



Epifauna dynamics at an offshore foundation – Implications of future wind power farming in the North Sea

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ABSTRACT

In the light of the introduction of thousands of large offshore wind power foundations into the North Sea within the next decades, this manuscript focuses on the biofouling processes and likely reef effects. The study explores the macrozoobenthos (biofouling) colonization at an offshore platform which is comparable to offshore wind turbine foundations. A total of 183 single samples were taken and the parameters water depth and time were considered comparing biofouling masses and communities. The blue mussel *Mytilus edulis*, Anthozoa and the Amphipoda *Jassa* spp. were the dominant species. The community from the 1 m zone and those from the 5 and 20–28 m zones can clearly be differentiated. The 10 m zone community represents the transition between the *M. edulis* dominated 1 m and 5 m zones and the Anthozoa dominated 20–28 m zone. In the future offshore wind farms, thousands of wind turbine foundations will provide habitat for a hard bottom fauna which is otherwise restricted to the sparse rocky habitats scattered within extensive sedimentary soft bottoms of the German Bight. However, offshore wind power foundations cannot be considered natural rock equivalents as they selectively increase certain natural hard bottom species. The surface of the construction (1280 m²) was covered by an average of 4300 kg biomass. This foundation concentrates on its footprint area (1024 m²) 35 times more macrozoobenthos biomass than the same area of soft bottom in the German exclusive economic zone (0.12 kg m⁻²), functioning as a biomass hotspot. Concerning the temporal biomass variation, we assume that at least 2700 kg biomass was exported on a yearly basis. 345×10^4 single mussel shells of different sizes were produced during the study period. It is anticipated that the *M. edulis* abundance will increase in the North Sea due to the expansion of the offshore wind farm development. This will result in the enhanced production of secondary hard substrate (mussel shells) and its associated fauna and will intensify filtration rates of the seawater. This predicted ecological system change is coined the 'Mytilisation' of the German Bight.

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1. Introduction

In the near future the wind energy industry will expand on a large scale into offshore regions of western European shelf seas. Thousands of large steel turbine foundations will function as artificial reefs within areas which are naturally characterised by extensive sedimentary soft bottoms. It is expected that the turbine foundations will affect marine life through noise emission (Wahlberg and Westerberg, 2005; Madsen et al., 2006;

Lindeboom et al., 2011), changed seafloor topography and sediment regimes (Wilson et al., 2010), and barrier effects (Masden et al., 2009). Additionally, strong implications for the subtidal ecosystem are expected from the settlement of macrozoobenthos on the artificial solid surface of the turbine foundations (Lindeboom et al., 2011). The macrozoobenthos communities on artificial hard substrata (biofouling or fouling) differ from natural macrozoobenthos communities on natural hard substrata (People, 2006; Wilhelmsson and Malm; 2008; Andersson et al., 2010) and on soft bottoms (Barros et al., 2001; Fabi et al., 2002; Langlois et al., 2006; Langhamer, 2010). In particular, in areas where natural hard substrata are rare, high numbers of artificial constructions favour the establishment of taxa such as cnidarians and mussels whose life histories include temporary or permanent

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attachment to solid substrates (Richardson et al., 2009). Increasing numbers of filtering mussels (Winter, 1973; Clausen and Riisgård, 1996) may influence particle and nutrient fluxes between the water column and the sediment, thereby potentially affecting the plankton biomass (Wilhelmsson and Malm, 2008). Mussels, in turn, provide secondary hard substrate attractive for other epifaunal organisms (Norling and Kautsky, 2007). Continuous mussel shell litter fall modifies the grain size of the sediment where shells aggregate at the seafloor, providing new habitats for hemi- and holo-sessile organisms such as Anthozoa and Hydrozoa which require solid attachment sites, and typical hard bottom crabs (Wolfson et al., 1979; Freire and González-Gurriarán, 1995; Riis and Dolmer, 2003). Aggregations of marine biota at wind turbines will change the benthic biomass and provide food for a variety of predators (Wolfson et al., 1979; Freire and González-Gurriarán, 1995; Page et al., 1999; Wilhelmsson et al., 2006; Krone et al., submitted). Accordingly, benthic invertebrate communities and the local physico-chemical conditions are expected to change around the structures (Wolfson et al., 1979; Falcão et al., 2007). Finally, artificial reefs such as wind turbine foundations have been found to act as stepping-stones for the dispersal of hard bottom organisms facilitating the spread of both exotic and indigenous species (Connell, 2001; Buller and Airoldi, 2005; Glasby et al., 2007; Bulleri and Chapman 2010; Zintzen and Massin, 2010; Kerckhof et al., 2012).

In the German Exclusive Economic Zone (EEZ) of the North Sea at least 5000 single turbines are envisaged to be built within the next 20 years (IEA, 2008; BMU, 2010). To date, 22 wind farms with 1540 turbines are authorised for construction (BSH, 2012) and one wind farm with 12 turbines is operating. The potential impacts of the massive biofouling associated with the large-scale introduction of numerous turbine foundations into the North Sea are of concern and the resulting ecological processes are not well enough understood (Inger et al., 2009; Gill, 2005). Studies on specific effects of biomass accumulations on artificial structures are costly and often not feasible in offshore waters. Accordingly, ecological implications have to be derived from the qualitative and quantitative composition of fouling communities sampled in the course of baseline monitoring programs. Previous studies indicate that the composition of the fouling assemblage and, thus, the ecological implications of offshore constructions depend on a variety of factors such as the material and the size of the construction, the time of exposure, distance from the shore, the wind and current regime, and the water depth (Kingsbury, 1981; Butler and Conolly, 1999; Whomersley and Picken, 2003; People, 2006; Zintzen et al., 2008a; Andersson et al., 2010).

Most biofouling studies on offshore constructions in the North Sea have been conducted on oil and gas rigs. The biomass and the composition of the epifauna varies between rigs in coastal waters of the North Sea and those under Atlantic influence with growth rates of some species differing by up to 50% (Kingsbury, 1981). Similarly, the fouling communities varied between scattered ship wrecks in Belgian waters indicating spatial variation depending on the water mass (Zintzen et al., 2006, 2008a, 2008b, 2010). Fouling communities on offshore constructions are often completely dominated by either mussels or Anthozoa. On four North Sea oil platforms (45–67 m depth) blue mussels, *Mytilus edulis*, dominated the fouling assemblages in the shallow subtidal while Anthozoa occurred mainly in the deeper sections (Whomersley and Picken, 2003). Eleven years after construction, the fouling communities on the rigs did not yet reach a climax stage. The young wind power projects in the southern North Sea have also been investigated from the beginning in 2002 with first results emerging. In Belgian North Sea waters, six concrete gravity foundations of offshore wind turbines were erected at water depths of 25 m. Within the first two years

after implementation, the fouling community displayed strong seasonal variations and lower numbers of taxa than that on older shipwrecks in the same region (Degraer and Brabant, 2009; Kerckhof et al., 2010). On turbine foundations of a Dutch wind farm (water depth: 21 m), 80–100% of the construction surface was covered by mussels down to a depth of 10 m while deeper sections were fully covered by Anthozoa and Hydrozoa (Lindeboom et al., 2011). As for most other North Sea constructions, the Amphipoda *Jassa* spp. (further also referred to as *Jassa*) and its tubes occurred all over the pylons. *M. edulis* dominated the fouling assemblages also on wind turbines in shallow (max. 14 m depth) coastal waters of the Danish North Sea (Leonhard and Pedersen, 2006). However, the mussel abundances varied substantially among the foundations within the wind farm.

