Energi E2 A/S

Development of the Fouling Community on Turbine Foundations and Scour Protections in Nysted Offshore Wind Farm, 2003

Report
June 2004

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Agern Allé 11
DK-2970 Hørsholm, Denmark

Tel: +45 4516 9200
Fax: +45 4516 9292
Initials: jba/msl
e-mail: dhi@dhi.dk
Web: www.dhi.dk

Client	Client's representative
Energi E2 A/S	Charlotte Boesen

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Authors: Jørgen Birklund, Anders Højgård Petersen	Date: June 2004
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0 ABSTRACT

I efteråret 2002 og i foråret 2003 afsluttedes opsætningen af møllefundamenter og tilhørende stenarbejder inklusive udlægning af erosionbeskyttelse omkring fundamenterne. Fotografering og videoptagelser samt indsamling af kvantitative prøver i oktober 2003 viste, at der i løbet af den første vækstsæson, var udviklet et begroningssamfund af blåmuslinger, rurer og makroalger samt en ledsagefauna af krebsdyr og fisk.

Rurer og blåmuslinger var kvantitativt dominerende og biomassen på mølleskafterne var omkring 10 gange højere end på fundamenternes sten og på erosionsbeskyttelsen. Biomassen af invertebrater på skafter og sten var ensartet vest, øst, nord og syd for fundamenterne, men ændredes med dybden på mølleskafterne som følge af en aftagende biomasse af rurer og blåmuslinger med stigende dybde. Samtidig øgedes biomassen af makroalger og abundansen af en række krebsdyr.

Makroalgesamfundet var domineret af rødalger. Forekomsten af alger øgedes med dybden og på stenene var biomassen omkring 2 gange højere end på mølleskafterne. Det skyldes sandsynligvis en kombination af en mindre pladskonkurrence fra rurer og muslinger og en reduceret bølgepåvirkning på større dybde. En analyse af algesamfundene vest, øst, nord og syd for fundamenterne gav et usikkert resultat og yderligere undersøgelser er nødvendige for at belyse algesamfundets udvikling.

Biomasse og abundans samt biomassen af makroalger på mølleskafter og sten var reduceret på transformerstationen i forhold til turbinefundamenterne. Det kan skyldes, at der er nedgravet flere kabler og været mere skibstrafik omkring transformerstationen. Det har medført et større sedimentspild og en hyppig ophvirvling af bundmateriale, som kan have hæmmet bundfældning og opvækst af organismerne og reduceret biomasse og abundans af begroningssamfundet i den første vækstsæson.

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Deployment of foundations and stones including scour protection around the foundations were conducted between the autumn 2002 and the spring 2003. Surveys in October 2003 showed that a fouling community of common mussels, barnacles and macroalgae and associated mobile species of crustaceans and fish was developed during the first reproductive season.

Common mussels and barnacles were the quantitatively dominant organisms and the biomass on the vertical shafts was about ten times higher than on the stones. The biomass was uniform independent of direction (W, E, N and S) but changed due to a decline in barnacles and mussels with increasing depth.

The community of macroalgae was dominated by redalgae. The diversity and biomass increased with depth and was about two times higher on stones than on shafts probably due to a less intensive competition for space and a reduced wave action at greater depth.

An analysis of the biomass of macroalgae in relation to direction was inconclusive and further analysis must await renewed surveys of the development of macroalgae.

The biomass and abundance of invertebrates and the biomass of macroalgae on the shaft and stones was reduced at the transformer station compared to the turbines. The seabed work and the traffic have been more intense around the transformer due to additional deployment of connecting cables on the seabed. The associated sediment spill of the extra earthwork and re-suspension of sediment caused by the propellers of the ships may have hampered the settling and growth of organisms and reduced the biomass and abundance of the fouling community in the first reproductive season.

1 BACKGROUND

The concrete foundations and the scour protection of stones around the foundations of the 72 turbines in the Nysted Offshore Wind Farm have a total surface area of about four hectares. These new hard physical structures have been introduced into the Rødsand area, in which the natural seabed consists mainly of sand.

When new hard structures are introduced into the marine environment, they will act as substrate for sessile organisms that will colonise it and develop a fouling community. This community may be more or less diverse, depending on the characteristics of the substrate and a number of environmental factors including salinity and exposure for waves. The community will include sessile animal and plant species as well as small mobile invertebrates. Small fish species are likely to be associated with community too. Furthermore, larger benthic or pelagic fish as well as sea birds may be attracted from the surrounding areas. Because of this so-called reef effect, the construction of Nysted Offshore Wind Farm will cause changes of the biological diversity and production of the local ecosystem.

On this background an investigation of the fouling community in the Nysted Offshore Wind Farm was initiated in September 2003. The investigation will provide information about the importance of the introduction of hard substrate in the local ecosystem. The gathered information will furthermore be very valuable in order to assess the environmental effects and biodiversity and recreational perspectives of large scale wind farm construction in the marine areas in Denmark as well as in neighbouring countries.

The changes caused by the introduction of hard substrate are often regarded as positive. Therefore, small or large-scale deployment of artificial reefs is used in several countries as an environmental management approach to restore or increase biodiversity, or to improve commercial or recreational fishery of the area.

The specific objective of the investigation in the autumn 2003 is to provide a qualitative and quantitative description of settling and development of the fouling community during the first productive season after the turbine foundations and scour protections has been introduced in the area. It is expected that the surveys will be continued in 2004 in with aim to follow the further succession and development of the fouling communities of invertebrates and macroalgae on the vertical shafts of the turbines and the surrounding stones.

2 MATERIALS AND METHODS

2.1 Location

The Nysted Offshore Wind Farm is located south of Lolland in Denmark about 10 km from the shore (Figure 2.1). The wind farm comprises 72 turbines distributed in 8 North to south oriented rows and one transformer station.

