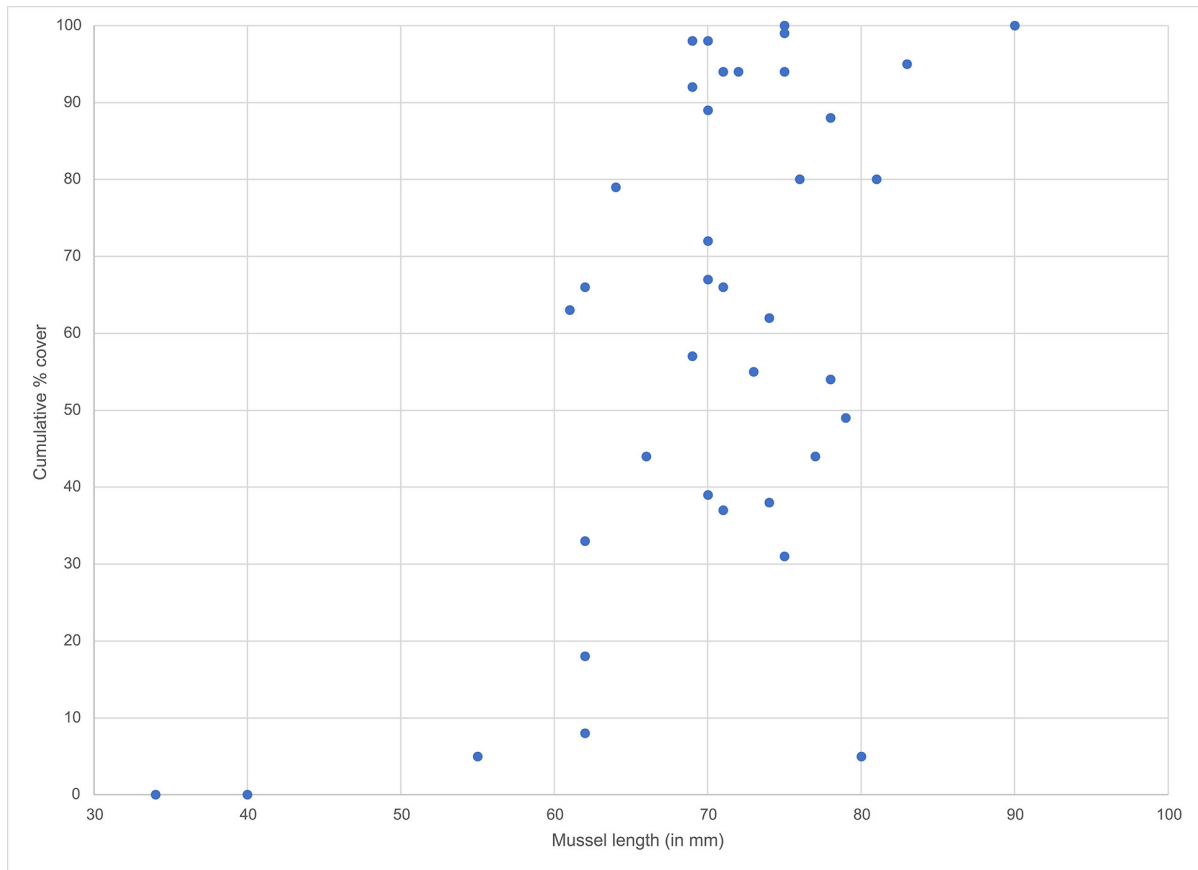
Figure 4. Cumulative percentage cover by associated species as a function of *Mytilus edulis* length (n = 38).
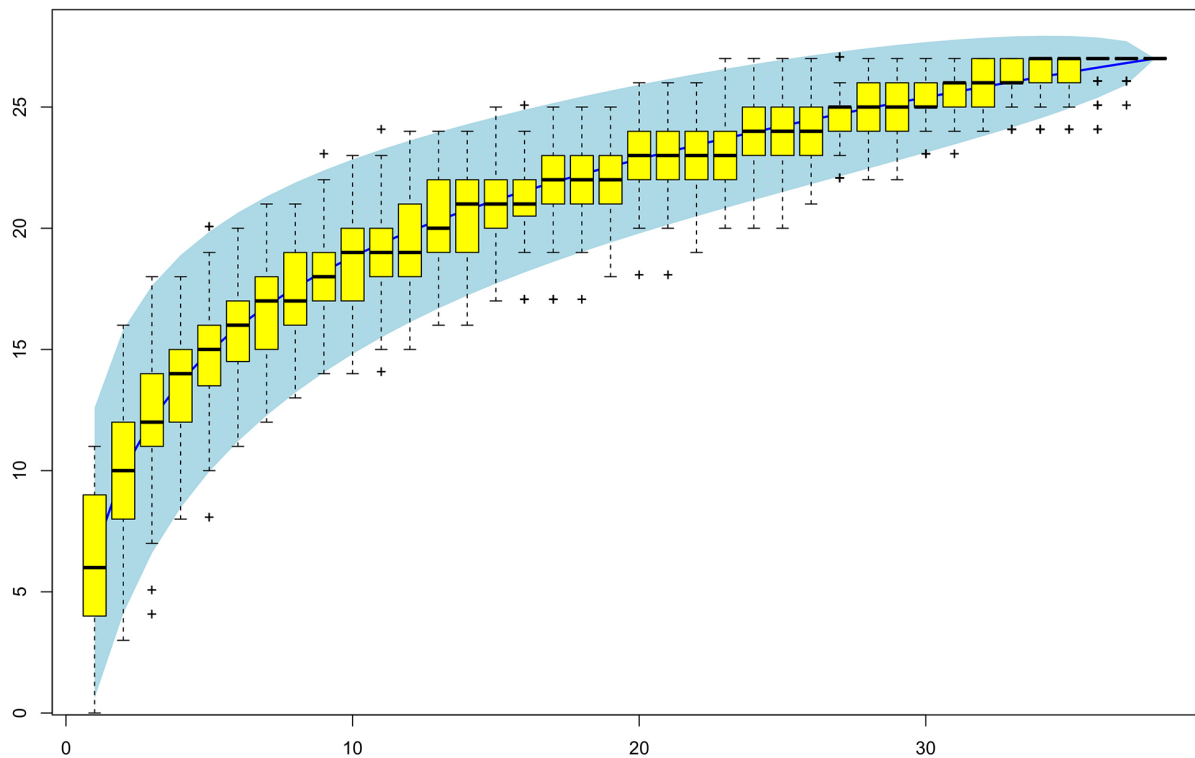
Figure 5. Species accumulation curve of the number of species associated with mussels for the number of mussels studied (box represents 1st and 3rd quartile, whiskers showing minimum and maximum values, with outliers as '+').