The aim of the present study was to investigate the biofouling community on the steel foundation of an offshore research platform in the south-eastern North Sea and to apply it as the first available basis to calculate the impacts of large scale offshore wind farming on marine ecosystems in the German Bight. We hypothesise that the blue mussel *M. edulis* will form large persistent stocks in the upper sublittoral as such colonies have been detected in neighbouring North Sea regions as well. We further hypothesise that large biomasses will accumulate at these artificial construction.

2. Material and methods

The investigated foundation of the platform is similar in size and shape and thus equivalent to common wind turbine foundations. Depth zone typifying fouling communities were identified and their temporal and spatial development was addressed. Dominant taxa abundances were compared between the construction and the rocky island of Helgoland. The biomass balance and the production of secondary hard substrate by mussel shell litter fall were calculated.

2.1. Study site

The investigation was conducted between April 2005 and October 2007 at the research platform FINO 1 (Forschung in Nord- und Ostsee 1) (Fig. 1) that was erected close to the location of future planned wind farms. This steel jacket construction was built in July 2003 in the south-western German Bight, at a water depth of 28 m below low tide level. The total submerged substrate surface measures 1280 m² and the square area beneath the structure (footprint area) measures 1024 m². The platform allows for research on physical and oceanographic conditions and the possible changes of the marine ecosystem due to the construction of offshore wind turbines. The seafloor around the platform consists of fine sand. The salinity ranged from 32.9 to 34.7 psu; the surface water temperature was 3 °C in spring, 19 °C in summer, and 14 °C in autumn. The water body was never stratified with regard to temperature and salinity during the study. Secchi depth varied between 4 and 7 m. The daily maximum tidal current velocity was 0.4 m s⁻¹ at 20 m depth and 1 m s⁻¹ at the surface. The average tidal range was 1.9 m (Joschko et al., 2008; Schröder et al., 2012).

2.2. Sample collection and processing

The epifauna was sampled from the vertical surfaces of the four main pylons by scientific divers during cruises of the research vessel *Heincke*. Scrape samples were taken in April, July/August, and October 2005 to 2007 at water depths of 1 m (0–2.5), 5 m (2.5–7.5), 10 m (7.5–15.0), 20 m (15.0–22.5), 25 m (22.5–27.0) and 28 m

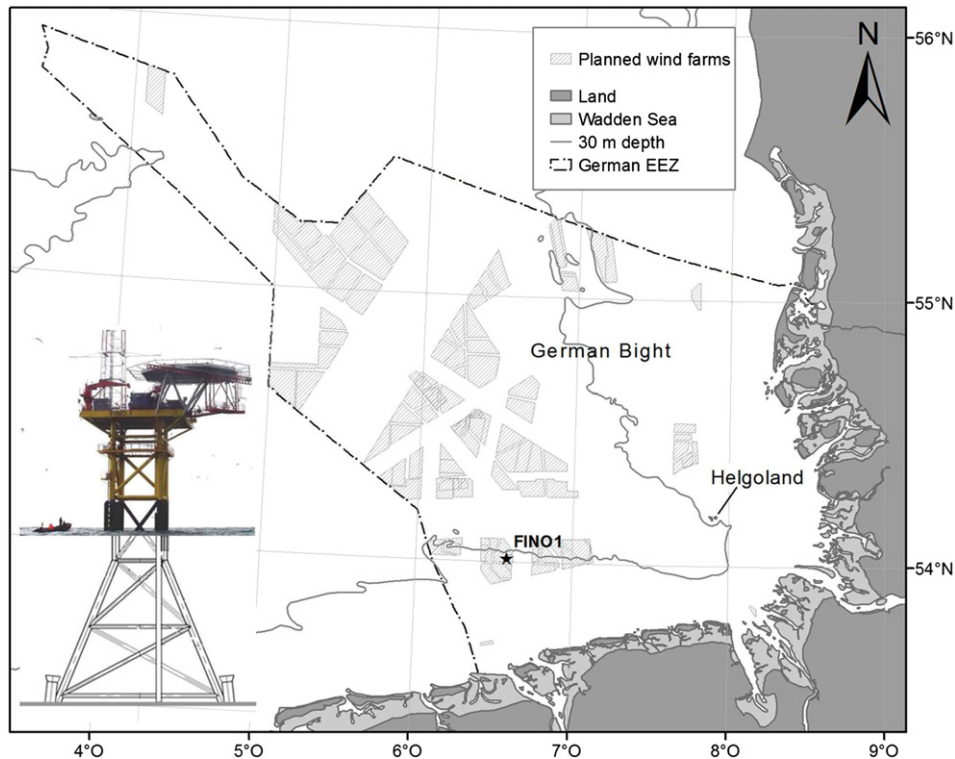


Fig. 1. The jacket construction of the research platform FINO 1 (with diving boat) and planned wind farms in the south-western German Bight. Map by J. Dannheim.

(27.0–30.0) below low tide level. A total of 183 samples were taken. At each sample campaign we aimed to take at least one sample per pylon and designated depth. Due to time constraints and for safety reasons, however, it was not possible to always sample each of the four pylons at all depths. Thus a total maximum of five samples (replicates) were randomly collected from the four pylons per depth (Table 1). At each depth the samples were taken at random positions. 20 × 20 cm samples were scraped off with a putty knife and captured in a mesh-bag (mesh size: 0.5 mm) attached to a metal frame. All samples were preserved in 4% borax-buffered formalin. In the laboratory, the samples were weighed (wet weight), pre-sorted, and the organisms preserved in 75% ethanol for later identification. The organisms were sorted and identified to the lowest taxon possible. Solitary taxa were counted. Large individuals, which were identified by eye (except Amphipoda and Hydrozoa), were separated from the complete samples. Subsequently, sub samples of 1 to 3 g were taken from large samples and sorted. All individuals of *M. edulis* were cleaned from byssus and epifauna, weighed and the shell length measured to the nearest 0.1 mm. After identification, the taxa were weighed. All wet weights were corrected by the factor 1.2 to account for weight changes due to storage in ethanol (Zintzen et al., 2008a, 2008b). Qualitative observations during the dives were documented.

2.3. Data analysis

Analyses were based on the biomass per taxon to allow an equal representation of colonial and solitary species. For the statistical analysis some 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 samples. The biomass of the tubes of *Jassa* spp. and the byssus threads of *M. edulis* were excluded from the analysis of the epifauna community.

2.3.1. Spatial and temporal variation of the epifauna biomass

To test for an effect of depth, the biomass data were analysed separately for each season applying one-way ANOVAs with subsequent Newman–Keuls Posthoc-Tests for pairwise comparison. For this, the data from all years were pooled to seasons. By grouping the seasons to spring (including all spring samples from 2005 to 2007), summer (including all summer samples from 2005 to 2007) and autumn (including all autumn samples from 2005 to 2007) and analysing them separately, the comparison of dependent samples (seasons and years) was avoided. Within a season, the samples from different pylons were treated equally and regarded as independent replicates. Prior to the analysis the biomass data

Table 1

Number of scrape samples of the epifauna taken in 6 depth zones (month, year) on the foundation of the research platform FINO 1.

Depth [m]	04.'05	07.'05	10.'05	04.'06	08.'06	10.'06	04.'07	08.'07	10.'07
1	1	5	4	4	4	4	4	4	1
5	2	3	4	4	4	4	4	4	3
10	2	4	4	4	4	4	4	4	4
20	2	0	2	4	4	4	5	5	3
25	2	4	2	4	3	4	4	4	3
28	0	4	2	4	5	3	4	4	1

were fourth root transformed to achieve homogeneity of variances (Bartlett's test for equal variances).

