

Early development of the subtidal marine biofouling on a concrete offshore windmill foundation on the Thornton Bank (southern North Sea): first monitoring results

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Abstract

In 2008 the building of a first windmill park some 30km off the Belgian North Sea coast began. Such offshore constructions represent a novel, artificial, hard substratum habitat on the Belgian continental shelf, where the sea-bottom consists mainly of sandy and muddy sediment. It is anticipated that in the coming years, several hundreds of offshore windmills will be constructed in a dedicated zone off the Belgian coast. SCUBA-based *in situ* techniques were used to document and sample the fouling assemblage on the hard substratum represented by the concrete foundations of the first windmills constructed in Belgian waters. Here this paper presents and discusses the results of the monitoring undertaken from February 2009 to February 2010. Despite the further offshore location and differences in substratum type, the preliminary results indicated that the overall structure of the marine biofouling assemblage at the Thornton Bank site is similar to that on the foundations of other offshore wind farms in Germany, Denmark and the Netherlands, as well as on other hard structures in the North Sea.

Keywords: marine biofouling, hard substratum assemblages, artificial reefs, offshore wind farm, North Sea, SCUBA

1. Introduction

After European Directive 2001/77/EC, which required that part of the electricity generated should be produced from renewable sources, came into force in 2004, the state of Belgium designated by Royal Decree a special marine zone for wind energy production (Fig 1). In 2008 the first windmill park was established on the Thornton Bank, a sandbank located some 30km off the Belgian coast.

The first phase of the construction work of the first park (C-Power) involved the construction of six windmills, which were fully operational by mid-2009. More than 60 windmills (with a total generating power of 300MW) are planned. In September 2009 the construction of a second park (Belwind) started, and it is foreseen that more than 200 windmills will be constructed in Belgian offshore waters over the next four years.

As part of the designation of the wind farm park zone, the Belgian state requires that the company carrying out the development sets up a monitoring programme to study and assess the effects that the structures and activities may have on the marine environment. The goal of the monitoring programme is twofold: first, it aims to detect and possibly mitigate significant damage to the environment, and secondly, it intends to gain knowledge and a better understanding of the impact that the development of such wind farms may have on the marine environment.

The monitoring programme has a wide scope, ranging from underwater sound characterisation, to studies on seabirds and socio-economic aspects. A component dedicated to the marine growth on the new artificial hard substrata that were deployed at sea was also included, since with the construction of windmills in the Belgian part of the North Sea (BPNS), a new habitat is being introduced in a region mostly characterised 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 windmill farms (Petersen and Malm, 2006).