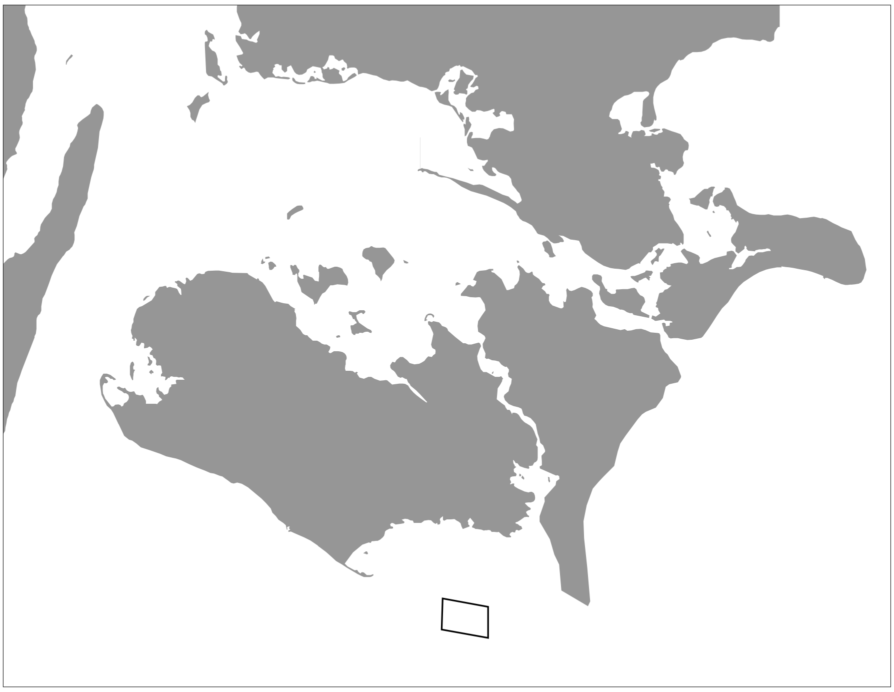


Figure 2.1 Location of the Nysted Offshore Wind farm

The natural water depth in the area varies between 6 and 9.5m. Winds from the western sector are the most frequent and strongest. Calculated waves heights are 3.6m at the Southwest corner, 3.3m at the Southeast corner and 2.6m at the north corners of the wind farm. The current velocity is highest at the south corners of the wind farm /5/.

2.2 Foundations and scour protections

The turbines and the transformer station are placed on gravity foundations made as concrete (Figure 2.2). The foundation consists of a cylindrical shaft with a diameter of 4.2m and a 3m high and 16m wide hexagonal basement divided in six cells (Figure 2.5). The six cells are filled with gravel and stones. The upper layer of stones has a nominated median diameter (d_{50}) of 70cm. At most of the turbines, scour protections of stones with a nominated thickness of 110 cm are placed on the seabed around the foundations. The upper layer of these protections is made of stones with a nominated median diameter (d_{50}) of 27cm. The outer diameter of the scour protections is about 25m (se Figure 2.2 right).

At the turbines of the southern row and a few other turbines, special anti collision protections was constructed instead of the ordinary scour protections. These protections surround the whole foundation or only the southern half of the foundations. The anti collision protections are made of sand and gravel covered with stones and are built up to the upper level of the hexagonal basement of the foundations. From approximately 1 m outside the foundations the protections slopes down to the surrounding seabed (see Figure 2.2 left)

The bases of the foundations are placed from 0m to 5m below the natural seabed. The surface of the stone fill in the basement chambers is in most cases 4.5m to 7.5m below the sea surface, but is up to almost 10 m below the surface at a few turbines. The surface of the scour protections is 1.5-2m further below (Figure 2,2 right). At the turbines at which the surface of the scour protections is below the natural seabed, the seabed outside the protections gradually slopes up to the natural level.

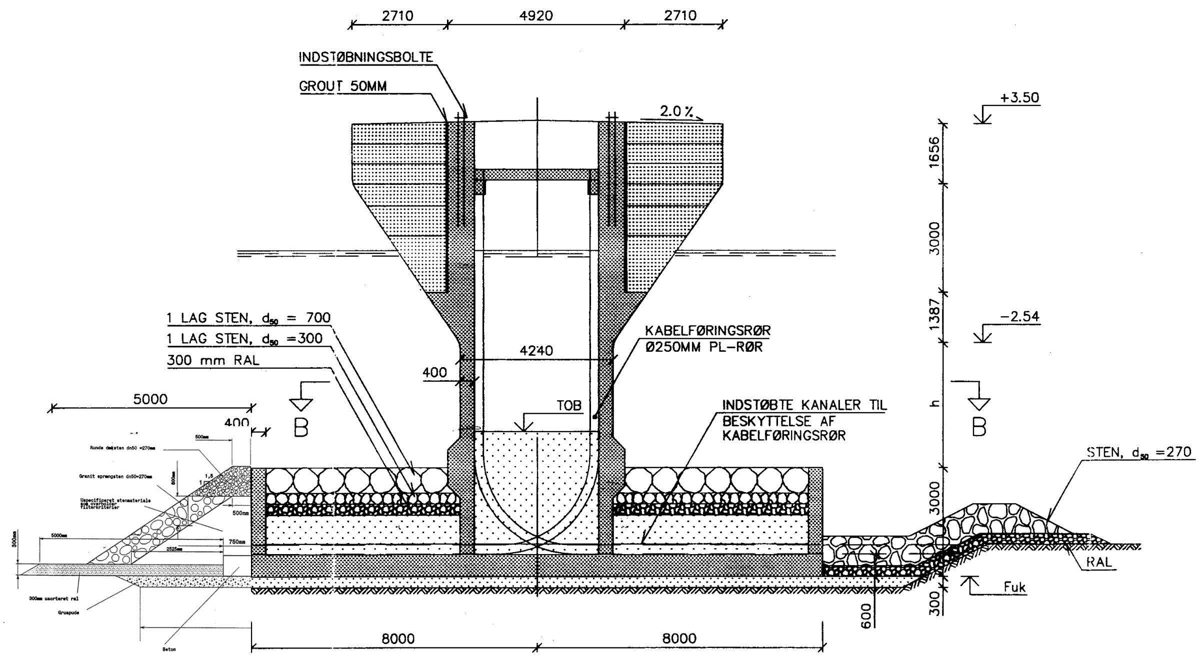


Figure 2.2 Turbine foundations in Nysted Offshore wind farm. Left: with anti collision protection. Right: with ordinary scour protection

The vertical concrete base for the turbines goes from the centre of the hexagonal basement to the water surface. The lower part is cylindrical with a diameter of 4.2m, while the upper part is conical reaching a diameter of 8m at the water surface (Figure 2.2).

The foundations were placed on the seabed during the period October 2002 to May 2003 while the stones fill and the scour protections were placed from March to June 2003.

2.3 Principles of the investigation

The fouling community was investigated on:

- The vertical concrete foundations (in the following called the shaft)
- The stone filling inside the cells of the hexagonal foundations
- The scour protections of stones outside the foundations.