After having identified those depth zones with similar effects on biomass, we then tested for an effect of time, i.e., the nine sampling events, applying separate analyses for each identified depth zone. For this, the data from each identified depth zone, were pooled to each of the 9 sample events. The data were then compared using Kruskal–Wallis-tests followed by Dunn's multiple comparison test (software GraphPad Prism™ v 5.04).

The total biomass on the entire underwater construction of the platform was calculated by multiplying the average biomass per m² by surface area of the respective depth zone (obtained from construction plans of the platform) and summing up the values from all depth zones.

2.3.2. Export of biomass and *M. edulis* shells

The potential biomass export from the epifauna on the foundation into the surrounding sediments was roughly estimated as the change in total biomass between two successive sampling events. Due to missing information on recruitment, turnover and growth between sampling events, biomass substitution between sampling events by new specimens and continuous faecal export had to be ignored. The change in the number of blue mussel (*M. edulis*) shells on the underwater construction was calculated for each depth zone to estimate the export of secondary hard substratum into the surrounding sediments. Shell production was quantified on a yearly basis, taking into consideration the changes in mussel numbers, the shell lengths, and the annual mussel biomass. The long term export of shells from the mussel stock in autumn 2007 was calculated using population turnover rates obtained from Wolfson et al. (1979).

2.3.3. Epifauna community

To detect global temporal and spatial variations the epifauna community was analysed by a two-way crossed ANOSIM (factors depth zone and sampling time). Each sample was treated separately. The sample data were square root transformed to reduce the influence of dominant species (Clark and Warwick, 2001). Samples taken in spring, summer and autumn were compared by a two-way crossed ANOSIM (factors season and depth zone). This comparison was done for each year separately to identify seasonal variations. Annual variations were analysed for each season separately by a two-way crossed ANOSIM (factors year and depth zone). Characteristic species of each depth zone were identified by similarity percentage (SIMPER) analysis of square root transformed data. Analyses were carried out using PRIMER™ v 6.0 (Clarke and Gorley, 2006). Following Clark and Warwick (2001) we defined depth zone characterising species by two conditions: 1. The taxon discriminates the depth zone from each other. It consistently ($\delta_i/SD(\delta_i) \geq 1$) contributes to the dissimilarity between the depth zones. It belongs to the top species, which constitute cumulatively at least 80% of the dissimilarity between at least two depth zones. 2. The taxon typifies the depth zone, contributing consistently to the similarity ($\bar{S}_i/SD(S_i) \geq 1$). It belongs to the top species, which constitute cumulatively at least 80% of the similarity within the depth zone. The depth zones were named after the typifying species which together comprise at least 50% of the biomass.

3. Results

A total of 58 taxa were identified to species level. To achieve a homogeneous taxonomic resolution among all samples, some species had to be combined on a higher taxonomic level resulting in a data set for the analysis which consisted of 35 taxa.

3.1. In situ observations

Around the high tide water level a thin layer of green algae (cf. Ulvaceae), few pacific oysters (*Crassostrea gigas*), and small numbers of barnacles were found occasionally but not sampled. During all visits, at 1 m depth the surface of the platform structure was permanently covered by a compact layer of *M. edulis* with an estimated thickness of up to 40 cm. At 5 m water depth, *M. edulis* was heterogeneously distributed in lower numbers and biomass than at 1 m depth. Mussels were patchily distributed among Anthozoa and the residential tubes of the Amphipoda *Jassa* spp. Below 5 m depth the substrate was almost completely covered by a brownish layer of *Jassa* tubes and Anthozoa of estimated 2 to 5 cm thick. *Jassa* was superabundantly present at the jacket construction. In each water depth their tubes covered the steel substrate between the mussels and the Anthozoa. From the diver's perspective *Jassa*, *M. edulis* and the Anthozoa (mostly *Metridium senile*) were the characteristic organisms on FINO 1. The diver repeatedly observed hundreds of horse mackerels (*Trachurus trachurus*) swimming around and inside the construction. Close to the seafloor, at a water depth of 28 m, many pouting (*Trisopterus luscus*) were observed. Inside the scour at the base of the platform, which was covered by shell detritus, swimming crabs (e.g., *Necora puber*) and edible crabs (*Cancer pagurus*) were frequently detected close to the pylons. Quantitative data on the vagile demersal megafauna are given in Krone (2012) and Krone et al. (submitted).

3.2. Epifauna biomass

In spring, summer, and autumn, the biomass at 1 m depth was significantly higher than at all other depths ($p < 0.001$; Fig. 2). It varied between 23.3 kg m⁻² in spring 2005 (a single sample) and 45.4 ± 22.3 kg m⁻² in summer 2007 with conspicuous seasonal fluctuation. The biomass was highest in summer and lowest in spring. However, the seasonal differences were statistically not significant ($p > 0.05$). The biomass did not vary significantly among the other depth levels and ranged from 0.5 ± 0.5 to 3.9 ± 0.4 kg m⁻². The biomass fluctuations did neither show a clear seasonal pattern nor a consistent trend. Consequently, the 1 m depth zone will be differentiated from a 5–28 m depth for the

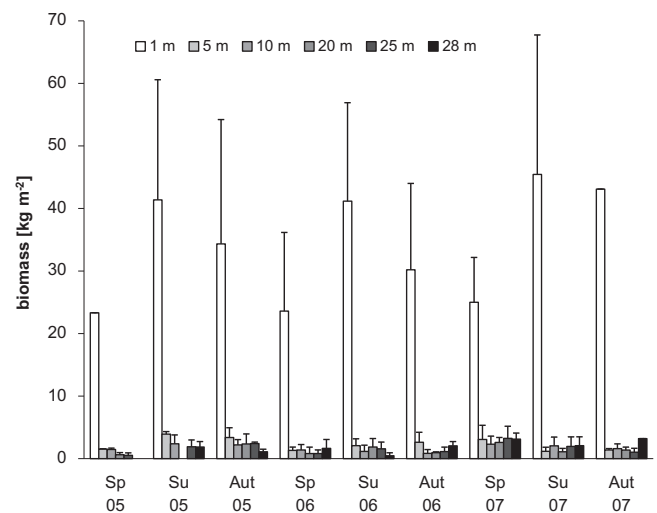


Fig. 2. Average biomass (±SD) of the epifauna on the underwater construction of the offshore platform FINO 1 at different water depths in spring (Sp), summer (Su) and autumn (Aut) up to five years after installation, 2005 to 2007. Only one sample was taken in spring 2005 at 1 m depth and in autumn 2007 at 1 and 28 m depth. No sample was taken in spring 2005 at 28 m and in summer 2005 at 20 m.

comparison of the total biomass. Within the 5–28 m depth zone, the biomass varied significantly between the sampling events ($p < 0.0001$). However, no consistent seasonal pattern was apparent. In spring 2007, the biomass was significantly higher than in spring 2005 (factor 2.4) and throughout 2006 (spring factor 2.9, summer factor 2.5, autumn factor 2.3). The only significant seasonal variation existed in 2007 with 1.9 times higher biomass in spring than in autumn ($p < 0.05$).