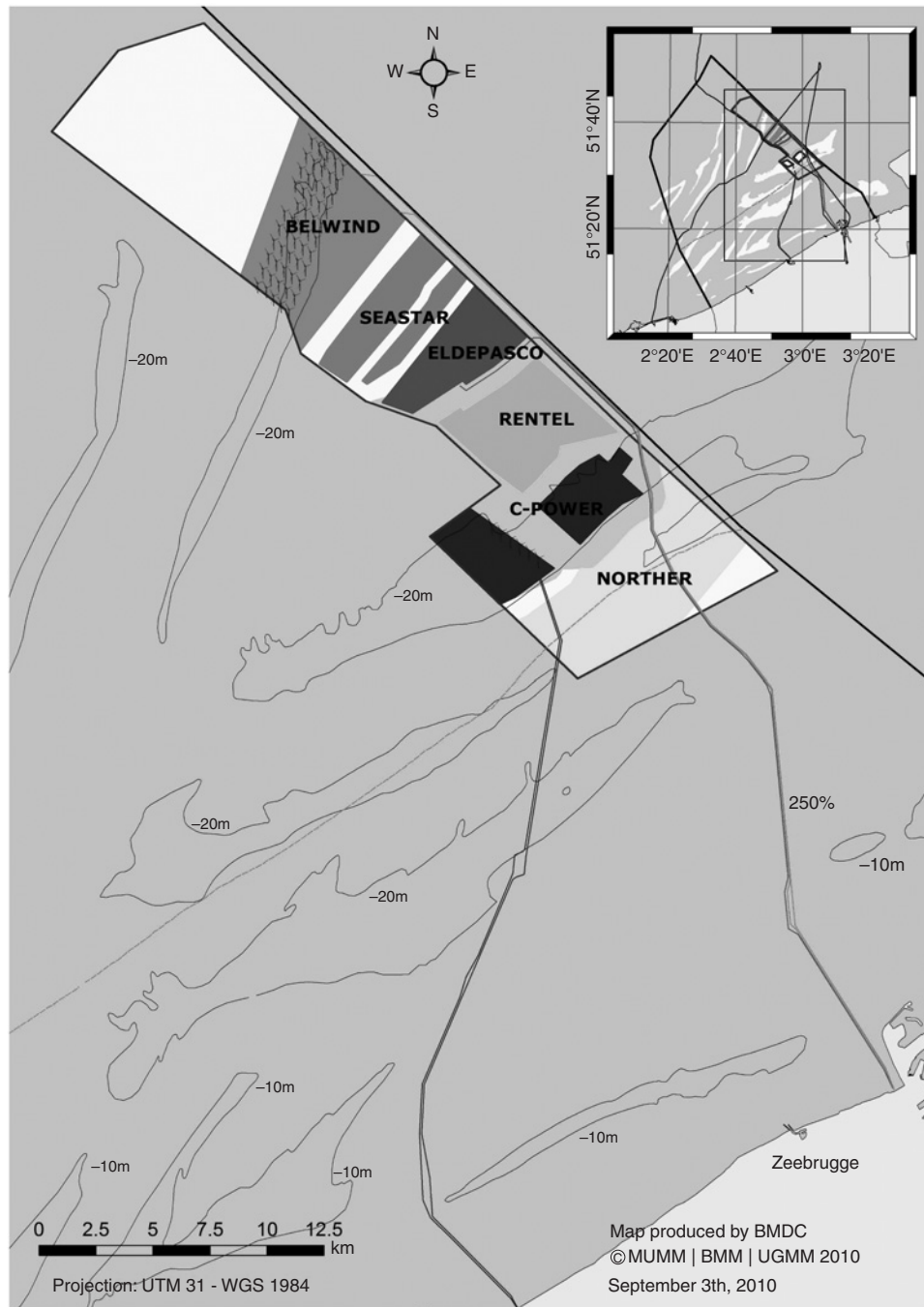


Fig 1: The zone in Belgian marine waters designated for wind energy production

It is well known that submerged artificial hard substrata are rapidly and intensively colonised (e.g. Horn, 1974; Connell and Slatyer, 1977). This has been found to be the case with the windmills in the North Sea (e.g. Schröder et al., 2006; Kerckhof et al., 2009). Fouling assemblages will develop successively, which may resemble encrusting biocoenosis 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 and the further spread of non-indigenous species (stepping stone effect).

It is also expected that certain warm water species that are now spreading to the north on hard substrata in the English Channel will take advantage of the increased presence of hard substrata to further spread into the North Sea. Alternatively, the foundations and their associated scour protection may allow for the re-establishment of biological assemblages previously present on nearby gravel beds.

The establishment of a biofouling assemblage is expected to follow a clear successional development: the new structures will be gradually colonised by a number of species. These organisms will each

influence the environment in a species-specific way, either by preventing other organisms from getting established (i.e. inhibition) or by creating the right circumstances for other species to join in (i.e. facilitation) (Connell and Slatyer, 1977). Consequently, the number of individuals of each species in the assemblage will change, and gradually new species will arrive that may progressively replace the first colonisers. This long-term process is known as ecological succession.

In addition to this process, shorter-term and often recurrent variations in species composition, known as seasonal fluctuations, also take place during the year. Both processes constitute the focus of this research, whose first results are presented here. The investigations on the subtidal part of the foundations were undertaken from February 2009 to February 2010, covering a full seasonal cycle.

2. Materials and methods

2.1. Study site

This study observed the fouling assemblage, i.e. the co-occurring organisms (*sensu*, Svane and Petersen, 2001) on the first six foundations of the C-Power windmill site. These windmills are situated on the Thornton Bank, a 20km-long natural sandbank located in the BPNS near the border between the exclusive economic zones of Belgium and the Netherlands (Fig 1). The bank lies some 30km offshore and belongs to the Zeeland banks system (Cattrijsse and Vincx, 2001). Local water depth is about 30m and the surrounding soft sediment seabed comprises medium sand with mean median grain size being $374\mu\text{m}$, SE $27\mu\text{m}$ (Reubens et al., 2009).

Hard substrata are rare in Belgian waters and include some natural boulder and gravel beds, e.g. in the Hinderbanken area, and some 300 shipwrecks (Zintzen, 2007). The novel hard substratum studied here consisted of concrete gravity based foundations (GBF) surrounded by scour protection of approximately 60m diameter. Each turbine foundation comprised a base slab, a truncated conical portion, a cylindrical portion and a platform (Demuyneck and Gunst, 2008).

The conical portion of the turbine foundation extended 14m above the seafloor and has an outside diameter that varied from 14m at the seafloor to 6.5m 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 were available for colonisation and provided 651m^2 subtidal surface area for windmill D5 (Kerckhof et al., 2009). Bathymetric variations within the wind farm area resulted in

minor deviations (of about 17%) in the subtidal surface area of the other windmills.

The six GBF were positioned in a straight line, 500m from each other, between 27 April and 29 May 2008, while the scour protection was deployed during the winter 2008 to 2009. All six turbines were deployed on a previously graded sandy bottom at the Thornton Bank site. The depth of the actual seabed around the GBF ranged from 20–25m (below mean sea level).

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 in autumn 2008 pilot sampling took place (Kerckhof et al., 2009). This preliminary sampling campaign – called ‘year one’ – took place on 12 September 2008, some three and one-half months after the building of the GBF, and included the use of SCUBA to collect four subtidal scrape samples taken at four different depths.

Sampling continued during 2009 and 2010. All samples analysed were collected between February 2009 and February 2010 (called ‘year two’), covering a full seasonal cycle. A total of 28 subtidal scrape samples for epibiota were collected on the foundation of windmill D5 (co-ordinates WGS 84: $51^\circ 32.88' \text{ N } 02^\circ 55.77' \text{ E}$), installed on 30 May 2008.

The main objectives of this investigation were: to study the development of the epifouling assemblages on the concrete foundation in the first and second year after installation (species composition, vertical zonation, seasonal and early successional changes). The monitoring programme of the subtidal hard substratum was designed around the availability of *in situ* sampling techniques. These techniques are probably best suited for sampling hard substrates in the depth ranges encountered in the Belgian part of the North Sea, where maximum depth never exceeds 52m.

