Seasonal variation and vertical zonation of the marine biofouling on a concrete offshore windmill foundation on the Thornton Bank (southern North Sea)

Article

Chapter 5. Seasonal variation and vertical zonation of the marine biofouling on a concrete offshore windmill foundation on the Thornton Bank (southern North Sea)

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Abstract

In late spring 2008 the first six concrete foundations of the C-Power wind farm were installed at the Thorntonbank, some 30 km off the Belgian coast. In the coming years several hundreds of foundations of various types and materials will be implanted in various wind farms in a designated area of the Belgian part of the North Sea (BPNS). With the construction of windmills, a new habitat of artificial hard substratum is being introduced in a region mostly characterized by sandy sediments. This has increased the habitat heterogeneity of the region and the effect of the introduction of these hard substrata – the so-called reef effect – is regarded as one of the most important changes to the original marine environment caused by the construction of wind farms. Consequently a monitoring programme was set up to study the development of biofouling on the new hard substrata associated with the windmills. Here, we address the species composition, vertical zonation, short term succession, and seasonal variation of the marine biofouling on a concrete offshore windmill foundation on the Thornton Bank.

During eight sampling campaigns between February 2009 and February 2010, scuba divers collected subtidal scrape samples at depths ranging from 4 to 25 m. In addition, the intertidal zone was sampled four times during the same period. During the sampling period, a total of 75 taxa (mostly species) were identified, including 13 spp. exclusively in the intertidal. Forty two spp. had not been previously recorded at the site under investigation. Our results confirm the previously observed vertical zonation with three zones: an intertidal – splash zone, a transitional barnacle-*Jassa* zone and an extensive subtidal zone and illustrate a strong seasonal signal in community structure. In the intertidal, the fine scale zonation became more apparent: by summer 2009 a conspicuous mussel belt was established in the transitional barnacle-*Jassa* zone and a clear zone of the intertidal barnacle (*Semibalanus balanoides*) became apparent in the splash zone. Larger algae were rare. For a number of species it remains unclear whether the observed changes in relative abundance reflect either a recurring seasonal cycle or a more gradual successional change, although a combination of both is more likely. Despite differences in substratum type our preliminary results indicate that the overall structure of the marine biofouling community encountered at the Thornton Bank site is similar to that encountered on the foundations of other offshore wind farms in Germany, Denmark and The Netherlands and on other hard structures in the North Sea. Three of the four non-indigenous species encountered in 2008 were found again in 2009: *Crepidula fornicata, Elminius modestus* and *Telmatogeton japonicus*.

Samenvatting

In de late lente van 2008 werden op de Thorntonbank, ongeveer 30 km uit de Belgische kust, de eerste zes windmolens van het C-Power windmolenpark gebouwd. Tijdens de komende jaren zullen in de daarvoor speciaal voorziene zone in het Belgische deel van de Noordzee (BDNZ) nog meer windmolens gebouwd worden in verschillende windmolenparken. Met de bouw van windmolens wordt een nieuw habitat van artificiële harde substraten gecreëerd in een gebied waar voornamelijk zandige sedimenten voorkomen. Daardoor zal de habitatheterogeniteit van het gebied verhogen. De introductie van harde substraten - het zogenaamde "reef effect" - wordt beschouwd als de belangrijkste verandering die de oprichting van windmolenparken in het oorspronkelijke mariene milieu zal veroorzaken. Daarom werd een monitoringprogramma uitgewerkt om de aangroei van organismen op de nieuwe harde substraten geassocieerd met de windmolens op te volgen en te bemonsteren. Hier gaan we in op de soortensamenstelling, de verticale zonering, de korte termijn successie en de seizoenale variatie van de aangroei op een van de betonnen windmolenfunderingen op de Thorntonbank.

Tijdens acht bemonsteringcampagnes werden tussen februari 2009 en februari 2010 subtidale schraapstalen genomen op dieptes van 4 tot 25 m. Daarnaast werd in dezelfde periode de intertidale zone vier keer bemonsterd. In de stalen werden 75 taxa (meestal soorten) geïdentificeerd waarvan 13 soorten alleen in het intertidaal aangetroffen werden. Tweeënveertig soorten waren nog niet in eerder onderzoek aangetroffen. Onze waarnemingen bevestigden de vroeger waargenomen dieptezonering in drie zones met een intertidale – spatzone, een overgangszone met *Jassa* en zeepokken en een

uitgebreide subtidale zone. Daarnaast konden we in de structuur van de aangroeigemeenschap een sterke seizoenale invloed vaststellen. In het intertidaal werd de onderverdeling van de zonering gedetailleerder: in de zomer van 2009 had zich in de *Jassa* – zeepokken zone een duidelijke mosselzone gevestigd en in de spatzone was een zone met gewone zeepokken (*Semibalanus balanoides*) ontstaan. Macroalgen waren zeldzaam. Voor een aantal soorten blijft het onduidelijk of de waargenomen veranderingen in relatieve abundantie de afspiegeling zijn van een terugkerende seizoenscyclus dan wel van een meer geleidelijke verandering in de successie al is vermoedelijk een combinatie van beide waarschijnlijker. Ondanks verschillen in het substraat tonen onze eerste resultaten aan dat de globale structuur van de aangroeigemeenschap op de funderingen op de windmolens op de Thorntonbank gelijkaardig is aan die aangetroffen op de funderingen van windmolens in Duitsland, Denemarken en Nederland en op andere harde substraten in de Noordzee. Drie van de vier niet-inheemse soorten aangetroffen in 2008 werden in 2009 opnieuw gevonden: *Crepidula fornicata*, *Elminius modestus* en *Telmatogeton japonicus*.

5.1. Introduction

In late spring 2008 the first six concrete foundations of the C-Power wind farm were installed at the Thorntonbank, some 30 km off the Belgian coast. Between September 2009 and February 2010 a further 56 steel monopile foundations were installed on the Bligh Bank. With the construction of windmills in the Belgian part of the North Sea (BPNS), a new habitat of artificial hard substratum is being introduced in a region mostly characterized by sandy sediments. This has enhanced the habitat heterogeneity of the region and the effect of the introduction of these hard substrata – the so-called reef effect – is regarded as one of the most important changes of the original marine environment caused by the construction of wind farms (Petersen & Malm, 2006).