3.3. Export of biomass and *M. edulis* shells

The total biomass on the platform construction was highest in summer 2005 at 5690 kg (Fig. 3). The seasonal fluctuations of the total biomass decreased from 2005 to 2007. Accordingly, the biomass was seasonally more stable on a high level of about 5000 kg throughout the 2007 sampling period. 50% of the biomass occurred in the 1 m depth zone. However, it has to be kept in mind that in autumn 2007 the biomass in the 1 m depth zone was estimated from a single sample. The total biomass in spring increased throughout the investigation period while the biomass in summer and autumn were roughly similar between the years. Averaging the masses of spring, summer and autumn per year a slight increase can be detected on a yearly basis during the study period. At present, however, the trend of increasing biomasses was only significant between the spring samples from the 5–28 m zone (compare section before). Abundance and length of *M. edulis* differed between the 1 m depth zone and all deeper levels. From 2005 to 2007, the abundance decreased from 22350 ± 15360 ind. m^{-2} to 4970 ± 2470 ind. m^{-2} in the 1 m depth zone and from 2470 ± 2360 ind. m^{-2} to 130 ± 240 ind. m^{-2} in the 5–28 m depth zone. Below the 1 m depth zone the abundance decreased at all depths. In the 1 m zone, the average shell length increased from 17.5 ± 14.8 mm in 2005 to 35.4 ± 18.6 mm in 2007. The mussel shells were an order of magnitude shorter in the 5–28 m zone and the shell length remained relatively stable at 2.9 ± 3.8 mm in 2005 and 2.4 ± 5.3 mm in 2007. Calculated for to the entire submarine surface in the 1 m depth zone, 882,600 complete shells (i.e., both valves) (17.5–29.6 mm) fell off the foundation during 2005 to 2006 (Fig. 4) and 232,600 complete shells (29.9–35.4 mm) during 2006 and 2007. Calculated for the 5–28 m depth zone, 2,089,400 shells with a length of 3.8–5.7 mm were detached from the platform foundation during 2006 to 2007 and 246,720 complete shells with a length of 5.3–5.7 mm from 2006 to 2007. In 2007, a total of 318,850 live mussels with an average shell length of 35.4 ± 18.6 mm occurred in the 1 m depth zone representing a total biomass of 2130 kg. A total of 120,360 specimens with an average shell length of 2.4 ± 5.3 mm colonized the 5–28 m depth zone with a total biomass of 105 kg. Due to shell weight (ash weight) being 0.24 ± 2.9

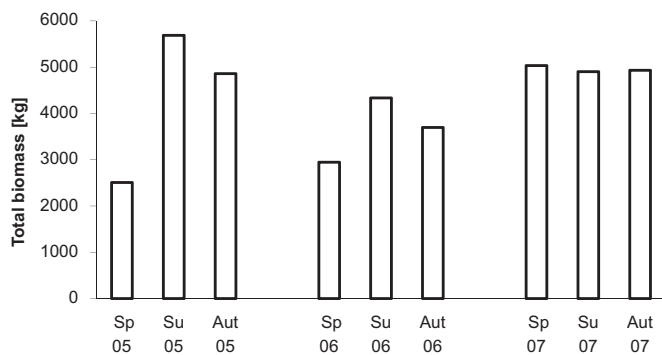


Fig. 3. Total biomass of the epifauna community calculated for the entire surface of the foundation of the offshore platform FINO 1 in the North Sea for the years 2005 to 2007 three to five years after establishment. Spring (Sp), summer (Su) and autumn (Aut).

times of the mussel's total biomass (Krone and Joschko, not published), 535 kg pure mussel shells were attached to the entire construction. Calculating with a ratio of 0.011 between volume (m^3) and the tissue biomass (kg) of living *Mytilus* colonies (Wolfson et al., 1979), the total attached mussel volume was $19 m^3$ during the final investigation year. The analogous average mussel layer width of 26 cm at 1 m depth (on $64 m^2$) and the not detectable <1 cm between 5 and 28 m (on $1215 m^2$) are conform to the divers' observations during sampling. The outer sides of the shells (presuming an elliptic planar surface) of *M. edulis* provided $303 m^2$ surfaces in 2007.

3.4. Epifauna community structure

3.4.1. Global differences

The structure of the epifauna community varied significantly between the sampling events ($R = 0.45$, $p < 0.001$) and between the depth zones ($R = 0.56$, $p < 0.001$). The community at 1 m depth could clearly be distinguished from the communities at all other depths while the community at 5 m depth differed from the communities found at 20, 25 and 28 m depth but not from the community at the 10 m depth (Table 2). The 10 and the 20 m depth zones contained similar communities. Finally, the communities in the 20–28 m depth zones were indistinguishable. Accordingly, three specific epifauna communities were identified typifying the 1, 5 and 20–28 m depth zones. The community in the 10 m depth zone was considered a transition between the 5 and the 20–28 m depth zones. Among the typifying taxa *M. edulis* was the dominant taxon with regard to biomass and constituted 96.2 and 40.7% of the total biomass in the 1 and 5 m zone, respectively (Fig. 5). Beneath the 1 m depth zone the biomass of the Anthozoa increased while the biomass of *M. edulis* decreased. Within the 20–28 m zone Anthozoa comprised 46.2% of the total biomass whereas *M. edulis* contributed less than 1% to the total biomass. The Amphipoda *Jassa* spp. were found at all depth zones and from 5 to 28 m they contributed between 22.2 and 27.5% to the total epifauna biomass.

Accordingly, four depth specific communities were identified

1. The '1 m zone **Mytilus** community with subordinate co-occurring *Jassa*'
2. The '5 m zone **Mytilus-Jassa** community with subordinate co-occurring Anthozoa and Bryozoa'
3. The '10 m transient zone **Anthozoa-Jassa** community with co-occurring *Mytilus*, Hydrozoa, *Asterias rubens* and Bryozoa'
4. The '20–28 m zone **Anthozoa** community with co-occurring *Jassa* and Hydrozoa'

Thus, *M. edulis*, Anthozoa and *Jassa* were the dominant species of the epifauna community. Calculated for the entire submarine foundation, the average biomass of these taxa during the study period was 2060 kg, 430 kg and 306 kg, respectively, while all other taxa together had an average biomass of 337 kg. *Jassa* residential tubes reached 832 kg and *M. edulis* byssus 72 kg. *M. edulis* reached 2,849,000, the Anthozoa 2,145,000 and *Jassa* 324,855,000 single specimens at the foundation.

3.4.2. Seasonal variations

Variations were detected in all three sampling years (square root transformed data, two-way crossed ANOSIM and two-way SIMPER, factors season and depth). But no obvious pattern could be detected. The communities differed between all three seasons in the first and last investigation year but not between. The depth segregation either follows no seasonal trend and its peculiarity varies undirected. But, during all years the depth variations of the community were stronger than the seasonal variations.

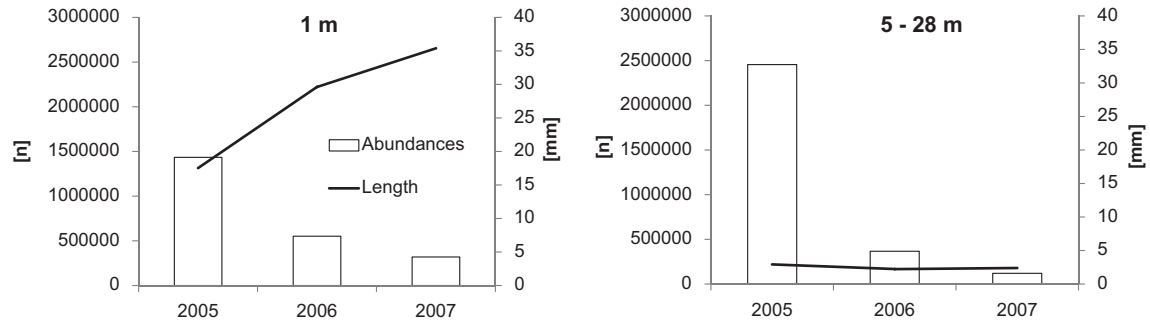


Fig. 4. Calculated total abundance and mean length of *Mytilus edulis* in the 1 m and the 5–28 m zone of the foundation of the offshore platform FINO 1, North Sea. Abundance and shell length from different seasons (spring, summer, autumn) were pooled for each year.