Subtidal samples were collected by scraping all the fouling organisms with a putty knife from a surface area of $0.25 \times 0.25\text{m}$ (e.g. Massin et al., 2002; Zintzen et al., 2008). All scraped material was collected in plastic bags that were sealed under water and transported to the laboratory for processing which entailed fixation (5% formaldehyde), preservation (75% ethanol), sieving (1mm mesh sieve), sorting and identification.

The organisms were identified to species level wherever possible, and the number of individuals was counted. Identifications were based on the most recent systematic literature and the World Register of Marine Species (WoRMS) was followed for the nomenclature and taxonomy. Densities were expressed as the number of individuals per m^2 . The abundance of colonial organisms was estimated

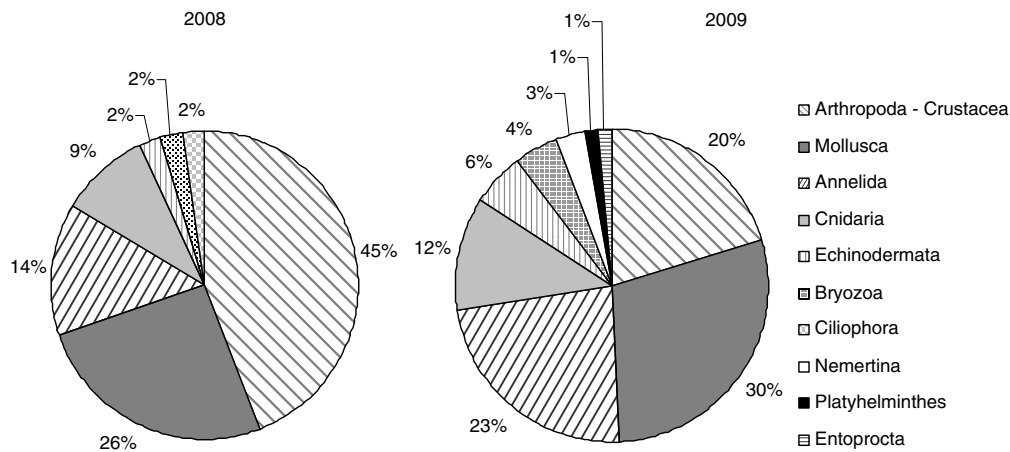


Fig 2: Proportion of the species richness represented by different phyla for the subtidal zone samples collected in 2008 and 2009; percentages indicate the relative proportion of the respective phylum ($n = 3$ samples 2008 and 23 samples 2009)

as the degree of cover, using the categories in EN ISO 19493 (European Standards/International Organization for Standardization, 2007).

Sampling was carried out in three periods of the year: early spring (from the end of February to April), early summer (from end May to July) and finally autumn (from September to October). In addition to the scraped quadrats, high definition video footage taken by SCUBA along the side of the pile 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 invertebrates. Video footage was collected by means of a Sony HDR-HC9 video camera in a Bluefin Light & Motion housing with a Light & Motion Sunray 2000 LED lighting system.

Twenty-five cruises lasting 24hr each were scheduled, of which 14 were accomplished. Of the 17 *in situ* sampling sessions made, a total of 43.5 person-hours under water were achieved resulting in 28 quadrats scraped and 6 videos transects. Depth references of all samples were obtained through time synchronisation between the Sony camera and a technical diving computer Liquivision X1, running V-Planner live software (HHS Software Corp, 2010).

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 they are usually smaller than 1mm, and hence not representatively retained on 1mm 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, i.e. 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 (Primer-E Ltd, Plymouth, UK), and principal component analysis (PCA) was used to determine the main structuring variables in the datasets (ter Braak and Prentice, 1988). The percent species abundance data were square-root transformed prior to numerical analysis in order to stabilise 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 only as a passive variable in the PCA analysis and, as such, did not influence the ordination (Lepš and Šmilauer, 2003). Multivariate statistics were performed using the package CANOCO v. 4.5 (ter Braak and Šmilauer, 2002).

3. Results

3.1. General diversity

In the sampling period of February 2009 to February 2010, a total of 63 species were identified from the subtidal part of the offshore turbine foundation (a full species list can be found in Annex 1). Fifty-nine species were discovered in the scrape samples (>1mm) and four species were only recorded in the study of the underwater video footage. Species belonged to eight phyla; no sponges or tunicates were found and three phyla, Mollusca, Annelida and Arthropoda-Crustacea, accounted for 73% of the species richness (Fig 2).

Several species were present as juveniles only, e.g. the North Sea crab, *Cancer pagurus*, and some