Three different techniques were applied:

- Underwater video recording to provide documentation and overview of the general conditions including the overall spatial variation, the height of the vegetation and the presence of fish and larger mobile invertebrates like crabs and shrimps.
- Underwater photography of images with a known area, and subsequent analysis with regard to the occurrence sessile organisms like common mussels, barnacles and macroalgae.
- Quantitative sampling of sessile organisms like common mussels, barnacles and macroalgae and small mobile invertebrate fauna associated with the sessile organisms.

The investigation included the foundations of seven turbines and the transformer platform. Video and photography were carried out at all of these foundations, while quantitative sampling was only carried out at four of these (Figure 2.3). The foundation was generally selected in order to represent different water depths and locations within the wind farm. Foundation C9 was selected in order to include a foundation with the additional anti collision protection. Ten cable connections were established to the transformer compared to two cable connections to the turbine foundations. In addition to the deployment of cables there has been more intensive traffic around the transformer and the propellers of the ships may have suspended bottom sediment. The transformer platform was therefore selected in order to see possible impacts on the development of fouling of sediment and intensive ship traffic.

In addition to the ordinary foundations, the vertical steel foundation of the older meteorological monitoring mast located in the wind farm was investigated using all three techniques (Figure 2.3). The monitoring mast was placed already in 1997, and the fouling community on the mast was investigated previously in 1999 and 2001. The mast was included in order to evaluate how the community on the vertical part of the concrete foundation (the shaft) may develop over a longer period.

A summary of the natural water depths at the selected turbines is given in Table 2.1. The table also includes the approximate water depth at the surface of the stone fill in the basement of the foundations and the surrounding scour protections. Finally the date of placement of the foundations and scour protections are presented.

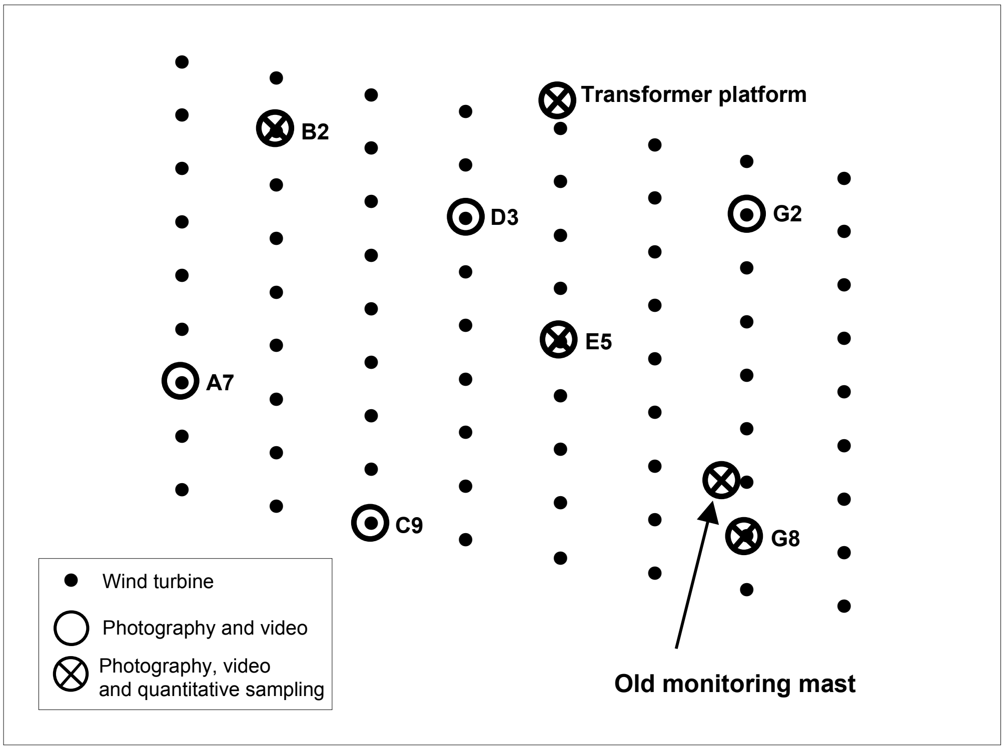


Figure 2.3 Locations used for the investigation of the fouling community at turbine foundations and scour protections in the Nysted Offshore Wind Farm in September-October 2003.

Table 2.1 Summary of water depths and dates relevant for the investigated locations

Turbine	**Depths (m)**				**Date of placement of Foundation**	**Date of placement of scour protection**
	Ambi-ent	Base of foun-dation	Surface of foundation (stone fill)	Surface of scour Protection		
Turbine A7	8.2	12.75	9.75	11.65	20.12.2002	08.04.2003
Turbine B2*	7.1	7.50	4.5	6.4	16.10.2002	20.03.2003
Turbine C9	8.3	8.50	5.5	7.4	24.02.2003	12.03.2003
Turbine D3	6.5	7.50	4.5	6.4	25.02.2003	28.03.2003
Turbine E5*	8.4	9.50	6.5	8.4	12.03.2003	01.05.2003
Turbine G2	7.5	9.25	6.25	8.15	15.04.2003	02.06.2003
Turbine G8*	7.4	9.25	6.25	8.15	11.05.2003	02.06.2003
Transformer*	5.9	7.50	4.5	6.4	20.12.2002	18.03.2003
Monitoring mast*	8.5				1997	

* Quantitative surveys

The foundations were deployed from October 2002 to May 2003. The time lapse between deployment of the turbines and the surveys in October 2003 was 19 weeks for turbine G8 and 49 weeks for turbine B2. The stones were put in position after deployment of the turbines and the "age" of substrate of stones varied between 14 weeks and 26 weeks at turbines G2, G8 and turbine C9, respectively (Table 2.2). The monitoring mast was established in 1997.

Table 2.2 *Time lapse in weeks between deployment of foundations and stone protection of the turbines and the surveys in September-October 2003.*

Turbine	Time lapse in weeks between deployment of foundations and the surveys in September – October 2003	Time lapse in weeks between Deployment of stones and the surveys in September – October 2003
Turbine A7	40	24
Turbine B2*	49	27
Turbine C9	30	28
Turbine D3	30	26
Turbine E5*	28	21
Turbine G2	23	16
Turbine G8*	19	16
Transformer*	40	27
Monitoring mast*	6 years	

* Quantitative surveys

2.4 Photography and video

2.4.1 Field procedure

Divers carried out all sampling and observation along four survey lines at each turbine. The lines were located on the northern, eastern, southern and western side of the foundations, respectively. The lines reached from the water surface down along the vertical concrete foundations, then along the surface of the stone fill and beyond the edge of the foundation to the border of the scour protections.