3.4.3. Annual variations

During the first and second year of the investigation (2005 and 2006) the communities did not differ at a seasonal basis ($R < 0.25$, $p > 0.05$). However, spring, summer and autumn communities changed between 2006 and 2007 ($R 0.48$, $p 0.001$; $R 0.44$, $p 0.001$; $R 0.30$, $p 0.001$). In spring, summer and autumn the 1 m zone differed strongly from all other depth zones ($R > 0.91$, $p 0.001$) due to very high *M. edulis* abundances. The segregation of the greater depths differed between the years and was lowest in 2007 in all three seasons.

Spring: The differences between the first and the third year in spring are mostly due to the occurrence of *Tubularia* spp. and in relevant masses with 5 times more Anthozoa and 1.5 times more *Jassa*. **Summer:** In summer, the differences between the first and third year were mostly because there were 1.5 times more Anthozoa, 5 times more *Tubularia* spp. 2.5 times fewer *Jassa* in the last study year. **Autumn:** The differences between the first and the third year in autumn were mostly due to 1.3 times more Anthozoa and 1.4 lesser *Jassa* and 7 times lesser Bryozoa in 2007.

The subsequently performed ANOSIM and SIMPER (factor depth zone, square root transformed data) revealed that the depth zone segregation below the 1 m zone varied during the whole study period and disappeared in autumn 2007. As seen in the biomasses of relevant species (Table 3) the Anthozoa became more abundant towards the final samplings throughout the study during all seasons. Their percentile share increased and reached high values. At the same time, the *M. edulis* share below the 1 m zone decreased in all seasons and years. At the last sampled data in summer and spring, the community in the depths from 5 to 28 m were dominated by the Anthozoa. *Mytilus edulis* occurred only with negligible shares and was not depth zone typifying. In 2007, the Hydrozoa *Tubularia* spp. reached depth-zone typifying relevance for the zones deeper than the 1 m zone. *A. rubens* appeared with relevant abundances but without conspicuously high masses. *Jassa* spp. contributed to all depth zone communities.

Table 2

R-values from pairwise comparisons of epifauna communities in different depth on the underwater construction of the offshore platform FINO 1 in the North Sea by a two-way crossed ANOSIM based on square root transformed biomass data (factors water depth and sampling event). Asterisks indicate significant differences ($p < 0.05$).

m	1	5	10	20	25
5	0.96*				
10	0.98*	0.14*			
20	1.00*	0.50*	0.16*		
25	1.00*	0.50*	0.24*	0.08	
28	0.96*	0.50*	0.24*	0.29*	0.09

4. Discussion

In future offshore wind farms, thousands of wind turbine foundations will provide habitat for a hard bottom fauna which otherwise restricted to the sparse rocky habitats scattered within extensive sedimentary soft bottoms of the German Bight. For the German Bight it was proved that an offshore construction functions as a biomass hotspot within extensive soft sediment seafloor terrains. Such constructions also produce secondary artificial hard substrates by mussel shell litter fall and most probably alter the local ecology due to the fact that they are colonized by allochthonous epifauna communities.

4.1. Biomass and substrate production

4.1.1. Biomass production

Approximately half of the total biomass (4300 kg on average; 5000 kg during the last year) was attached to the 1 m zone. More than 90% of the mass was *M. edulis*. Throughout the investigation, the biomass in the uppermost sections of the underwater construction right below the sea surface fluctuated between 25 and 40 kg m⁻² but remained high with no consistent interannual development. On oil rigs, the biomass remained stable at this depth 5 years after construction (Kingsbury, 1981). In contrast, the biomass increased in deeper water levels of the platform FINO 1 throughout the study period. In the long term, this increase might lead to biomass below 20 m depth that is comparable to that found in the 1 m depth zone also in the deeper levels of at least 20 m (Kingsbury, 1981).

With 4.9 kg m⁻² biomass (calculated for the FINO 1 footprint area of 1024 m²) the platform represents a macrozoobenthos hotspot within a sedimentary environment where the average

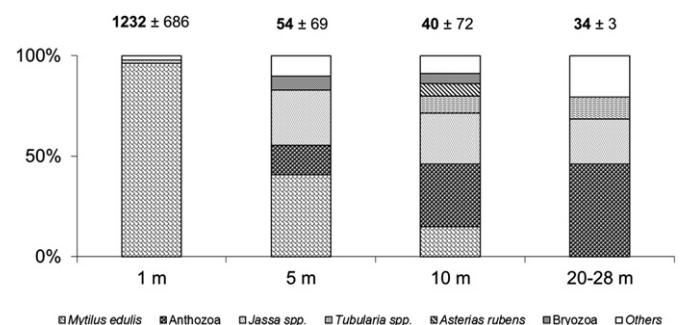


Fig. 5. Average contribution (%) of the depth zones typifying taxa (identified by SIMPER analysis) to the total epifaunal biomass in each depth zone on the underwater construction of the offshore platform FINO 1. Numbers above the bars give the average total biomass (0.04 gm⁻² ± SD) of the epifauna in each depth zone.

Table 3

Average non transformed biomasses and percentile shares of depth zone characterising species (revealed by SIMPER analysis with square root transformed biomasses, see text for definition) at all investigation years and seasons. Less than two samples in groups at 1 m in spring 2005 and autumn 2007. For the characterising species at the 5 and 10 m zones in 2005 the preconditions $\delta_i/SD(\delta_i) \geq 1$ and $S_i/SD(S_i) \geq 1$ were assumed (less than 3 replicates).