It is well known that submerged artificial hard substrata are rapidly and intensively colonised (e.g. Horn, 1974; Connell & Slayter, 1977). This had been found to be the case with windmills in the North Sea (e.g. Schröder et al., 2005; Kerckhof et al., 2009). Fouling assemblages will develop successively, which may resemble epibioses on natural substrata (e.g. Connell, 2001). The windmills will also permit the establishment of species previously not present in an environment dominated by soft sediment habitats, as well as the further spread of non-indigenous species (stepping stone effect). It is also expected that certain warm water species will take advantage of the increased presence of hard substrata to further spread into the North Sea. Alternatively, the foundations and associated scour protection may allow for the re-establishment of biological communities previously present on nearby gravel beds.

The establishment of a biofouling community is expected to follow a clear successional development: the new structures will be gradually colonized by a number of species. These organisms will each influence the environment in a species-specific way, as such preventing other organisms to get established (i.e. inhibition) or creating the right circumstances for other species to join in (i.e. facilitation) (Connell & Slatyer, 1977). Consequently, the number of individuals of each species in the community will change and gradually new species will arrive that may progressively replace the first inhabitants. This long term process is known as ecological succession. Next to this process also shorter-term and often recurrent variations in species composition, known as seasonality, take place during the year. Both processes constitute the focus of this research.

The main objectives of this investigation were:
- to study the development of the epifouling communities on the concrete foundation in the first and second year after installation (species composition, vertical zonation, seasonal and successional changes)
- to determine to which extent non-indigenous species colonized the new hard substrata

5.2. Material and Methods

5.2.1. Study site

The C-Power wind farm is located on the Thornton Bank, a 20 km long natural sandbank located in the BPNS, near the border between the exclusive economic zones of Belgium and the Netherlands. The bank lies some 30 km offshore and belongs to the Zeeland banks system (Cattrijsse & Vincx, 2001). Local water depth is about 30 m and the surrounding soft sediment seabed is composed of medium sand (mean median grain size 374 μm, standard error 27 μm) (Reubens et al., 2009).

At present six windmills are built on the bank. The six concrete foundations of these windmills were placed on a line, 500 m from each other, between 27 April and 29 May 20008. Each turbine foundation consists of a base slab, a truncated conical portion, a cylindrical portion and a platform (Demuynck & Gunst, 2008). The conical portion of the turbine foundation rises 14 m above the seafloor and has an outside diameter that varies from 14 m at the seafloor to 6.5 m at the top, i.e. the junction with the cylindrical part. The conical part of the foundation and the sub- and intertidal portion of the cylindrical part are available for colonisation by subtidal and intertidal organisms comprise 651 m² subtidal and 92 m² intertidal surface area for windmill D5, the foundation where all samples for this investigation were collected. Because of bathymetric variations within the wind farm area, minor deviations in the subtidal surface area of the other windmills (about 17%) exist.

5.2.2. Sample collection and processing

A monitoring programme was set up to sample the hard substrata associated with the windmills (Kerckhof et al., 2008), and the first sampling took place in autumn 2008 (Kerckhof et al., 2009). Sampling was continued in 2009 and 2010. All samples analysed here were collected on the foundation of windmill D5, (co-ordinates WGS 84: 51°32,88'N - 2°55,77'E, installed on 30 May 2008) between January 2009 and February 2010, covering a full seasonal cycle. A total of 27 scrape samples for epibiota were collected consisting of 23 subtidal and four intertidal samples (table 1).

Table 1: Samples collected at the foundation of windmill D5 between January 2009 and February 2010.

Subtidal Samples			Intertidal Samples	
Date	**Sample code**	**depth (in m)**	**Date**	**Sample code**
16/02/2009	CP/09/2 S1	25.0	29/01/2009	CP09/1 1
	CP/09/2 S3	20.0		
	CP/09/2 S2	15.0		
19/03/2009	CP09/3 S3	22.5		
	CP09/3 S1	10.0		
03/07/2009	CP09/4 S1	21.0		
	CP09/4 S3	15.6		
	CP09/4 S2	4.0		
16/07/2009	CP09/5 S1	20.5	16/07/2009	CP09/5 1 & 2
	CP09/5 S2	13.5		
	CP09/5 S3	6.5		
12/08/2009	CP09/7 S1	15.0		
	CP09/7 S2	15.0		
	CP09/7 S3	15.0		
24/08/2009	CP09/9 S1	15.0		
	CP09/9 S2	15.0		
	CP09/9 S3	15.0	28/09/2010	CP09/10 1 & 2
22/10/2009	CP09/11 S1	15.0		
	CP09/11 S2	15.0		
	CP09/11 S3	15.0		
24/02/2010	CP10/1 S1	15.0	24/02/2010	CP10/1 1 & 2
	CP10/1 S2	15.0		
	CP10/1 S3	15.0		

Subtidal samples were collected by scraping the fouling organisms with a putty knife from a sampling surface area of 0.25 m x 0.25 m. Due to practical constraints intertidal scrape samples were collected in a non-quantitative manner. All scraped material was collected in plastic bags that were sealed under water and transported to the laboratory for processing – fixation (5% formaldehyde – seawater solution), sieving, sorting, preservation (75% ethanol) and identification. Sieving was done through a 1 mm mesh-sized sieve. The fraction >1 mm was analysed.

The biota (further called species) were identified to species level whenever possible. Identifications were based on the most recent systematic literature and we followed the World Register of Marine Species (WoRMS) for the nomenclature and taxonomy. Densities were expressed as the number of individuals per m². The abundance of colonial organisms was estimated as the degree of coverage, using the categories in EN ISO 19493 (2007). Video footage collected by the divers was used to determine to what extent the scrape samples represent the actual fauna and to identify a number of rare, large and/or mobile invertebrate species that are otherwise not (adequately) represented in the scrape samples. In the intertidal, the presence of certain macro algae was noted. Depth of the subtidal samples was measured with a pressure gauge from a Liquivision X1 dive computer as the depth from the water surface at sampling time.

5.2.3. Data analysis

Colonial organisms were excluded from diversity analyses, except for species richness (N_0), and two species, *Odostomia turrita* and *Pusillina inconspicua*, were further excluded as these species are usually smaller than 1 mm, and hence not representatively retained on 1 mm sieves.