Video recordings along all survey lines were made with a hand held digital video camera. Still photographs were taken with a digital camera mounted on a frame with two strong flashlights (Figure 2.4). Before each picture was taken, the frame was placed firmly on the substrate in order to ensure that the image covered a well-defined area of $0.24m^2$ (40×60 cm).

Figure 2.4 *Equipment used for digital photography of the fouling community at Nysted Offshore Wind farm in September-October 2003*

Along each survey line, photos were taken just below the water surface (0.5m) and at depth intervals of 1m (1.5m, 2.5 m etc) to just above the stone filling (Figure 2.5). Thus, a total of 4-9 photos were taken along the vertical part of each line.

Along each survey line three photos on the surface of the stone fill and two on the scour protections were taken. The specific location of these photos are described in Table 2.2, and shown on Figure 2.5.

Table 2.2 Location of photos taken on stone fill and scour protections.

1	On stone fill, about 1 m from the vertical foundation (the shaft)
2	On stone fill, midway between vertical foundation and the outer edge of the foundation. (about 2.5 m from vertical foundation)
3	On stone fill, 0-1m from the outer edge of the foundations (depending on the direction).
4	On scour protection approximately 0.5 m outside the foundation
5	On the scour protection 2-3 m outside the foundation (at some turbines this image was actually located outside the scour protection or sand, shells and mussels may have covered the stones).

On the monitoring mast photos were taken only on the western side, which was assessed to have the thickest layer of mussels. Photos were taken at 1m intervals from 1m below surface and to a depth of 8m.

2.4.2 Image analysis

The images were examined and the coverage of common mussels, barnacles and macro-algae were assessed.

The video recordings were used as a basis for a general site description and to support the interpretation of the still photos. The video recording also gave a good impression of the occurrence of fish species and larger invertebrates (crabs).

2.5 Quantitative sampling

Quantitative sampling of organisms was carried out at three selected turbines (B2, E5, G8), the transformer platform and at the monitoring mast (Figure 2.3).

2.5.1 Field procedure

A square steel frame was applied for the sampling. A bag made of plankton net with a mesh size of 300µm was attached to another frame mounted perpendicular to the first one. When taking the samples, a diver held the frame against the substrate and used a steel scraper to scrape off all organisms and to collect these in the net bag. The net bag was subsequently detached and closed by means of velcro tape on the inside of the bag. The net bags were taken to the survey vessel, and the content was carefully transferred to labelled plastic bags. The samples were subsequently stored in a deep freezer for later analysis in the laboratory.

Samples were taken on the eastern, southern, western and northern sides of the vertical concrete foundations, at water depths of 1m and 3m and just above the stone fill (Figure 2.5). In total, 12 samples (4×3) were taken at each vertical foundation (the shafts)

On the stone fill and scour protections three samples were taken in each direction. The samples were taken about 1m from the vertical foundation, 1m inside of the outer edge of the hexagonal basement and about 1.5m outside the basement (Figure 2.5). Thus, a total of 12 samples were taken on the stone fill and the scour protection of each turbine.

The sample sizes were 0.0225m^2 (15×15 cm) at the vertical foundations and 0.0625m^2 (25×25 cm) at the stone fill and scour protections. The smaller sample size at the shaft was chosen for practical reasons, because it was expected to be easier to obtain quantitative samples of the mobile invertebrate species using a smaller sampling frame. Furthermore, a large number of very small mussels are expected at the early stages of colonisation particularly at the vertical foundations, which makes the sorting of large samples very elaborate. The smaller sample size can be scientifically justified by assumption that the fact that the fouling community at the smooth concrete shaft would be more homogeneous than at the stone fill and scour protections. This assumption was confirmed during the sampling.

On the monitoring mast samples of 0.0625m^2 (25×25 cm) were taken on the western side of the mast. Samples were taken at 1m intervals down to a depth of 8m. Previous surveys of the mast in 1991 and 2001 suggested that the thickness of the fouling layer was uniform around the foundation. The samples collected in the uppermost 5 m in 2003 are therefore assumed to be comparable with samples collected in the same depth range in 1999 and 2001. There is no stone protection around the mast.