		Taxa	Biomass [g 0.04 m ⁻²] and [%]							
			1 m		5 m		10 m		20–28 m	
2005	Spring	<i>Mytilus edulis</i>	753.8	94.3	20.2	48.7	26.8	71.8	<0.1	<0.1
		<i>Jassa</i> spp.	17.3	2.2	10.4	25.2	6.9	18.6	5.5	55.5
		<i>Asterias rubens</i>	21.5	2.7	5.9	14.3	1.7	4.5	1.5	15.7
		Bryozoa	2.6	0.3	4.4	10.7	1.4	3.8	0.4	3.9
	Summer	<i>Mytilus edulis</i>	1316.7	93.4	25.3	31.6	0.6	1.2	2.6	6.7
		<i>Jassa</i> spp.	46.6	3.3	23.7	29.6	39.9	68.0	13.8	36.8
		Anthozoa	25.2	1.8	12.1	15.2	7.4	15.7	12.9	34.3
		Bryozoa	2.6	0.2	8.8	11.0	4.7	10.0	3.3	8.8
	Autumn	<i>Mytilus edulis</i>	1093.5	97.7	37.7	48.0	11.0	27.4	0.1	0.3
		<i>Jassa</i> spp.	16.1	1.4	30.5	38.8	9.5	23.8	1.8	4.6
		Anthozoa	2.9	0.3	4.5	5.7	10.3	25.6	31.5	81.6
		Bryozoa	1.1	0.1	2.9	3.7	1.1	2.9	2.6	6.7
2006	Spring	<i>Mytilus edulis</i>	796.3	93.6	19.8	50.7	18.7	46.9	<0.1	<0.1
		<i>Jassa</i> spp.	11.2	1.3	9.2	23.5	12.1	30.4	6.1	28.6
		Bryozoa	2.2	0.3	7.1	18.2	4.9	12.4	0.7	3.3
		green algae	24.1	2.8	0.1	0.2	0.0	0.0	0.0	0.0
	Summer	<i>Mytilus edulis</i>	1504.0	97.6	34.0	52.1	5.7	17.9	0.1	0.3
		<i>Jassa</i> spp.	17.4	1.1	13.9	21.3	8.9	28.0	13.8	38.7
		Anthozoa	4.9	0.3	2.7	4.1	0.2	0.5	4.1	11.6
		<i>Asterias rubens</i>	0.1	<0.1	8.5	13.0	0.6	1.8	0.8	2.3
	Autumn	Bryozoa	11.7	0.8	5.2	8.0	4.4	13.7	12.1	34.0
		<i>Mytilus edulis</i>	1117.6	98.5	24.3	39.6	0.01	0.01	<0.1	0.1
		<i>Jassa</i> spp.	7.4	0.6	14.0	22.8	2.3	10.8	1.2	4.9
		Anthozoa	2.6	0.2	14.3	23.3	16.6	77.0	17.8	73.5
	<i>Asterias rubens</i>	0.3	<0.1	3.0	4.9	1.2	5.7	0.5	1.9	
	Porifera	1	0.1	1.1	1.8	0.1	0.6	0.6	2.7	
	Bryozoa	3.7	0.3	3.6	5.9	0.5	2.3	2.7	11.0	
	2007	Spring	<i>Mytilus edulis</i>	899.7	97.5	29.5	49.5	0.02	0.05	0.03
<i>Jassa</i> spp.			14.1	1.5	19.0	31.9	10.8	22.9	16.1	43.0
Anthozoa			2.4	0.3	4.4	7.5	12.7	26.9	5.7	15.3
<i>Tubularia</i> spp.			1.6	0.2	3.3	5.5	14.3	30.4	10.5	28.0
Summer		<i>Mytilus edulis</i>	1631.5	96.8	0.3	1.5	0.2	0.3	1.9	3.9
		<i>Jassa</i> spp.	20.9	1.2	5.0	22.9	2.9	5.5	1.6	3.2
		Anthozoa	10.9	0.6	11.1	50.3	32.3	62.1	36.2	74.1
		<i>Tubularia</i> spp.	2.7	0.2	3.8	17.2	7.9	15.2	5.8	11.8
Autumn		<i>Asterias rubens</i>	6.1	0.4	0.2	1.0	3.6	6.9	1.2	2.5
		Porifera	2.3	0.1	1.1	5.2	3.8	7.4	0.1	0.3
		<i>Mytilus edulis</i>	1549.7	96.0	0.6	1.8	0.1	0.1	-	-
		<i>Jassa</i> spp.	51.3	3.2	4.9	15.7	3.9	10.5	2.6	7.4
	Anthozoa	2.3	0.1	22.1	71.4	24.4	65.6	26.4	76.1	
	<i>Tubularia</i> spp.	1.2	0.1	1.3	4.3	2.2	5.9	3.1	8.9	
	<i>Asterias rubens</i>	1.2	0.1	2.0	6.6	3.7	10.0	1.9	5.6	

macrozoobenthos biomass is 0.12 kg m⁻² (Dannheim, not published). When extrapolated to 5000 wind turbine foundations in the German EEZ (28.539 m²), our results predict an additional 25,000 tons of biomass in that region which is equivalent to the macrozoobenthos biomass of 208 km² of sandy soft bottom areas or an increase of 0.8% of total macrozoobenthos biomass in the German Bight. This biomass will be continuously exported from the artificial constructions into the surrounding sediments as released metabolic waste products or (dead) individuals that fall off the substratum. The largest biomass difference at FINO 1 was detected between summer 2005 with 5700 kg and the following spring 2006 with 3000 kg. The biomass of animals which are substituted by new recruits as well as the growth during this period was ignored and, therefore, 2700 kg are expected to be a conservative estimate of the potential net export of biomass within a period of nine months, more so as biofouling turnover rates within periods of 11–18 months have been reported (Wolfsson et al., 1979; Kingsbury, 1981). Consequently, a calculated yearly minimal net export of 13,500 tons from 5000 turbines is a conservative estimate. These masses may represent a secondary net production of biomass in the eutrophic North Sea (Carstens et al., 1990; Radach, 1992; Hickel

et al., 1993; Beusekom et al., 2008). The prospering communities on the artificial structures intensify the transformation of particulate organic matter (POM) into biofouling masses – which will be available for consumers of higher trophic level (Wolfsson et al., 1979; Freire and González-Gurriarán, 1995; Page et al., 1999; Reubens et al., 2011; Krone et al., submitted). In turn, substantial increases of predators may lead to an alteration of the predatory pressure on certain prey organisms (Baum and Worm, 2009).

4.1.2. 'Mytilusation'

M. edulis are common in the Wadden Sea and on natural hard substrates in the North Sea, but also on man-made constructions (Kingsbury, 1981; Riesen and Reise, 1982; Whomersley and Picken, 2003; Reise, 2005; Buschbaum et al., 2009; Kerckhof et al., 2010). Investigations from the Belgian and Dutch North Sea areas (Lewis et al., 2000; Zintzen et al., 2008a) and from the English Channel coasts (Hiscock et al., 2010) have shown that *M. edulis* generally does not settle on entirely submerged shipwrecks or settles only for short time periods in very low densities. In contrast, offshore constructions (with intertidal zones) in the southern, eastern and central North Sea are strongly colonized by *M. edulis* in surface near

water depths after only a few years of exposure. In the Belgian North Sea, *M. edulis* typically formed dense belts in the shallow subtidal zone at the six gravity based concrete foundations of the wind farm 'C-Power' three years after establishment of the structures in 20 m water depth (Kerckhof et al., 2012). West of the FINO 1 area, at the Dutch wind farm 'Egmond aan Zee' (36 wind turbine steel monopiles, 15–20 m water depth), *M. edulis* formed area-wide stocks dominating the fouling communities five years after the establishment of the wind farm (Bouma and Lengkeek, 2012). The monopiles were covered with *M. edulis* down to at least 7 and at most 12 m depths, only occasionally interrupted with belts of low and patchy coverage. In the uppermost metres at an offshore platform 18 km off the Dutch coast *M. edulis* formed a 65 cm strong belt from which sicker layers may fall off under its own weight (Leewis et al., 2000). At the Danish wind farm 'Horns Rev' (80 turbines on steel monopiles at 7 to 14 m water depth), *M. edulis* dominated the top three meters only three years after the establishment of the wind farm and contributed 90% of the total biomass on all piles. Also, at the Swedish west coast, the biofouling on wave power buoys was dominated by *M. edulis* (85% of biomass), while the mussels were not reported to be present on the fully submerged buoys foundations at 25 m depth (Langhamer et al., 2009). Finally, further offshore in the central and northern North Sea, *M. edulis* dominated the fouling communities at four investigated oil rigs (80 and 167 m water depth, respectively) down to a depth of 20 m within a study period of 10 years (Whomersley and Picken, 2003). At present, FINO 1 represents the first construction spanning the whole water depth within the open German Bight, the centre of Belgian, Dutch and Danish North Sea areas and the central North Sea, which has been sampled continuously beyond the initial colonisation phase (Joschko et al., 2008). At FINO 1, *M. edulis* accounted for about 75% of the whole epifaunal biomass. It occurred almost exclusively in the uppermost depth zone where the numbers decreased during the course of the investigation while shell size increased. Thereby, the *M. edulis* biomass remained on a high constant level in the 1 m depth zone (0–2.5 m depth). At deeper levels, however, mussel biomass and abundance decreased. This depth proliferation of *M. edulis* is rather low, compared to the findings from piles and platforms located in other areas of the North Sea. Numbers derived from this study should thus be seen as very conservative estimates for extrapolations to larger areas. Nonetheless, transferring the *M. edulis* colonisation recorded at FINO 1 to thousands of comparable offshore wind turbine foundations planned in the future will lead to a 'Mytilisation' of offshore regions within the entire south-eastern North Sea. This will most likely affect the local ecosystem through the production of secondary hard substrates, the massive release of planktonic larvae, and an intensified filtration of the surrounding waters.