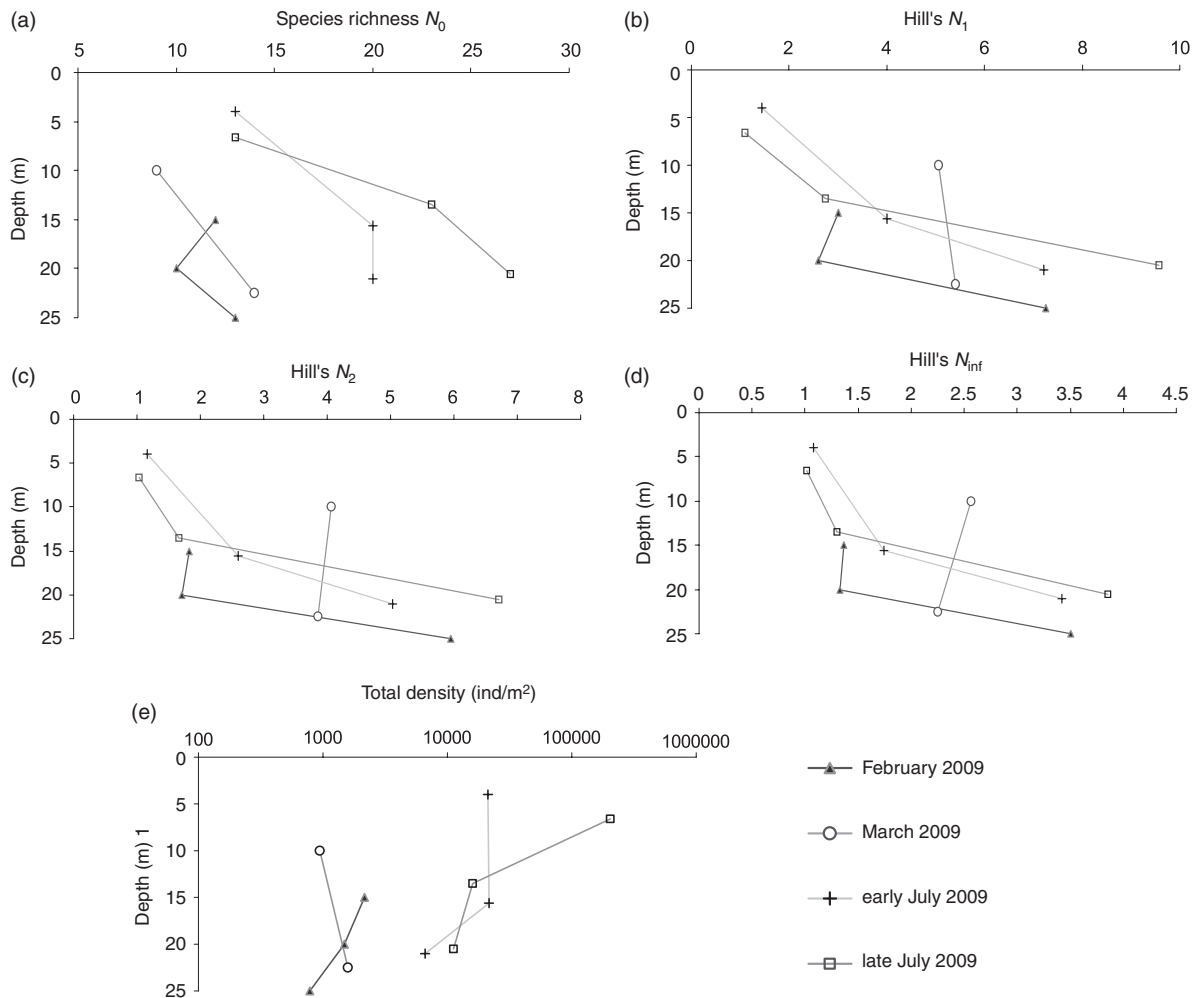


Fig 3: Species richness as Hill's N_0 (a) and Hill's diversity indices N_1 (b), N_2 (c) and N_{inf} (d) and the density (e) for four subtidal depth transects

juvenile stages of benthic species. 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*.

3.2. Zonation

Analysis of four subtidal depth-transects showed that species richness and evenness increased with depth. Additionally, species richness generally increased independently of depth from February to July (Fig 3). The dominance of *Jassa herdmani* decreased with increasing depth in summer and in winter (Fig 4). The overall higher densities in the shallow samples are caused by the high abundance of *J. herdmani*. In winter 2009, *Potamoceros triqueter*, *Actinaria* sp., *Pisidia longicornis* and *Mytilus edulis* were dominant at 20m and 25m depth; in summer, other taxa, such as *Phyllodoce mucosa*, *Balanus crenatus* and *Asterias rubens*, were most abundant at 15m and 20m depth.

3.3. Seasonal variation

The analysis of eight sets of samples taken at 15m depth showed a relatively low species richness at the start of the current monitoring period (~10 species in winter 2009; Fig 5). Species richness doubled from March to July 2009 and remained fairly stable thereafter (~20 species). A similar seasonal pattern was found for overall abundances, with low densities February to March 2009 (~1000–2000ind/m²) and higher abundances thereafter (~20.000ind/m²).

The analysis of the relative species abundance (Fig 6) showed the relative decline of certain early colonisers, 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. Meanwhile, 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 to October 2009.