For the analysis of diversity, Hill's diversity indices (order 0, 1, 2 and infinity) were calculated (Hill, 1973). N_0 attributes the same weight to all species, independent of their abundance. It can be seen as the species richness, the number of species in the sample. N_1 gives less weight to rare species while N_2 gives more weight to abundant species. N_{inf} only takes into account the most abundant species. These indices were calculated using PRIMER 6 (Plymouth Marine Laboratory). We used Principal Component Analysis (PCA) to determine the main structuring variables in our data sets (ter Braak & Prentice, 1988). The percent species abundance data were square-root transformed prior to numerical analysis in order to stabilize their variances. Only species encountered in at least two samples and with a relative abundance of more than 1% were included in the ordinations. Time since installation (time) was included in the PCA analysis only as passive variable, and as such did not influence the ordination (Lepš & Šmilauer, 2003). Multivariate statistics were performed using the package CANOCO v. 4.5 (ter Braak & Šmilauer, 2002).

Two depth transects were chosen to illustrate the main changes in relative abundances of the epifouling communities (February and July, representing respectively winter and summer; Figure 3)

5.3. Results

5.3.1. General diversity

In the sampling period of February 2009 to February 2010, a total of 75 taxa, further called species, were identified from the offshore turbine foundation (full species list can be found in Annex 1). Fifty nine species were discovered in the scrape samples (> 1 mm), four species were only found by the study of the underwater video footage including three Decapoda which had previously been found on the foundations in 2008 and additionally the presence of three macroalgae was noticed by visual inspection of the intertidal zone. Of the total of 75 species, 42 species had as yet not been encountered on the foundations and 33 species were previously detected in 2008. On the other hand 17 of the 50 species found in 2008 (Kerckhof et al., 2009) were not recorded again in this sampling period.

In this sampling period, species belonging to twelve phyla (or correspondingly large taxonomic divisions) were found (Annex 1). In comparison with 2008 four new phyla were present while one was not found again. On the other hand no sponges or tunicates were found.

Several species were present as juveniles only e.g. the North Sea crab *Cancer pagurus* and some juvenile stages of bottom dwelling benthic species were encountered as well. After the winter of 2009, some species such as the bivalves *Aequipecten opercularis* and *Heteranomia squamula* were not found again. In the winter of 2010, new species were present in the samples including a second species of *Tubularia*, *T. indivisa* and the entoproct *Pedicellina nutans*.

In the subtidal zone three phyla: Mollusca, Annelida and Arthropoda – Crustacea, accounted for 73 % of the species richness (Figure 1). The same three phyla, but in a different order, were also the most dominant ones in 2008, accounting for 83 % of the species.
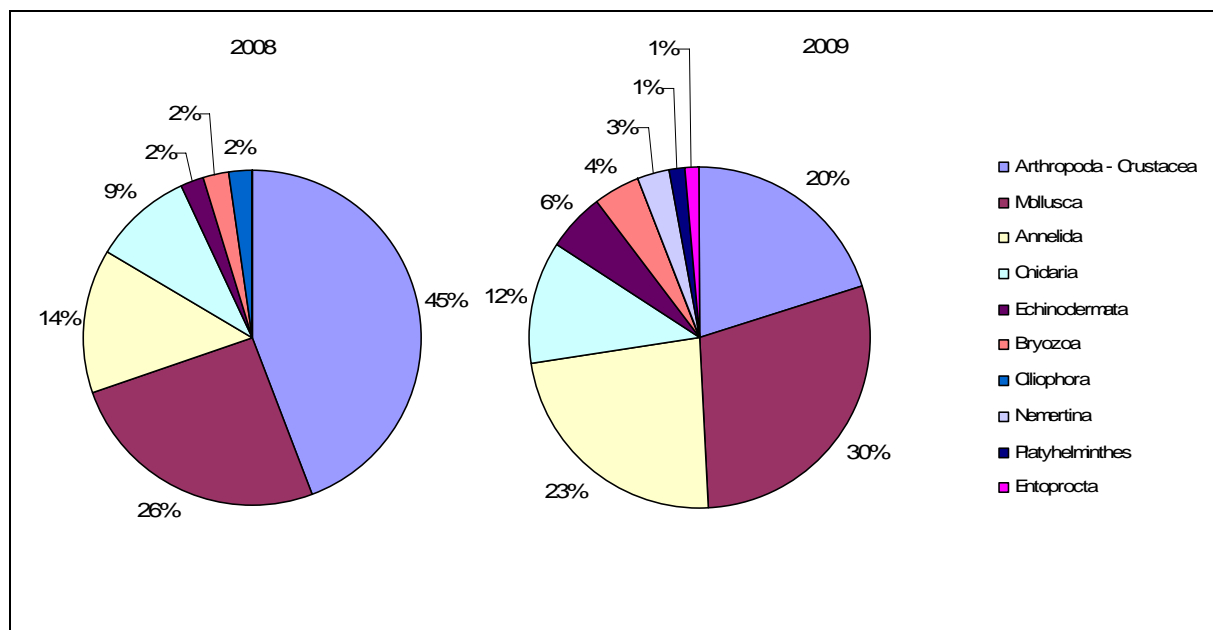

Figure 1. Proportion of the species richness of the phyla in the subtidal zone for 2008 en 2009. Percentages indicate the relative proportion of the respective phylum (n = 3 samples 2008 and 23 samples 2009)

5.3.2. Zonation

The previously observed zonation pattern of three distinct zones (Kerckhof et al., 2009) remained generally apparent. The intertidal – splash zone, formerly almost solely dominated by the presence of the giant midge *Telmatogeton japonicus*, became somewhat more subdivided, with a lower conspicuous zone dominated by the barnacle *Semibalanus balanoides*. Above this barnacle zone, in the splash zone, green algae were sparsely represented while the giant midge *T. japonicus* was found year round. This species also descended into the *Semibalanus* zone. In between the *S. balanoides*, specimens of the New Zealand barnacle *Elminius modestus* were observed. Larger algae were rare, and only a few isolated specimens of *Fucus vesiculosus* and *Porphyra umbilicalis* were noticed.

Most notable was the establishment of a conspicuous mussel *Mytilus edulis* belt in the transitional barnacle – *Jassa* zone by the summer of 2009. In this zone, mussels had covered the initial barnacles *Balanus perforatus* while the tube dwelling amphipods *Jassa* spp. were still present.