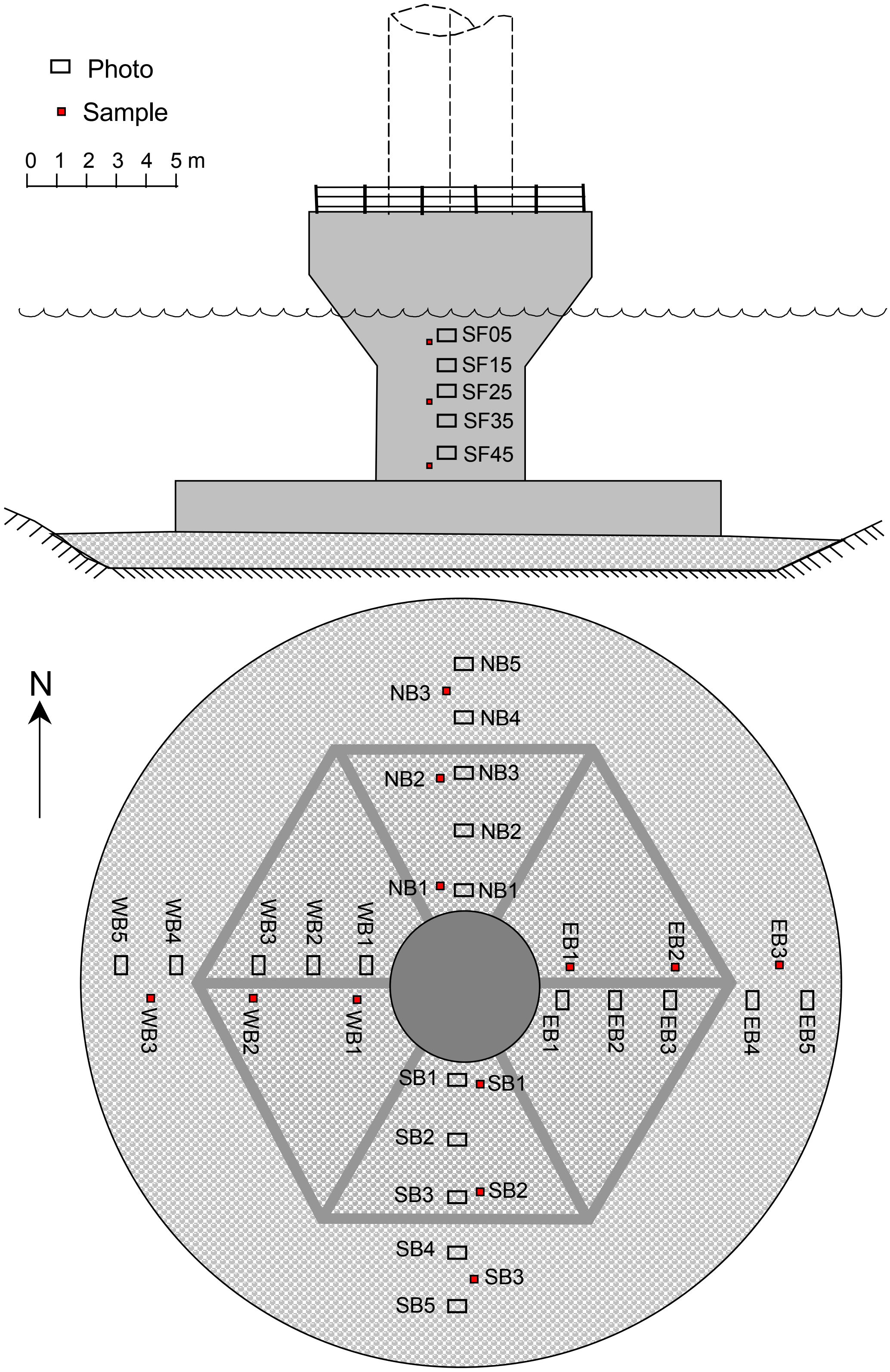


Figure 2.5 *Investigation of the fouling community on turbine foundations and scour protections in the Nysted Offshore Wind Farm. Top: Side view. Bottom: Top view. Sample and image codes are indicated.*

2.6 Laboratory treatment and statistical analysis

2.6.1 Laboratory treatment

The quantitative samples were sorted and all invertebrates were identified to species level or to the highest possible taxonomic level. The abundance and biomass (wet and dry weight) of all fauna species were determined. The common mussel (*Mytilus edulis*) and the barnacle *Balanus improvisus* were by far the most dominant sessile fouling organisms. Small mussels were very abundant and divided in three size classes using sieves with different mesh sizes. The size classes of mussels were> 3.5mm, 3.5-10mm and> 10mm. The number of mussels <3.5mm were estimated on the basis of the wet weight of counted sub samples. The number of mussels in the two other size groups was counted. Very few mussels on the foundations were >10mm and the shell length were measured using a digital slide ruler. Mussels larger than 10mm from the monitoring mast was measured in selected samples.

The biomass (dry weight) of all red algae, brown algae and green algae were determined and the species in the samples were recorded.

2.6.2 Statistical analysis

The fouling community in 2003 was in the early stage of development and common mussels and barnacle totally dominated biomass and abundance. Abundance of small mussels (<3.5mm) was extremely high and biomass is therefore the most appropriate estimator of the present state of the development of the community. The structure of the communities of invertebrates and macroalgae respectively were analysed using multivariate techniques based on the PRIMER software /3/. Classification and ordination was based on fourth root-transformed biomass data (dry weight) and calculation of Bray-Curtis similarity.

The analysis was initially done for each turbine because of the different age of the substrate and position in the wind farm. The age and nature of the substrate also differ at the individual turbines and separate analysis was conducted for the vertical shaft of concrete and the stones (called the bottom). In addition, shaft and bottom data from the turbines (B2, E5, G and transformer) were subject for similar multivariate analysis.

3 RESULTS AND DISCUSSION

3.1 Description of the fouling community based on photos and video

The images have been stored on two CD-ROMs. Annex 1 explains the naming of the images and provides a summary of the images including comments on missing images.

The findings based on a visual examination of the still photos are summarised in Annex 2.

3.1.1 Epi-fauna and macroalgae

The overall impression based on examination of the photos was that the development of the fouling community was similar at the turbines but different at the transformer station. The **shafts** (the vertical surfaces of the foundations) were in most occasions covered by a dense layer of small common mussels (*Mytilus edulis*). At the uppermost station 0.5m below the surface there was a narrow barnacle zone (Figure 3.1). Mussels covered the barnacles on the remaining part of the shafts and the coverage of barnacles is therefore underestimated in Annex 2.

Macroalgae were absent or scant in the uppermost metres of the shafts and confined to isolated tufts of redalgae. The density of macroalgae increased with depth but the thallus of the algae was short and the coverage may be underestimated. Due to the predominance of mussels few other organisms were observed. However, small colonies of encrusting bryzoans were present on few bare surfaces and small spots of white polyps were observed attached to the mussels.

The assessment of the fouling community on the stone fill and the surrounding scour protection (called **stones** in the following) was difficult due to the three-dimensional nature of the substrate.

The coverage of macroalgae on the top stones was often 50% or more (Figure 3.2). Redalgae were conspicuous and in general larger than brownalgae but the general visual impression was that the coverage of redalgae was less than the coverage of brownalgae. Greenalgae were scant and the coverage low.

Figure 3.1 Barnacle zone close to the surface followed by a dense population of common mussels (Mytilus edulis).