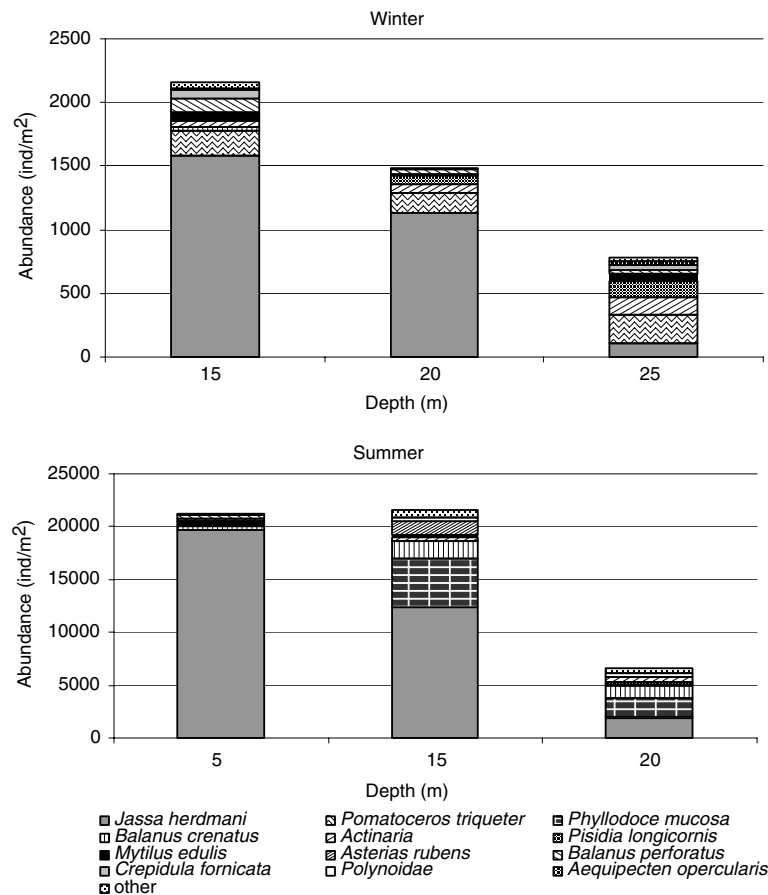


Fig 4: Absolute abundances of major taxa in winter and summer subtidal depth transects

Summer (July) densities increased 10- to 20-fold compared with winter ones (February to March; Fig 3). The relative abundance of *Jassa* spp. was high during the whole study period, except for a decline in March 2009. Furthermore, the appearance of *Corophium acherusicum*, another tube building amphipod, from August 2009 onwards is noteworthy with densities reaching 2.000ind/m² in February 2010.

The first two PCA axes together account for 74% of total environmental variance (Fig 7). 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*), but is 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 ordination also illustrates that the relative abundance of *J. herdmani* was highest in the winter samples and lowest in (early) summer samples.

4. Discussion

4.1. A dynamic assemblage: zonation, succession and seasonality

Being fast and very intensive with a rapid species turnover, 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 and 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 that reproduce early in the year had already disappeared from the water column. These species were, therefore, not able to colonise the foundations during the first year, thus species breeding and settling in late summer and early autumn were favoured during the initial colonisation, taking advantage of the lack of competition. As a consequence, the first year of the study witnessed the dominance of one species, the bryozoan *E. pilosa*, which, in other conditions, would probably have never become so dominant (Kerckhof et al., 2009). During the second year, there was more competition for the available space.

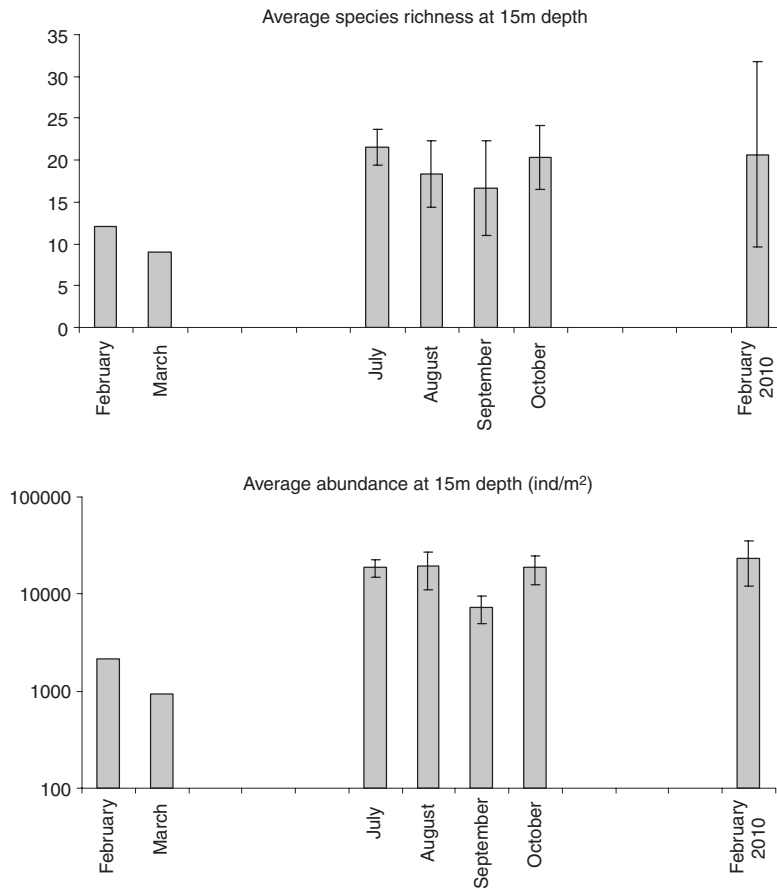


Fig 5: Temporal variation of the mean species richness (upper panel spp./m²) and abundance (lower panel ind./m²) at 15m depth; Values are means +/- standard deviation

As expected, drastic changes in the assemblage structure were observed during the study period, when the propagules of early reproducers arrived at the foundations, increasing 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 disappeared completely (e.g. *A. opercularis*). Therefore, within the sampling period, seasonal progression rather than succession was observed and the species composition of samples from February 2009 and 2010 was more similar to each other than to samples taken at other times.

During the sampling period February 2009 to February 2010, the indigenous barnacles *B. crenatus* and *S. balanoides*, being typical early breeders (Bassindale, 1964) and therefore 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 hydrozoans, *Tubularia larynx*. On the other hand, the later breeding barnacles, *B. perforatus* and *Megabalanus 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

indicated by the presence of many empty shells. However, larger individuals were able to survive under the mussel cover. There was even a spatfall observed in autumn 2009, although it was not as heavy as in 2008.