Analysis of four subtidal depth-transects shows that species richness and evenness increased with depth. Additionally, independent of depth, species richness generally increased from February to July (Figure 2). Densities increased 10-20 fold from winter (February-March) to summer (July) (Figure 2). Furthermore, the dominance of *J. herdmani* decreases with increasing depth in summer well as in winter (Figure 3). In winter 2009 *Potamoceros triqueter*, *Actinaria* spp., *Pisidia longicornis* and *M. edulis* were dominant at 20 and 25 m depth. In summer, other taxa, such as *Phyllodoce mucosa*, *Balanus crenatus* and *Asterias rubens* were most abundant at 15 and 21 meter depth.
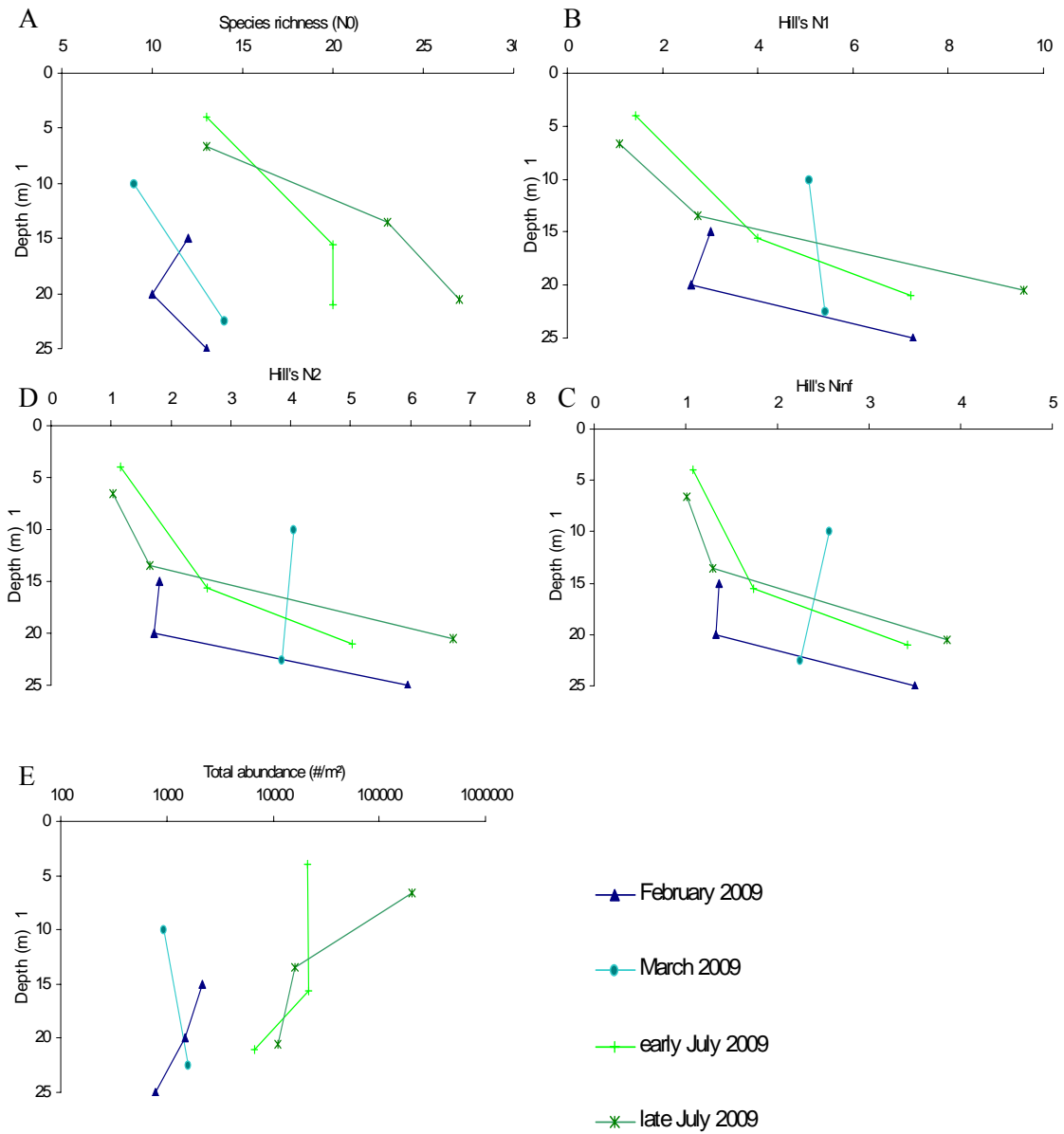
Figure 2. Species richness (Hill's N_0 – A), Hill's N_1 (B), N2 (C) and N_{inf} (D) diversity indices, and abundance (E) for four subtidal depth transects.
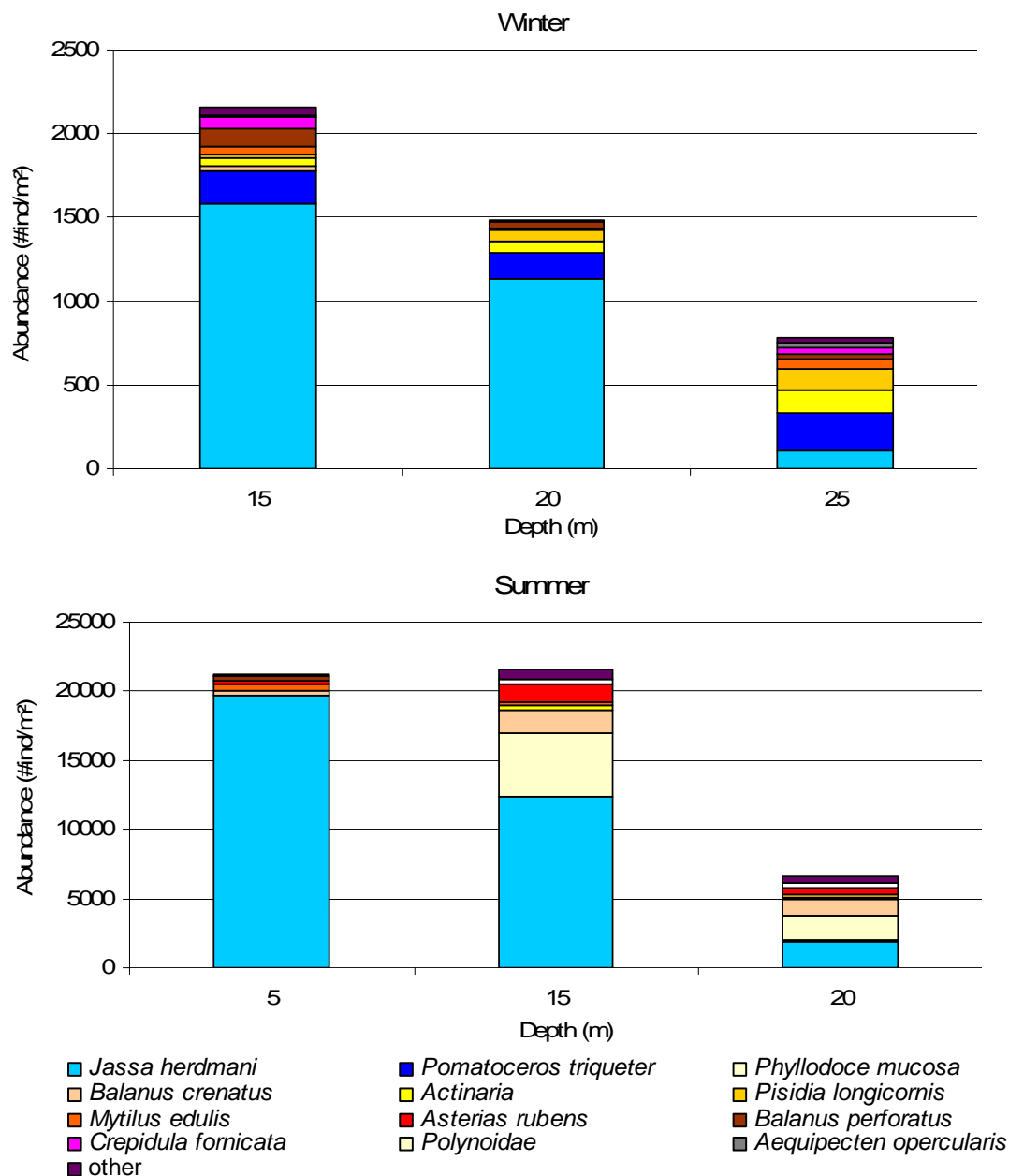
Figure 3. Absolute abundances of major taxa in winter and summer subtidal depth transects.