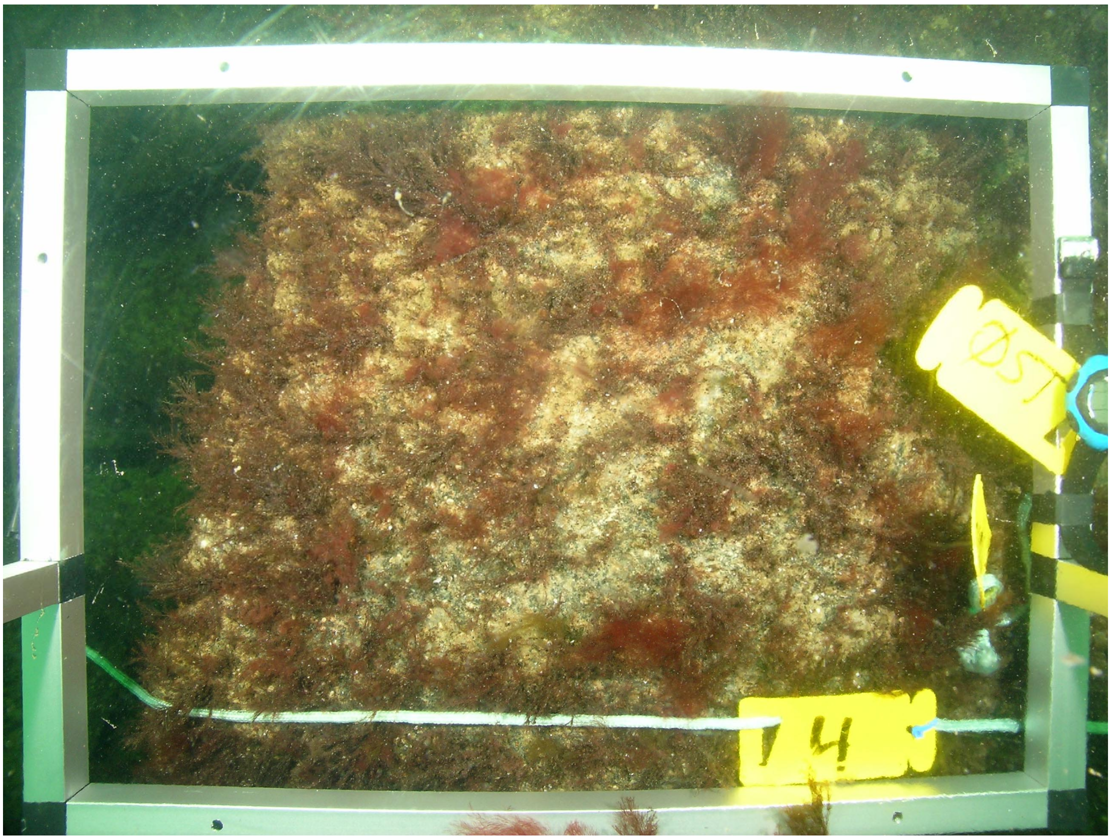


Figure 3.2 Stones with a dense coverage of macroalgae.

The density of mussels on the shaft of the transformer station was lower than on the other turbines and the coverage of barnacles was apparently higher partly because the barnacles was visible and not covered by a mussel layer. The coverage of macroalgae on stones around the transformer station was also less compared to the coverage of algae on stones around the turbines.

The monitoring mast was totally covered by dense mosaic of mussels. Redalgae attached to mussels was scarce. Barnacles were attached to the surface of large mussels and the coverage of barnacles appeared to be higher between 6-8m than at depths between 1-5m.

3.1.2 Fish and larger invertebrates

The semi- pelagic two-spotted Gobi (*Coryphopterus flavescens*) was very numerous close to the stones and also abundant in the free water in the lee area between the shafts and the stones and between the wall of the foundations and the scour protections. Pairs and single individuals of Goldsinny-wrasse (*Ctenolabrus rupestris*) were common close to the stones and were also seen exploring deeper crevices of the stone layer. The black goby (*Gobius niger*) was fairly common resting on stones and making characteristic small leaps between the stones.

The crab (*Carcinus maenas*) was common and more specimens were probably hiding in the numerous spaces in the mosaic of stones. A few shrimps (*Palaemon elegans*) were observed in tufts of macroalgae.

3.1.3 Uncertainty in interpretation of photos

The interpretation of photos was rather unproblematic on the smooth surfaces of the shafts but difficult on the rough surfaces of stones. The living conditions are different on the uppermost stones compared to the deeper stones and the photos focus on the top stones. Assessment was therefore confined to the top stones in focus of the pictures. The number of stones and the coverage of the substrate of top stones within the photo frame were assessed. The coverage of sessile animals and macroalgae were expressed as a percentage of the of top stones and not related to the area of the photo frame.

Short tufts of macroalgae, which makes its difficult to assess the coverage of barnacles and mussels, dominated the fouling community on top of the stones. Barnacles were mostly visible at the edges of the stones. The dense and short populations of macroalgae seem to have favoured deposit of silt at the base of the thallus and this also hampered assessment of presence and coverage of barnacles and mussels. Barnacles and especially the small mussels are therefore underestimated on the stones.

3.2 Invertebrates

3.2.1 Biomass and abundance of the fouling community

The average total biomass of the fouling community of sessile and mobile invertebrates on the **shafts** varied roughly between 700 gDW/m^2 and 1400 g/DW/m^2 (Table 3.1). The biomass of the fouling community on the shafts was in general ten times higher or more than the biomass on the stones. Sampling was more easy and efficient on the smooth vertical surfaces of the shafts than on the uneven rough surfaces of the stones but it is assessed that different sampling efficiency only contribute little to the measured differences in biomass between shafts and stones.

The lowest biomass was measured on shafts of turbine B2 and the transformer station and the highest on shafts of turbines E5 and G8.

The total biomass of the fouling community on the shafts in 2003 was not related to the age of the substrates, cf. Table 2.2. The highest biomass was measured on shafts of turbines deployed in April and May 2003 (E5 and G8) and the lowest biomass on shafts of turbine B2 and the transformer deployed in October- December 2002. This result may appear unexpected but reproduction is confined to the spring and summer and there was probably only a very limited settling on foundations deployed in late 2002. However, settling and development of the fouling community has been fast during the first reproductive season in 2003.

Common mussels (*Mytilus edulis*) and the barnacle *Balanus improvisus* were the dominant components of the fouling community. The biomass of other taxa including mobile crustaceans, polychaetes and gastropods were inferior (Annex 3).

Table 3.1 Total biomass and biomass of common mussels (Mytilus edulis), barnacles (Balanus improvisus) and other taxa of fouling organisms. Rounded average values for shafts and stones.