4.2. A rich and diverse assemblage

In all, 63 species were found in this study, which is a similar number to that found in other studies on early colonisation of artificial hard substrata, (e.g. van Moorsel and Waardenburg, 2001, who recorded 44 macrofaunal invertebrates in a study of an artificial reef off Noordwijk, the Netherlands). Another example is Orejas et al. (2005), who identified a total of 51 species on the FINO 1 research platform in the German Bight, with 44 species in the scrape samples and seven identified solely from photographs. However, the species richness 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.

Despite differences in substratum type, the preliminary results of this study indicated that

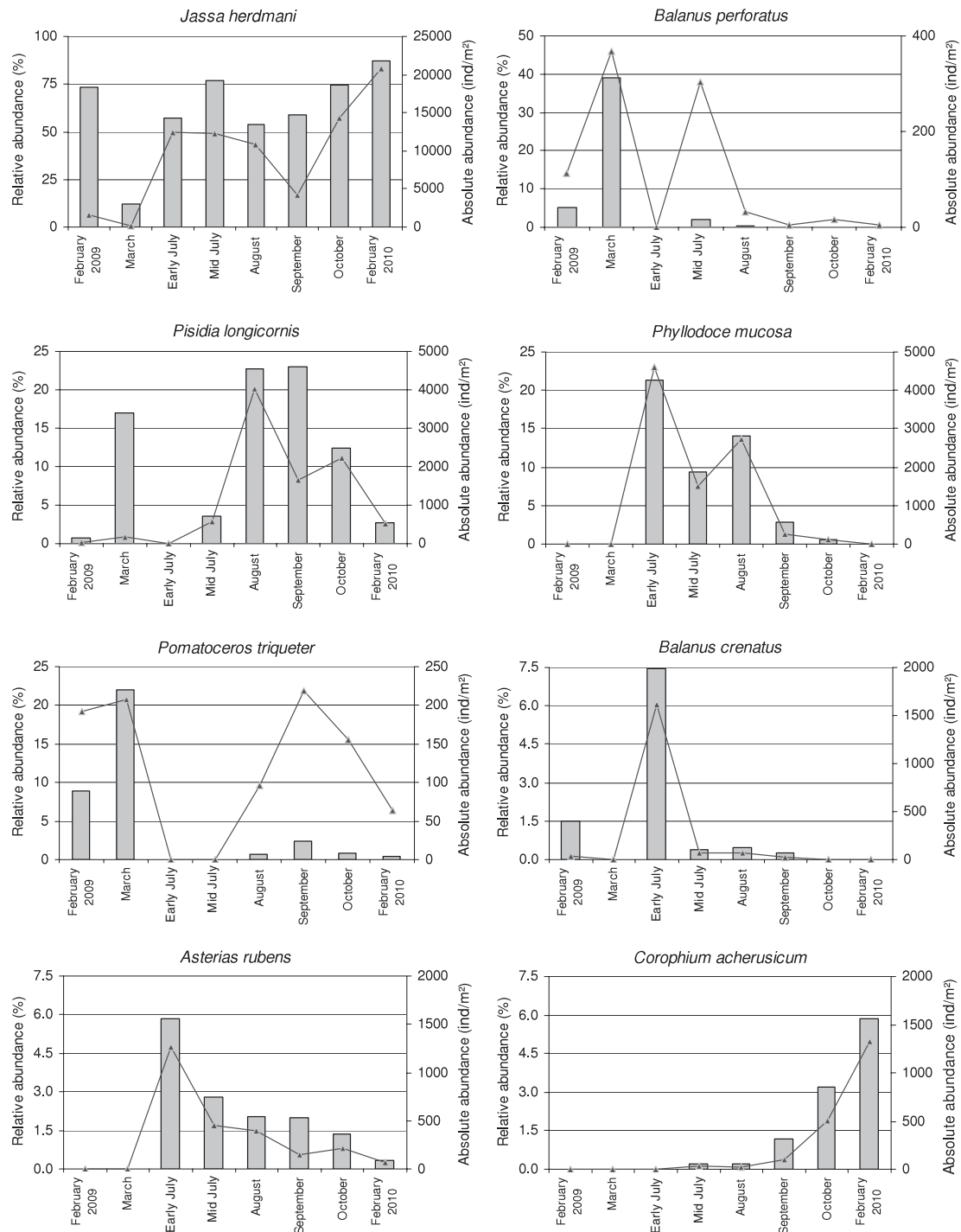


Fig 6: Temporal variation of relative (bars) and absolute (line) abundance of taxa at 15m depth

the overall structure of the marine biofouling assemblage encountered at the Thornton Bank site is similar to that encountered on the foundations of other offshore wind farms in Germany, the UK, Denmark and the Netherlands, and on different types of hard structures in the North Sea (e.g. Orejas et al., 2005; Leonhard and Pedersen, 2006; Bouma and Lengkeek, 2009; Emu Ltd, 2008a,b; Whomersley and Picken, 2003). Overall the assemblage composition changed from one dominated by a single species, *E. pilosa* (Kerckhof et al., 2009), in the first months to a multi-species

assemblage. This increase in species evenness may be explained by the fact that the three-dimensional matrix formed by calcareous polychaete tubes and empty barnacle shells provided shelter – especially for the young stages of certain species – as well as additional space for the settlement of other species.