provide a specific secondary substratum for sessile species within the mature subtidal epifouling community.

At this offshore wind farm, initial settling of blue mussels was observed in 2010 (i.e., ~6 months after installation), predominantly in the intertidal zone where the mussel population developed into a typical intertidal mussel belt similar to those described in Joschko *et al.* (2008) for the German Bight. As a mussel population further develops, the mussels grow and start occupying more space, but do not necessarily increase in numbers (Suchanek 1985). In established intertidal mussel beds, individual mussels can gradually move to outside of the patches. A similar thinning effect likely also happened on the foundations with individual large mussels gradually moving downwards, which may explain the presence of solitary larger mussels on the permanently submerged parts of the piles (e.g., -15 m as observed in this study). Even after 11 years, relatively low numbers of mussels are observed below the intertidal zone which is in marked contrast with findings elsewhere (Krone *et al.* 2013; Hutchison *et al.* 2020). This may be due to foundation type as jackets structures are often entirely covered by mussels (Hutchinson 2020; personal observations on the jacket structures in C-Power phase 2 and 3), the location further offshore resulting in lower numbers of spat in the water column or a combination of both.

Natural aggregations of mussels, which generally form horizontal intertidal aggregations, are bioengineered microhabitats that are structurally more complex than the surrounding, often soft sediment, substratum (Suchanek 1985). Such mussel beds consist of three major components: the mussel matrix, a diverse assemblage of associated organisms and accumulated detritus at the base of the mussel bed (Suchanek 1985). In our study, on the vertical surface of the foundation, two of the three aforementioned components are presumably of reduced importance due to

the tidal position of the investigated mussel bed. Because the subtidal mussel population on the turbine foundation is composed of solitary large individuals that have likely moved down the foundation as a result of the thinning effect, these mussel aggregations are characterized by a loose matrix structure. This may cause detrital particles such as faeces and pseudofaeces, to wash out easily instead of accumulating between the byssus of the mussels. This is also the case for inorganic components such as shell debris. This, together with the strong currents, may explain the lower number of mobile species looking for shelter or dwelling among the mussels to feed, e.g., *Harmothoe* spp., *Eulalia* spp., as observed in this study. It is likely that sample manipulation, including the rinsing and sieving contributed to this finding. One free living species, the brittle star *Ophiothrix fragilis*, was prominently observed amongst the mussels by the divers during sampling and both species formed a typical association (see also Mavraki *et al.* 2020), which – to our knowledge – has not been observed elsewhere. The suspension feeding *O. fragilis* may take profit from the absence of fine sediments and strong currents as in our study, because high levels of sedimentation can prevent them from feeding and eventually inhibit respiration (Aronson 1989; Jackson 2008; de Kluijver & Ingalsuo 2012). Encrusting organisms, such as barnacles, encrusting bryozoans and calcareous tube forming polychaetes apparently flourish in this setting of strong currents hence their observed prevalence.

Mussels often outcompete barnacles attached to the primary substratum (e.g., Menge 1976), now the large mussels offer a secondary substratum for barnacle settlement. This is illustrated by the presence of relatively small individuals and juveniles of the barnacles *Verruca stroemia*, *Balanus perforatus* and *Balanus crenatus* indicate recent settlement.

On the concrete gravity base foundations at the nearby C-Power wind farm the plumose

anemone *M. senile* dominated the subtidal species assemblage resulting in a species poor community (Kerckhof *et al.* 2019). Several other studies demonstrated an association of low species richness when the community is dominated by *M. senile* (Zintzen *et al.* 2006; Coolen *et al.* 2015, 2018; van der Stap *et al.* 2016). *Metridium senile* is a superior spatial competitor, which has been attributed to its clonal reproduction, mobility and locomotion (Nelson & Craig 2011). Additionally, it actively predates on larvae of other species, preventing their settlement on adjacent substrata, and by actively killing new settlers by smothering them (Nelson & Craig 2011). In this study, we demonstrate that the shells of *M. edulis* provide a secondary substratum for settlement of encrusting species there where the primary substratum (i.e., the pile) has already been fully colonized and counteracting the effect of dominant *M. senile*. The results in a positive relationship between the abundance of *M. edulis* with species richness and diversity (Zupan & Rumes, in prep).

The near absence of encrusting species on the primary substratum is not only due to a lack of available suitable substratum but may in part be an artifact of the sampling technique. In samples collected by scraping the biota of the substratum, due to the used technique, one can imagine that small encrusting organisms are less efficiently collected, easily destroyed, or simply not collected which may blur the picture of the abundance and species diversity. However, this would not explain that in 2010 a total of 17 different sessile species, five of which are encrusting, were recovered from the primary substratum. It is possible that even more (mobile) species were associated with the mussels but that these were separated during the rinsing and sieving. The sessile and hemi-sessile species found on the mussels differ from those previously found on the piles and are more similar to that of the scour protection. This may be due to the fact that the secondary substratum provided by the mussels differs in physical properties (e.g., microhabitat complexity) from the primary (vertical) substratum of the pile.

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