Foundation	Total biomass		*Mytilus edulis*		*Balanus improvisus*		Other taxa	
	Shafts	Stones	Shafts	Stones	Shafts	Stones	Shafts	Stones
	gDW/m^2	gDW/m^2	gDW/m^2	GDW/m^2	gDW/m^2	GDW/m^2	gDW/m^2	gDW/m^2
B2	713	78	401	62	310	15	2	1
E5	1425	99	671	71	751	28	3	<1
G8	1334	90	536	49	797	41	<1	<1
Transformer	688	30	181	13	507	16	<1	<1
Mast	5619		5347		261		11	

The biomass of the common mussel accounted for 40-56% of the total biomass on the shafts of turbine B2, E5 and G8 but only accounted for 26% of the total biomass on the shaft of the transformer. Compared to the shafts common mussels contributed more to the total biomass on stones (43-79%). Barnacles were the dominant component of the fouling community at the transformer station and the biomass of common mussels was below the biomass at the turbines. More intense seabed work and traffic and expected higher concentrations of sediment in the water around the transformer may have reduced the settling and survival of mussels. The reduced number of mussels has favoured the growth of barnacles. In spite of a lower density the biomass of barnacles is higher on the transformer than on turbine B2.

The total abundance of fouling organisms ranged between 77000/m^2 and 386000/m^2 on the shafts and between 18000/m^2 and 91000/m^2 on the stones (Table 3.2). The abundance of invertebrates at the transformer station was much lower than the abundance at the turbines.

Table 3.2 Total abundance and abundance of common mussels (Mytilus edulis), barnacles (Balanus improvisus) and other taxa of fouling organisms. Rounded average values for shafts and stones.

Foundation	Total abundance		*Mytilus edulis*		*Balanus improvisus*		Other taxa	
	Shafts	Stones	Shafts	Stones	Shafts	Stones	Shafts	Stones
	Ind./m^2	Ind./m^2	Ind./m^2	Ind./m^2	Ind./m^2	Ind./m^2	Ind./m^2	Ind./m^2
B2	222000	83000	178000	77000	40000	1000	3600	4500
E5	386000	91000	361000	88000	19000	1800	5800	1600
G8	300000	60000	278000	57000	21000	1500	1300	1400
Transformer	77000	18000	66000	17000	10000	900	800	500
Mast	78000		64000		4600		9400	

Common mussels accounted in most occasions for more than 90% of the total abundance. However, the shell length of the mussels was mostly below 3.5mm and this was especially the case on stones, where few mussels were larger than 3.5mm (Annex 4). Mussels with a shell length between 3.5-10mm were numerous on the shafts of the turbines but the length of very few mussels were more than 10mm.

The density of barnacles was between 10000/m^2 and 40000/m^2 on the shafts and much lower (900/m^2 - 1800/m^2) on the stones. The lowest density was measured at the transformer station. The abundance of other taxa of fouling organisms was also low at the transformer station (400-500/m^2) compared to a density of 1300-5800/m^2 at the turbines.

The species composition and abundance of other taxa of fouling organisms besides common mussels and barnacles are shown in Annex 5. Crustaceans were the most diverse taxonomic group and 12 species were identified. The amphipods *Gammarus spp.*, *Microdeutopus sp.* and the tube building *Corophium insidiosum* were by far the most abundant Genera or species on both shafts and stones. There was a vertical zonation on the shafts where the density of *Microdeutopus sp.* and *C. insidiosum* was highest at the deepest sampling station 3m below the surface.

The abundance of the other species of crustaceans was low and so was the density of juvenile specimens of polychaetes (*Nereis sp.*), bivalves (*Cerastoderma sp.* and *Mya arenaria*) and the gastropods *Hydrobia sp.* and *Rissoa albella*. The gastropod *Rissoa albella* is normally associated with vegetation but the other species belongs mostly to the infauna characteristic of the sandy bottom surrounding the turbines.

The **monitoring mast** has been in position for 6 years. The fouling community on the mast may be indicative for the future development of the fouling community on the shafts of the turbines. The average total biomass of the fouling community on the mast was 5600 gDW/m^2 or about 4 times higher than the highest biomass measured on the shafts of the turbines in 2003. Common mussels accounted for 95% of the biomass and barnacles less than 5%. The mussels formed a several cm thick layer around the substrate and barnacles have settled on the shells of larger mussels (Figure 3.3).

The average density of mussels was 64000/m^2. Mussels with shell length <3.5mm, 3.5-10mm and >10mm accounted for 58%, 23% and 19% of the total number respectively.

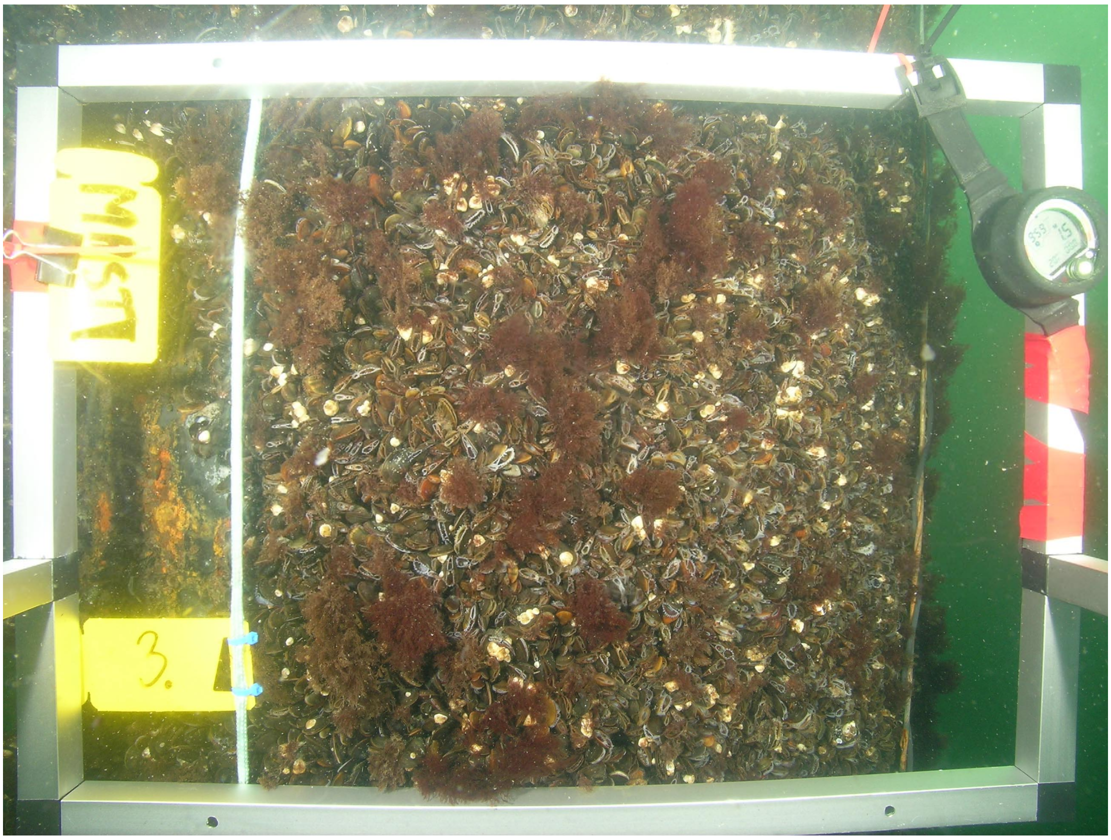


Figure 3.3 Barnacles (Balanus improvisus) attached to common mussels (Mytilus edulis) on the monitoring mast, October 2003.