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

One of the most abundant species was *J. herdmani*, which reached maximum densities (of specimens retained on a 1mm sieve) up to 200.000ind/m²

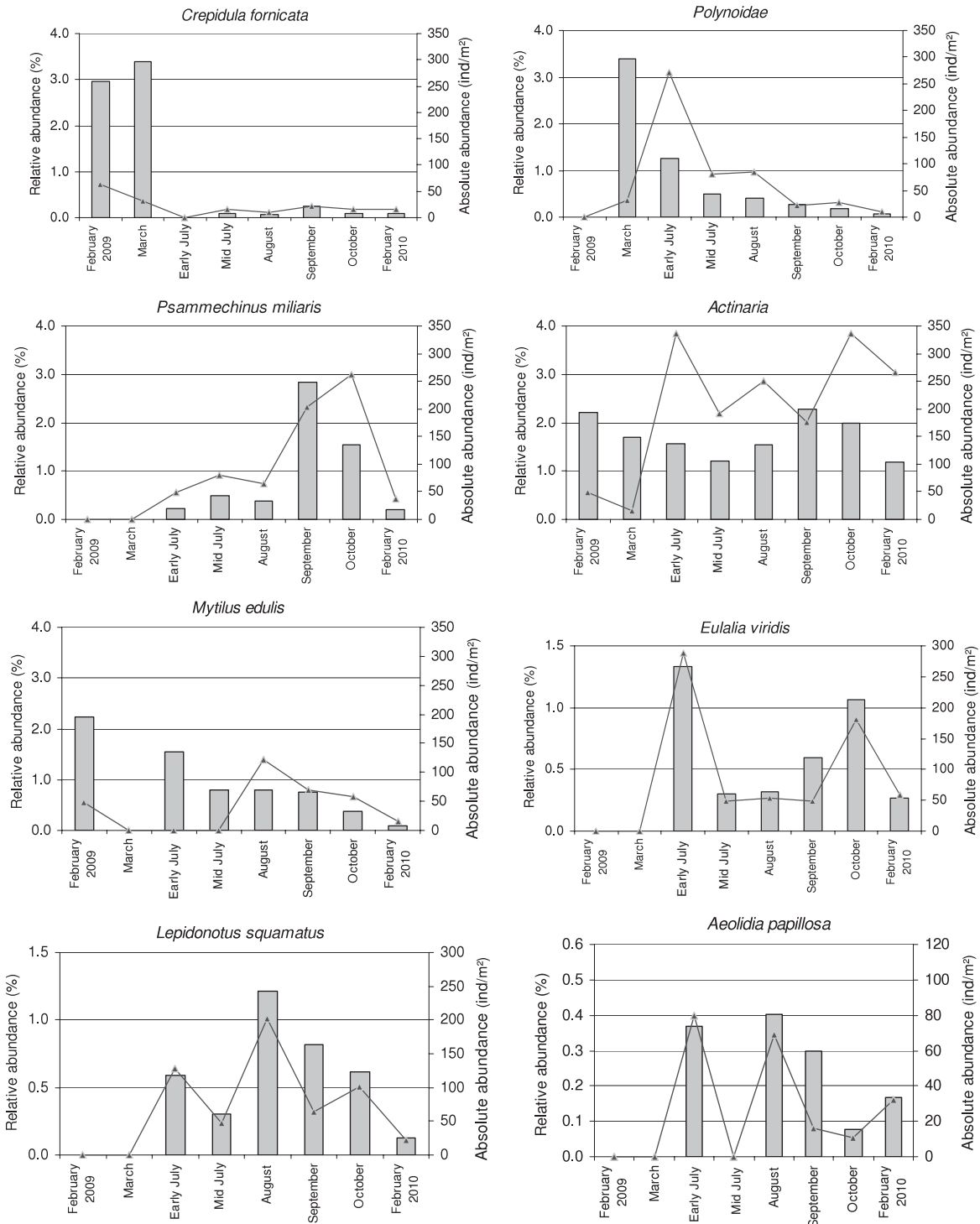


Fig 6: Continued

(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 and Pedersen, 2006; Orejas et al., 2005), where even higher densities were recorded (max. >1.317.045ind/m² in Orejas et al., 2005). This species is most common in the shallow subtidal down to 15m. Although *J. herdmani* is a short-lived species, it has almost year-round reproduction and

high fecundity (Nair and Anger, 1980), like its congener *J. falcata* (with which it has often been confused). Consequently, juveniles were found in nearly all seasons. *Jassa herdmani* builds tubes and constructs mats that 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. On the other

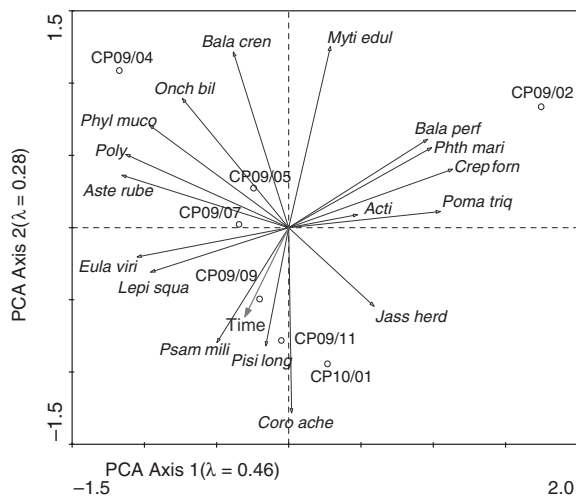


Fig 7: Principal component analysis (PCA) biplot on the centred and standardised species relative abundance data (vectors) of seven sets of scrape samples taken at 15m. (Taxon code: see Annex 1); Samples are indicated by the month and year of sampling, and time (since installation) was projected as a supplementary variable, so it did not influence the ordination

hand, *Jassa* constitutes an important food source for fish species associated with the hard substrata (Reubens et al., 2010).