5.3.3. Seasonal variation

The analysis of eight sets of samples taken at 15 m depth showed a relatively low species richness at the start of the current monitoring period (~10 species in winter 2009; Figure 4). Species richness doubled from March to July 2009 and remains fairly stable thereafter (~20 species). In February 2010 species richness varied strongly between the three replicates (respectively 9, 22 and 31 species were present). A similar seasonal pattern was found for overall abundances, with low densities in February-March 2009 and higher abundances thereafter, mostly caused by high densities of *J. herdmani*.
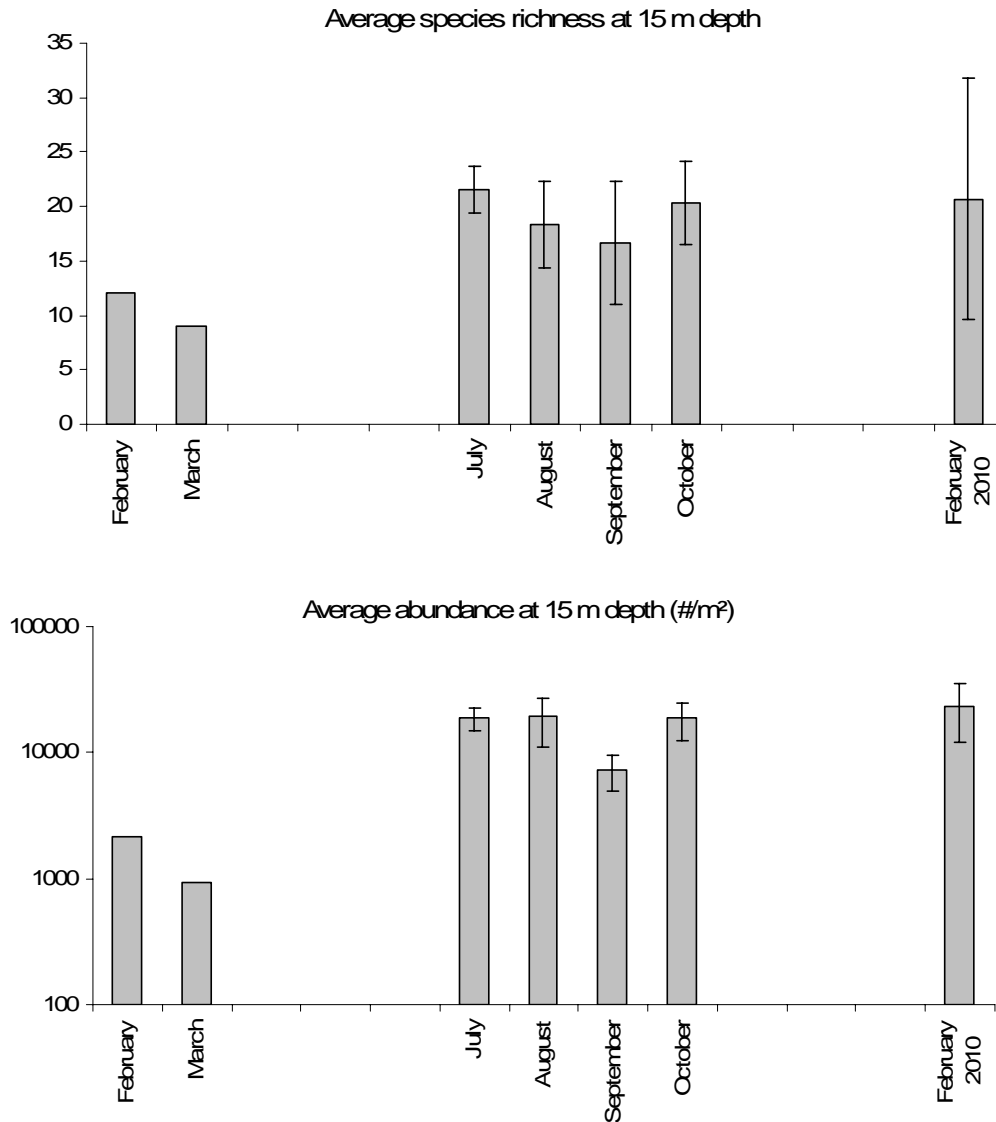
Average species richness at 15 m depth

Average abundance at 15 m depth (#/m²)

Figure 4. Temporal variation of the average species richness (upper panel spp. /m²) and abundance (lower panel; ind./ m²) at 15 m depth. Values are mean values + standard deviation

The analysis of the relative species abundance (Figure 5) showed the relative decline of certain early colonists such as *P. triqueter* and *B. perforatus,* while new species gradually became more abundant. Other species such as *B. crenatus* and *A. rubens* experienced an obvious peak in abundance in early summer and became less abundant thereafter, while certain free living Polychaetes such as *P. mucosa* (in July and August) and *Eulalia viridis* remained present in the community for a longer period of time. The relative abundance of *P. longicornis* was high in March 2009 and again in August − October 2009.