The substrate export consisting of mussel shells from ceased animals changed qualitatively throughout the study period, because the mussel numbers decreased and the shells became larger from year to year. The last detected standing stock contained 319,000 double shells at the 1 m zone and 120,000 at all deeper zones; totalling 2000 kg mussel shells. Assuming a yearly turnover (Wolfson et al., 1979), this amount of shells would also be exported every year. The revealed annual hard substrate production (303 m² mussel shell surface) may alter the substrate characteristic of the surrounding sea bottom to some degree. Yearly, 878,000 single shell halves sink onto the bottom. Therefore the reef effect exceeds by far the habitat creation by the construction of ~1300 m² steel surface. Within 15 years, calculated 4545 m² mussel shells, 3.5 times of the construction surface, will be added to the seafloor. Many of the shells will be ground to sand and covered by sediment, however, as found below mussel aquacultures (Freire and González-Gurriarán, 1995) and offshore rigs (Wolfson et al., 1979)

the production of long lasting shell debris may lead to coarser, shell-dominated sediment and enriched structure diversity. Aggregated as well as dispersed shells potentially serve as attachment sites for sessile reef forming organisms such as *Sabellaria* spp. (Holt et al., 1998) and *Ostrea edulis* (Schmidt, 2009). This additional stock in offshore locations will be a permanent larvae source for settlement in artificial and natural offshore and coastal habitats. Another 10⁴ tons or 1.6 × 10⁹ individuals of *M. edulis* (calculated for 5000 wind turbines) would add an additional 60% and 33% (calculated with FINO 1 data from 2005 and 2007) of the already existing German Wadden Sea mussel population to the ecosystem (Nehls et al., 2009). With an average filtration rate of 1.5 to 3.0 l h⁻¹ individual⁻¹ (Mølenberg and Riisgård, 1979; Famme et al., 1986; Clausen and Riisgård, 1996) this offshore mussel population will filtrate an amount of seawater which is within the range of the combined effluent of the rivers Elbe, Weser, Ems, and Eider (4.56 × 10⁹ l h⁻¹) into the German Bight. Therefore, the mussels are expected to influence the water clearance through their filtering activity at least on a local scale. At the same time, the mussels' high productivity may lead to an increased amount of sinking (pseudo-) faeces and subsequently to an organic enrichment in the surrounding sediments below. Depending on the site-specific sediment characteristics increased sedimentation rates, organic enrichment and nutrient entries can cause depletions or increase of benthic communities (Kaspar et al., 1985; Wilding, 2012). Future *M. edulis* stocks might occupy an important role as a quantitatively new link between the pelagic and benthic ecosystem by increasing annual deposition of nutrients and by circulating and regenerating some share of the nutrient demands for pelagic primary production (Kautsky and Evans, 1987).

These calculations are based on the abundance, biomass and the specific distribution pattern of *M. edulis* on FINO 1 in the years 2005–2007. Previous studies have shown that *M. edulis* populations on offshore construction can extend into much deeper waters (Kingsbury, 1981; Whomersley and Picken, 2003) and a recent optical inspection of FINO 1 revealed that *M. edulis* is expanding into deeper water levels (Winter, unpublished results) indicating that the mussel biomass will further increase even after longer periods of time after the construction of the platform. Current studies at the first German wind farm 'alpha ventus' (6 tripod foundations and 6 jacket foundations, water depth 30 m) located directly next to the research platform FINO 1 revealed that three years after its establishment the foundations were similarly colonised by *M. edulis* as those of FINO 1, i.e., in the surface near depth range down to 2.5 m and recently also more dominating in the 5–10 m depth zones (Preuß et al., 2012). To what extent the expected *Mytilus*-colonisation and 'Mytilisation' will take place and how strong its influence on North Sea ecosystems will be, remains to be proven and also depends on the size, shape and material of the future wind turbine foundations. For example, tripod constructions, a favoured foundation type for offshore wind turbines, provide more settlement surface than that provided at FINO 1 and thus, will presumably allow for stronger *M. edulis* induced reef effects than predicted here. Conversely, monopile foundations, providing clearly less settlement surface, might reduce future reef effects and hence, the 'Mytilisation'. In addition, future research will need to show, whether an increase of *Mytilus* populations could take place in all other potential offshore wind power regions, or if site-specific effects can prevent strong colonization processes. Conversely, intertidal constructions located far away from natural and artificial *M. edulis* stocks (e.g., attached to wind power foundations) in the northern regions of the North Sea might not be colonized as strongly, because they might lie outside the distributional range of *M. edulis* larvae as has been concluded by Forteach et al. (1982). Wind power foundations in

such areas would then not support 'Mytilisation'. However, the depth distribution of *M. edulis* tends to be positively correlated with the distance to the coast or the actual depth at the position of the wind farm. For example, foundation structures at FINO 1 and at Belgian wind farms which are located close to the coast erected in shallow water depths were found to show increased settlement numbers of *M. edulis* closer to the surface than those structures located in the central North Sea. High abundances of the *M. edulis* predating sea star (*A. rubens*) in coastal waters may, in fact, counteract the mussels high larval support and spat fall capacity. Hence, 'Mytilisation' might underlie an onshore-offshore gradient.

4.2. Epifauna communities on the artificial structure

The biomass of the epifauna community remained relatively stable on a yearly basis with a tendency towards higher values in summer while the structure of the community changed during the investigation. With 58 identified taxa, the number of identified taxa increased by 14 between the first two years and the following three to five years after establishment (Orejas et al., 2005). This increase is most likely due to the longer duration of exposure and thus, the increased successional processes under continuous planktonic recruitment. Nonetheless, the comparably high number of 78 species which was found at the Belgian wind farm 'C-Power' could not be detected, even though both wind farms had been established and operating for about the same period of time. This might reflect onshore-offshore gradients or distances of larval origin contributing to artificial hard substrate communities, and might also reflect Atlantic water gradients of colonization, more so as the 'C-Power' wind farm is more under Channel water influence than is FINO 1. As mentioned in the 'Mytilisation' discussion, such site-specific components must be considered when monitoring ecological impacts of the wind power biofouling in different North Sea areas. On other offshore constructions, substantial changes in the epifauna community still occurred nine years after construction (Whomersley and Picken, 2003; Butler and Conolly, 1999). The epifauna on the underwater construction of FINO 1 was vertically structured into three distinct communities. In the 1 m zone the community was dominated by *M. edulis*. In the 5 m depth zone, the *M. edulis* cover became interspersed by tubes of the Amphipoda *Jassa* spp. Below the 5 m zone down to the seafloor the community was dominated by Anthozoa. In some seasons, the distinction of these three communities was less pronounced and was not evident in summer 2005 and in autumn 2007. Whether a uniform community will develop below the *M. edulis* belt in the long term, as it has been described for steel foundations in Danish and Dutch coastal waters (Leonhard and Pedersen, 2006; Lindeboom et al., 2011), remains to be seen. The composition of the epifauna community varied seasonally, however regular seasonal cycles with typical spring, summer or autumn communities were not evident, even though some species showed consistent biomass cycles each year. For example, biomass of *M. edulis* was lowest in spring and highest (approximately double) in summer. Biomass of the Anthozoa was lowest in spring. Similar pronounced seasonal biomass fluctuations have been reported from soft bottom epibenthos (Reiss and Kröncke, 2004). Macroalgae were almost entirely absent from the platform construction. Water turbidity would allow macroalgae to proliferate in the German Bight into water depths of at least 7 (green algae), 10 (red algae) and 5 m (brown algae), respectively (Lüning and Dring, 1979; Pehlke and Bartsch, 2008) at FINO 1. Dense brown algae stocks have been reported from large oil platforms in the central North Sea (Fortearth et al., 1982; Kingsbury, 1981). The lack of algae may be a result of the young age of FINO 1 community where constantly changing biofouling layers may not allow enough time for an algal

community to develop. The exposed conditions found at FINO 1 may hinder the establishment of brown algae such as e.g., *Fucus* spp. that rather thrive in more sheltered conditions, which do not exist at such an offshore location. Other reasons may be the variability between individual offshore constructions in general, where succession depends on the date of exposure or the presence of grazing species (Kingsbury, 1981).