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

5. Conclusions

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 assemblage composition were observed.

Subtidally, the assemblage changed in temporal terms from one dominated by only one species (*Electra*), to a multi-species assemblage. However, only a limited number of species were actually abundant, and many were present as juveniles only. For a number of species it remains unclear whether the observed changes in relative abundance reflect a recurring seasonal cycle or a more gradual successional change, although a combination of both is more likely. Despite differences in substratum type, the preliminary results of the study suggest that the overall structure of the marine biofouling assemblage found at the Thornton Bank site is similar to that found on the foundations of other offshore wind farms in Germany, Denmark and the

Netherlands, and on other hard structures in the North Sea.

At the beginning, there were some reservations regarding the feasibility of monitoring of the subtidal marine epifouling on the offshore windmills in Belgian offshore waters using *in situ* SCUBA-based sampling techniques. However, the overall results and experiences obtained during the first two years of the monitoring programme demonstrate the feasibility of the sampling protocol applied, in spite of the remaining bottlenecks mainly related to weather conditions and underwater visibility, which reduce the efficiency of the sampling.

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Annex 1: List of all the organisms sampled during the surveys identified to the lowest taxonomic level**CNIDARIA****Hydrozoa**

Clytia hemisphaerica (Linnaeus, 1767)
Hydractinia echinata (Fleming, 1828)
Obelia sp.
Tubularia indivisa Linnaeus, 1758
Tubularia (Ectopleura) larynx Ellis & Solander, 1786

Anthozoa

Metridium senile (Linnaeus, 1767)
Sagartia troglodytes (Price in Johnston, 1847)
Urticina felina (Linnaeus, 1761)

NEMERTINA**Lineidae**

Oerstedtia dorsalis (Abildgaard, 1806)

PLATYHELMINTHES

Leptoplana tremellaris (Müller, 1774) Örsted 1843

ANNELIDA

Chaetopterus variopedatus Cuvier 1827
Eulalia viridis (Johnston, 1829)
Gattyana cirrhosa (Pallas, 1766)
Harmothoe pachenstegeri Michaelsen, 1896
Harmothoe extenuata (Grube, 1840)
Lanice conchilega (Pallas, 1766)
Lepidonotus squamatus (Linnaeus, 1758)
Myrianida (Autolytus) sp. (*prolifera-edwardsi-brachycephalus* complex)
Nereis (Eunereis) longissima Johnston, 1840
Nereis pelagica Linnaeus, 1758
Pectinaria koreni (Malmgren, 1866)
Pholoe synophthalmica Claparède, 1868
Phyllodoce mucosa (Örsted, 1843)
Phyllodoce longipes Kinberg, 1866
Pomatoceros triqueter (Linnaeus, 1758)
Sabellaria spinulosa Leuckart, 1849

MOLLUSCA**Bivalvia**

Aequipecten opercularis (Linnaeus, 1758)
Abra alba (Wood W., 1802)
Heteranomia squamula (Linnaeus, 1758)
Mytilus edulis (Linnaeus, 1758)
Venerupis senegalensis (Gmelin, 1791)

Gastropoda

Aeolidia papillosa (Linnaeus, 1761)
Crepidula fornicata (Linnaeus, 1758)
Cuthona gymnota (Couthouy, 1838)
Epitonium clathratulum (Kanmacher, 1798)
Facelina bostoniensis (Couthouy, 1838)
Nassarius incrassatus (Ström, 1768)
Odostomia turrita Hanley, 1844
Onchidoris bilamellata (Linnaeus, 1767)
Onchidoris muricata (Müller, 1776)
Pusillina inconspicua (Alder, 1844)

ARTHROPODA–CRUSTACEA**Cirripedia**

Balanus crenatus Bruguière, 1789
Balanus perforatus Bruguière, 1789

Annex 1: Continued

Amphipoda

Corophium (Monocorophium) acherusicum (Costa, 1851)
Jassa herdmanni (Walker, 1893)
Phtisica marina Slabber, 1769

Decapoda

Cancer pagurus Linnaeus, 1758
Liocarcinus holsatus (Fabricius, 1775)
Maja squinado (Herbst, 1788)
Macropodia linaresi Forest & Zariquiey-Alvarez, 1964
Necora puber (Linnaeus, 1767)
Pagurus bernhardus (Linnaeus, 1758)
Pilumnus hirtellus (Linnaeus, 1761)
Pisidia longicornis (Linnaeus, 1767)
Stenothoe valida Dana 1852

ENTOPROCTA

Pedicellina nutans Dalyell 1848

BRYOZOA

Cyclostomatida

Cheilostomatida

Electra pilosa (Linnaeus, 1767)
Conopeum reticulum (Linnaeus, 1767)
Callopora dumerilii (Audouin, 1826)

ECHINODERMATA

Asteroidea

Asterias rubens Linnaeus, 1758

Echinoidea

Psammechinus miliaris (Gmelin, 1778)

Ophiuroidea

Ophiura sp. juv.