The relative abundance of *J. herdmani* was high during the whole study period except for a decline in March 2009. Furthermore, the appearance of *Corophium acherusicum,* another tube building amphipod (densities up to 2.000 ind./m² in February 2010), from august 2009 on is noteworthy.
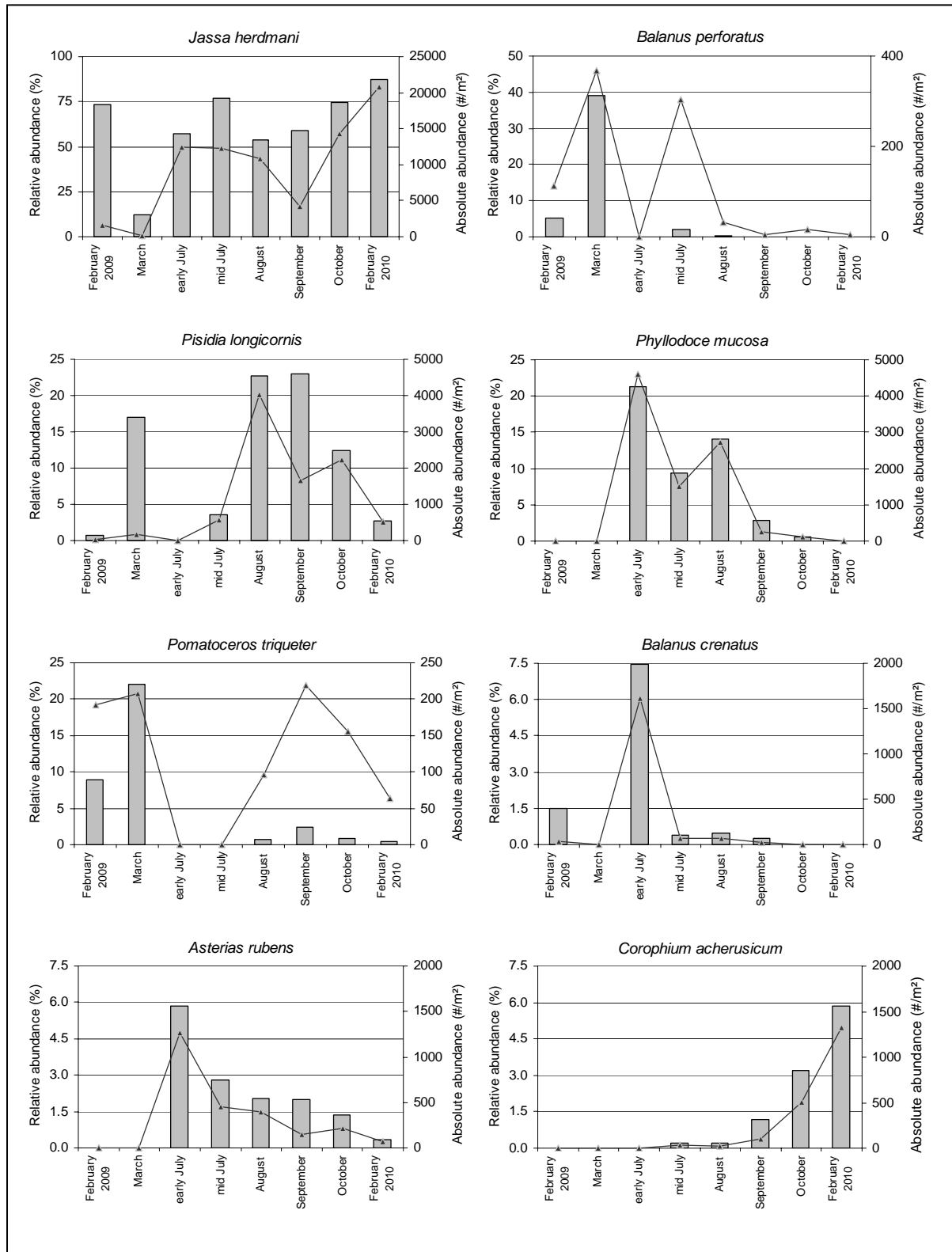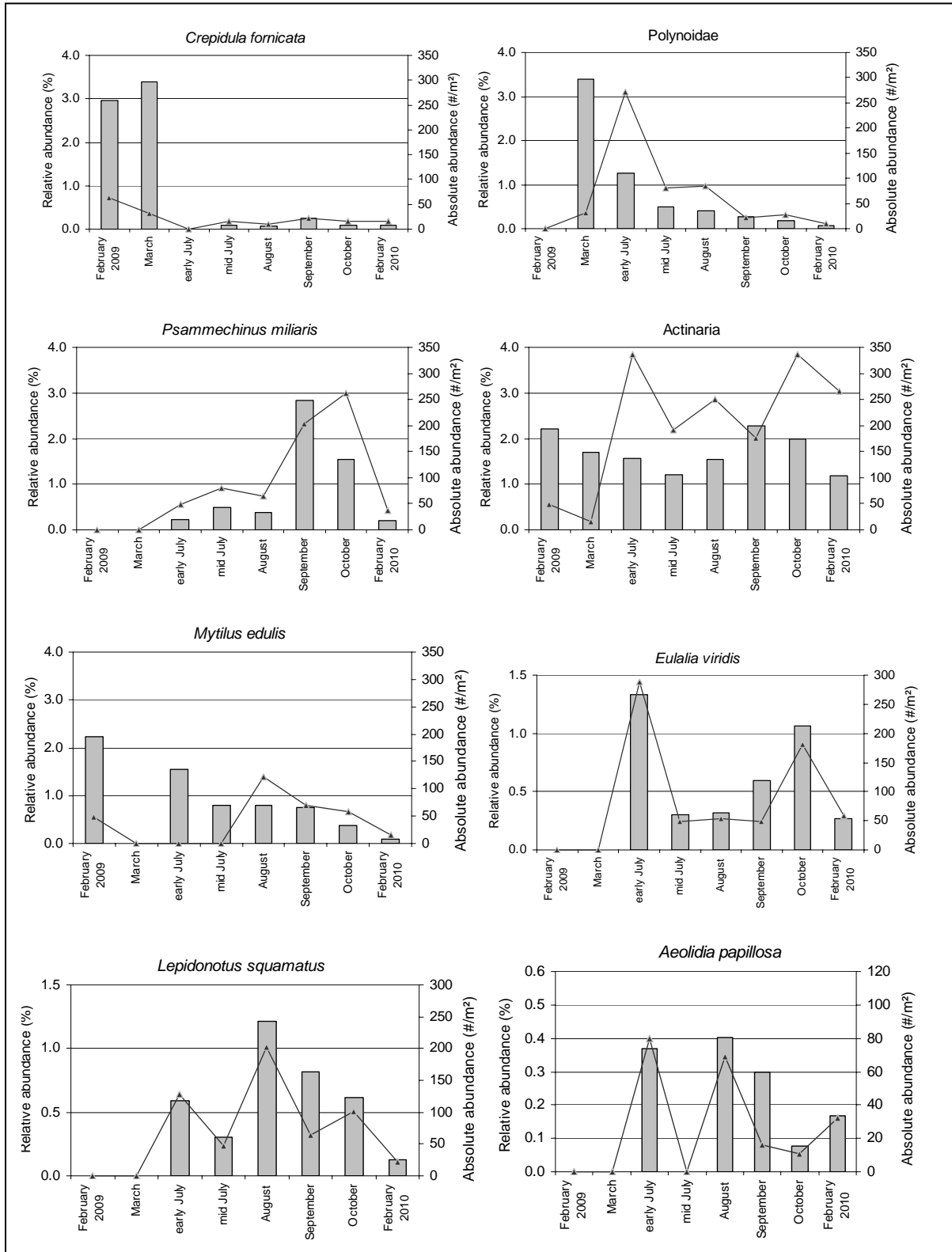
Figure 5. Temporal variation of relative (bars) and absolute abundance (line) of taxa at 15 m depth.
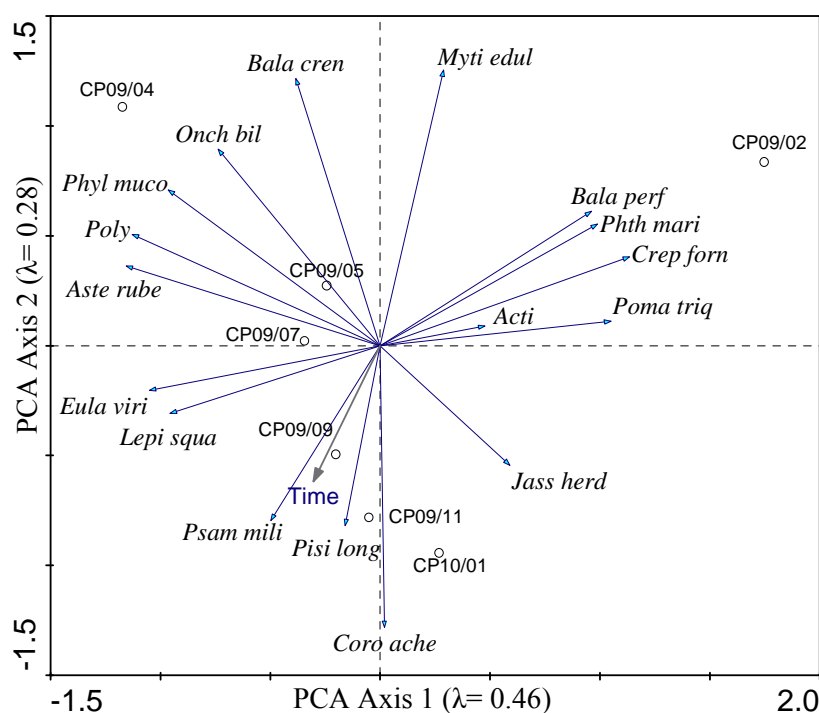
Figure 6. Principal components analysis (PCA) biplot on the centered and standardized species relative abundance data (blue vectors) of seven sets of scrape samples taken at 15 m. Taxon and sample codes: see table 1 and Annex 1. Time (since installation) was projected as supplementary variables, and as such did not influence the ordination.