The community below the 1 m zone was dominated by Anthozoa. The many juvenile *M. edulis*, which were observed in deeper sections of the foundation at the beginning of the investigation period, vanished over time and the Anthozoa started to take over in addition to *Jassa*. The Hydrozoa *Tubularia* spp. started to contribute significantly to the deep community during the 5th year after construction. Increasing amounts of *Tubularia* spp. agree with observations by Zintzen et al. (2008a, 2008b) and Krone (not published) who found that most shipwrecks in deeper waters were dominated by Anthozoa or Hydrozoa. The subtidal zonation pattern on FINO 1 differs from those on offshore platforms in deep waters of the central and the northern North Sea where *M. edulis* dominated since the third year after construction down to a water depth of 20 m. In deeper levels from 20 to 140 m, Hydrozoa and Anthozoa (on a single platform) dominated the communities while the tubes of *Jassa* did not seem to contribute conspicuously to the surface coverage (Whomersley and Picken, 2003). At concrete foundations of offshore wind turbines in Belgian waters, *M. edulis* dominated stocks were reported from the shallow subtidal down to 20 m during the first two years after construction (Kerckhof et al., 2010). At FINO 1, *Jassa* rather than *M. edulis* dominated the surface cover in the 15–20 m water depths. Perhaps in the Belgium case the juvenile cover will also decrease due to crabs and star fish as their main predators (Wolfson et al., 1979; Reise pers. comm.). As well as in the case of 'Mytilisation' the different zoning of concrete gravity foundations and the steel jacket FINO 1 as well as general differences between the communities on these two substrates (Connell, 2001; Andersson et al., 2010) need to be considered in future in-depth epifauna research and impact assessments.

The dominant epifauna species on FINO 1, *M. edulis*, Anthozoa (mostly *M. senile*) and *Jassa* also occur in the littoral of the island of Helgoland (Anger, 1978; de Kluijver, 1991; Reichert and Buchholz, 2006) which is the only really comparable natural rocky littoral site in the south-eastern North Sea. At Helgoland, *M. edulis* is restricted to the lower intertidal where the species reaches a surface coverage of only 0–5.7% (Reichert et al., 2008). Deeper, down to 17 m water depth, *M. edulis* is not abundant either with a maximum surface coverage of 2.6% (De Kluijver, 1997). These mussels densities appear negligible as compared to the dense *M. edulis* belt on FINO 1. *M. senile* as well as Anthozoa are patchily distributed. Within the patches these species might occur with densities comparable to those on the FINO 1 underwater construction. However, large areas of the Helgoland rocky subtidal are almost entirely free of these species. Thus, the artificial hard substrata provided by the wind turbines might add a benthic component to the process of 'jellification' of coastal seas (Richardson et al., 2009) as they allow for the colonization of highly abundant Anthozoa. *Jassa*, which is very abundant on FINO 1, occurs also in the natural intertidal of Helgoland, albeit in lower densities than on the offshore platform (Reichert and Buchholz, 2006; Reichert et al., 2008). Only on the artificial hard substrata of Helgoland, such as pontoons and jetties, these Amphipoda reached densities of up to about 20,000 individuals m⁻² (Nair and Anger, 1979; Beermann and Franke, 2012). In comparison FINO 1 provides ten times more *Jassa* per m² than Helgoland's artificial habitats. The permanent presence of *Jassa* with its lifespan of 149 to 252 days (Nair and Anger, 1979) may yield 1.5 to 2.5 times per year of the 306 kg (plus 830 kg tubes) and 3.3×10^8 individuals are being

produced at FINO 1. They may serve as a rich and easily accessible food resource for e.g., large pouting coveys (*Trisopterus luscus*) which feed in the vicinity from artificial hard substrata on *Jassa herdmani* (Reubens et al., 2011).

All three dominant species found at FINO 1 are filter feeders, most likely adapted to the strong hydrodynamic demands, and presumably profit from being highly exposed to the surrounding currents at the offshore constructions. At the same time, the lack of morphological diversity in the structures on site and the homogeneous design of the spatial niche provided, which is practically not present at Helgoland's habitats, most likely leads to the massive area-wide coverage of these individual species. Conversely, this type of area-wide coverage could probably be interrupted by artificially creating increased structural diversity in the provided settlement surfaces. Wind turbine foundations will likely provide stepping-stones for the spread of hard bottom species. In this context, Lindeboom et al. (2011) suggest that the function of wind turbine foundations will hardly exceed those of the thousands of shipwrecks, which have been present in the North Sea for a long period of time. However, among 64 investigated shipwrecks in the German Bight not a single one (Krone and Schröder, 2011) has been visibly colonized by *M. edulis* (Krone and Schröder, not published). Additionally, the pacific oyster *Crassostrea gigas*, which is restricted to a maximum water depth of 15 m (Miossec et al., 2009), has not been detected on shipwrecks or in the deeper sections of FINO 1 while the intertidal of the platform has been successfully colonized by *M. edulis* and the invasive oyster. These examples clearly demonstrate that wind turbine foundations will add an extensive qualitatively new intertidal and shallow subtidal habitat in the North Sea and, thus, also numerous stepping-stones for the spread and stock enhancement of species which are able to colonize this habitat.

5. Conclusion

Because scientific offshore-diving projects are highly time-, staff- and money consuming, methodological constraints need to be taken into consideration and must be acknowledged when interpreting the results and predicted scenarios. Since weather conditions hardly allow for offshore sampling in winter, this season was not included. However, the present study provides the most comprehensive biofouling data set from offshore artificial constructions for the south-eastern North Sea. It is a basis for impact scenarios related to the large-scale introduction of artificial reefs and for long-term studies in this area. Our results show that offshore constructions such as platforms and wind turbines, not only increase the amount of settlement surface available for hard bottom communities in the North Sea. They also provide new hard substrates which allow for massive population increases of certain hard bottom species which do not occur in comparable natural rock habitats. Especially in the case of *M. edulis*, this might result in a 'Mytilisation' of the ecosystem caused by the introduction of thousands of turbine foundations providing new settlement grounds. That underlines that artificial hard substrates from wind farm foundations should not be considered a replacement for removed or destroyed natural rocky habitats (Kerckhof et al., 2012). The high numbers of suspension feeders on the surfaces of the constructions will remove large amounts of suspended particles from the water column and provide valuable food for intermediate and top predators, potentially altering the local food net. Although the cumulative effects of numerous wind turbines in future wind farms cannot be appropriately estimated yet the predicted 'Mytilisation' and better food availability for vertebrates and invertebrates are suggested to be major future effects on the ecosystem. Further research is required to assess whether the epifauna

community structure and its depth distribution at FINO 1 remain stable over time and whether other foundation types support different communities.

The process of 'Mytilisation' and its effects on the cycling of matter and energy as well as the associated generation of biogenic reefs are still at the very beginning as only a small percentage of the thousands of planned wind turbines have been built so far.

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Sample processing, Analysis, Article preparation
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Sample processing, Article preparation
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Sampling, Article preparation, Statistics

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