The first two PCA axes together account for 74% of total environmental variance (Figure 6). PCA axis 1, which explains 46% of the total variation, is positively related with taxa that were most abundant in the February 2009 sample (*P. triqueter, C. fornicata, B. perforatus* and *Phtisica marina*). PCA axis 2, which explains 28% of the variation, is positively related with taxa that were most abundant during early summer 2009 (including *B. crenatus* and *M. edulis*); and negatively related with the taxa that became more abundant in samples collected in autumn 2009 to winter 2010 (including *C. acherusicum, P. longicornis* and *Psammechinus miliaris*). The figure also illustrates that the relative abundance of *J. herdmani* was highest in the winter samples, and lowest in (early) summer samples.

5.4. Discussion - Characteristics of the fouling assemblage

5.4.1. A dynamic community – zonation, succession and seasonality

Being fast and very intensive, with a rapid species turn over, the early colonisation of the foundation of the windmills showed two typical characteristics of the first colonisation phases in an ecological succession (e.g. Horn, 1974; Connell & Slatyer, 1977; Kerckhof et al., 2009).

The time of arrival and the availability of free substratum are extremely important for the organisms. The concrete foundations were installed in late spring 2008, at which time the meroplanktonic propagules of species with an early reproduction had already disappeared from the water column. These species were hence not able to colonise the foundations during this first year and species breeding and settling in late summer and early autumn were thus favoured during the initial colonisation and were able to take advantage of the lack of competition. As a consequence, in the first year we could witness the dominance of one species, the bryozoan *E. pilosa,* which in other conditions would have never become so dominant. During the second year, there was more competition for the available space.

As expected, drastic changes in the assemblage structure were observed during the second year, when the propagules of early reproducers arrived onto the foundations, which increased the competition for space and food. As a consequence some early colonisers such as *E. pilosa*, *P. triqueter* and *P. marina* became less abundant, while others even disappeared completely e.g. *A. opercularis*. Within the sampling period we hence observed seasonal progression rather than succession and the species composition of samples from February 2009 and 2010 was more similar than that of samples taken on other moments.

In the splash zone, formerly completely dominated by *T. japonicus*, a band with the intertidal barnacle *S. balanoides* was established just above the mussel zone in 2009. Mussels and barnacles are the dominant fauna elements in the intertidal shallow subtidal. Similar zonation patterns with a mussel / barnacle belt in the shallow subtidal – intertidal can be seen on artificial hard substrata in the intertidal zone and on other wind farms in the North Sea (e.g. EMU, 2008a; EMU, 2008b; Whomersley & Picken, 2003; Joschko et al., 2008; Bouma & Lengkeek, 2009). *Telmatogeton japonicus* was present year round and formed a monoculture above the barnacle zone, but was also present in the *Semibalanus* zone. We believe that the observed zonation may already resemble the climax zonation for the splash and infralittoral zone.

During the sampling period February 2009 – February 2010 the indigenous barnacles *B. crenatus* and *S. balanoides*, being typical early breeders (Bassindale, 1964) and not present in 2008, were found in large numbers. This was also the case for other common hard substratum species such as the starfish *A. rubens*, and the pioneer hydrozoan *Tubularia larynx*. On the other hand the later breeding barnacles, *B. perforatus* and *M. coccopoma* declined in abundance. The barnacle *B. perforatus*, a warm water species spreading into the North Sea, suffered from mortality caused by predation and smothering, as proven by the presence of many empty specimens. However, larger individuals were able to survive under the mussel cover. There was even a spatfall noticed in autumn 2009 although not as heavy as in 2008.

In the infralittoral - shallow subtidal establishment of a conspicuous belt of the blue mussel *M. edulis* was observed that gradually expanded to greater depths, in the deeper zone however their abundance is limited due to the predation by *A. rubens*.

5.4.2. A rich and diverse community

From 2008 to 2009 species richness increased from 50 species in 2008 to 75 species, including 64 macrofaunal subtidal species (> 1 mm). This is similar to other studies on early colonisation of artificial hard substrata such as van Moorsel (2001), who recorded 44 macrofaunal invertebrates in a study of an artificial reef off Noordwijk (the Netherlands) and Orejas et al. (2005), who identified a total of 44 species in the scrape samples and an additional seven identified on photographs on the FINO 1 research platform in the German Bight. However, it is significantly less than in a study of the long established epifaunal assemblages of two shipwrecks at the BPNS, where Zintzen et al. (2006) found 99 macrofaunal invertebrates in the scrape samples. Species richness may hence continue to increase over the course of the next few years as certain taxa have yet to be recorded from the foundations.

Overall the subtidal community composition changed from one absolutely dominated by a single species (*E. pilosa*) to a more multi-species community. This increase in species evenness may be due to the fact that the three-dimensional structures formed by calcareous structures of polychaete tubes and empty barnacles provide shelter - especially for the young stages of certain species - and additional space for the settlement of other species.

5.4.3. *Jassa*, a key species at the windmill foundations

One of the most abundant species is *J. herdmani,* with maximum densities (of specimens retained on a 1 mm sieve) up to 200.000 ind. /m² (in July 2009). The dominance of *Jassa* spp. has been noted in many other studies dealing with artificial substrata in the North Sea, such as shipwrecks (e.g. Zintzen, 2007) and windmills (e.g. Leonhard & Pedersen, 2006; Orejas et al., 2005), where even higher densities were recorded (max. > 1.317.045 ind./m² (Orejas et al., 2005). This species is most

common in the shallow subtidal down to – 15 m. Although *J. herdmani* is a short-lived species, it has an almost year round reproduction period and the species has a high fecundity (Nair & Anger, 1980). Consequently, juveniles were found in nearly all seasons. *Jassa herdmani* builds tubes and constructs mats which smother underlying species such as barnacles in addition to making the available surface less suitable for the settlement of other species. Hence, a negative correlation between *Jassa* abundance and species richness in the depth transects was observed. The presence of the *Jassa* tubes hampers the settlement of larvae of other species. On the other hand *Jassa* provides an important food item for the fish species associated with the hard substrata (Reubens et al., this volume).

The occurrence of another tube building amphipod *C. acherusicum* also deserves our attention. Despite the offshore location of the C-Power site, which places it under the governance of clear Channel water (Kerckhof et al., 2009) there must be enough fine sediment present in the water for *Jassa* and *Corophium* to build their tubes.

5.4.4. Presence of non-indigenous species.

In 2008 four non-indigenous species were found: the slipper limpet *Crepidula fornicata*, the New Zealand barnacle *Elminius modestus*, the giant barnacle *M. coccopoma* and the giant midge *T. japonicus* (Kerckhof et al., 2009). All four species were already known from the area and are opportunists and early colonisers, taking advantage of man-made structures and disturbed conditions for settlement (Kerckhof et al., 2007).

In 2009 only *M. coccopoma* had disappeared. This subtropical species, occurring in the infralittoral fringe, probably suffered from smothering by mussels and *Jassa* and also from the colder winter 2008-2009. Although this species is now part of the North See fauna and individuals are able to survive for several years, most populations typically do not to survive for more than one year as they are overgrown by other species. As a coloniser of newly available substrata, settling in late summer (Kerckhof unpublished), it may in most cases not find suitable surfaces to settle. The three other species all thrived in 2009 with *C. fornicata* present in nearly all subtidal samples. On the video footage its presence was conspicuous all over the foundation. A maximum density of 192 ind./m² was recorded in March 2009 and the overall mean was 41 ind./m². This species is also increasing elsewhere in European waters as well, including the BPNS (Kerckhof et al., 2007).

Despite being non-indigenous, *T. japonicus* is very common on exposed vertical offshore structures, such as buoys and pilings. On the buoys in the BPNS, it forms a distinct belt in the upper littoral and splash zone (Kerckhof, unpublished). This was also the case on the foundation of the windmill under investigation in this study. On buoys, densities can reach over 3000 ind/m² (Kerckhof, unpublished). The species was also present in high numbers on the pilings of the Danish Horns Rev offshore wind farm (Leonhard & Pedersen, 2006), where it formed a monoculture in the high intertidal and splash zone. However Bouma & Lengkeek (2009) did not mention this species for a wind farm off the Dutch coast. The presence of *E. modestus* on the offshore structures of the windmills illustrates the fact, already noted by Kerckhof et al. (2007), that this species is not limited to coastal waters.

5.5. Conclusions

The fouling process on foundations of the C-Power wind farm is comparable with that on other wind farms and on other artificially hard substrata in the North Sea. The observed species assemblages clearly demonstrate a transitional situation with increasing species richness, and a decrease in numbers of early colonisers. Both a medium-term seasonal signal and a long-term successional signal in community composition were observed.

Subtidally, the community changed from one dominated by only one species (*Electra*) to a rather multi-species community wherein it should however be noted that only a limited number of species was really abundant, and many were present as juveniles only.

Only three of the four previously encountered non-indigenous species were found in 2009: the slipper limpet *C. fornicata*, the New Zealand barnacle *E. modestus*, and the giant midge *T. japonicus*.

5.6. Acknowledgements

5.7. References

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