The maximum shell length of the mussels on the mast was about 50mm. The median length of mussels larger than 10mm was 16-20mm. The size of the mussels measured was similar in samples collected from 1m to 7m below the surface (Annex 6).

The biomass and density of common mussels was surveyed in 1999 and 2001 at the top 5 metres of the monitoring mast. The results in 2003 are compared with the previous results in Table 3.3.

Table 3.3 Biomass and abundance of common mussels (Mytilus edulis) at the top 5 metres of the monitoring mast in 1999, 2001 and 2003.

Depth	Biomass (g wet weight/m^2)			Density (Ind./m^2)		
	1999	2001	2003	1999	2001	2003
1m	7.0	14.5	9.6	17000	53000	109000
2m	7.4	14.9	13.2	42000	23000	45000
3m	8.4	17.1	12.8	26000	41000	68000
4m	8.9	19.5	11.9	18000	33000	35000
5m	10.0	15.5	9.7	19000	24000	74000
Range	**7-10**	**15-20**	**10-13**	**17000-42000**	**23000-53000**	**35000-109000**

The biomass of mussels in 2003 was lower than in 2001. The maximum length of mussels was 50-58mm in 1999-2003 and the median length of mussels larger than 10mm were similar in 2001 and 2003. The maximum shell length of the mussels was reached already in 1999 two years after deployment. The biomass measured in 2001 four years after deployment was probably close to the maximum attainable biomass on a vertical surface in the area.

When the mussels grows the thickness of the fouling layer increases and becomes more vulnerable to the drag of waves and currents which eventually will exceed the strength of the byssus threads of the mussels attached to the surface. Pieces of the mussel "carpet" will therefore be torn off in rough weather and leave open spaces suitable for renewed settling and recruitment of barnacles and mussels. In addition to a physical control of the fouling community predation of mussels from eiders may be a potential regulating factor provided that eiders are able to or willing to forage on vertical surfaces in proximity of the turbines. Crabs may predate on small mussels but the effect is probably of minor importance due to the limited numbers of crabs. Starfish is absent in the area due to the low salinity. Cod may predate on mussels but the abundance of amphipods and small fish species associated with the fouling community will most likely be the preferred food items of larger fish species.

3.2.2 The structure of the fouling community

Structure on shafts and stones: Analysis based on the biomass of the fouling community showed that the structure of the community on the shafts and stones differed significantly at the turbines and the transformer station. This finding is obvious from the results of the MDS ordinations in Figure 3.4a and Figure 3.4b and confirmed by the results of ANOSIM tests in Table 3.4.

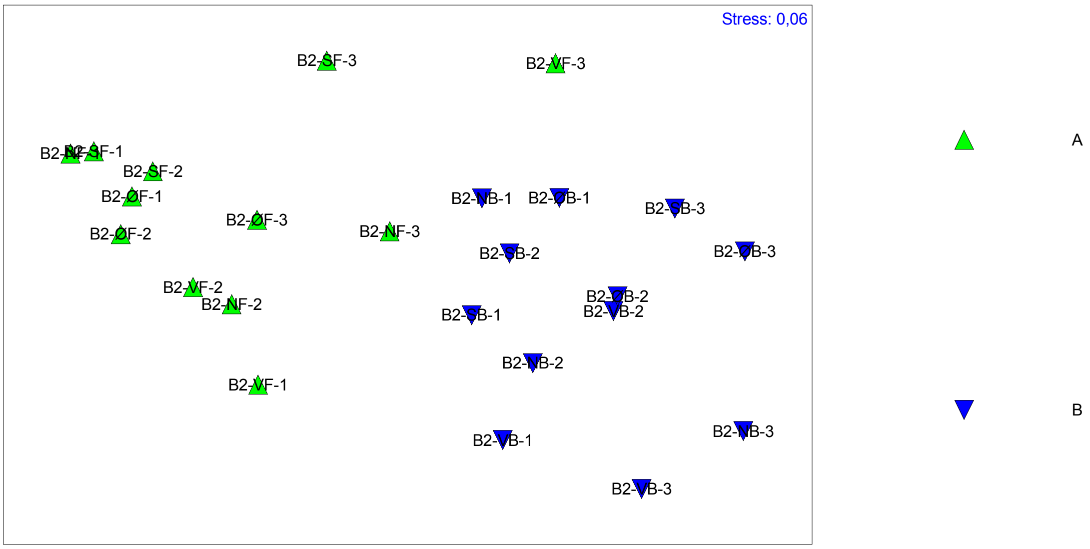
Table 3.4 Results of a One- way analysis of the similarity of the fouling community on the shafts versus the stones in 2003.

Foundation	Sample statistic (Global R)	Significance level of sample statistic
B2	0.784	0.1%
E5	0.883	0.1%
G8	0.980	0.1%
Transformer	0.948	0.1%

The community structure was determined by the predominance of common mussels and barnacles on the shafts (Figure 3.5a, Figure 3.5b, Figure 3.6a and Figure 3.6b).

The dominance of barnacles and mussels on the shafts is probably caused by a combination of less competition from macroalgae during settling, higher influx of larvae and better availability of food due to a higher current velocity in the surface water. Barnacles and mussels are able to settle in very high current velocity and able to sustain the physical impact of waves. In addition, barnacles and mussels are adapted to changes in water level and exposure to air and extreme temperatures. Filamentous macroalgae are more sensitive to mechanical abrasion and colonisation in deeper water with less impact of waves is more likely. Deposition of fine sediment in deeper water and among macroalgae smothers the substrate and probably hampers the settling of barnacles and mussels.

B2 - biomass fauna 2003



E5 - biomass fauna 2003

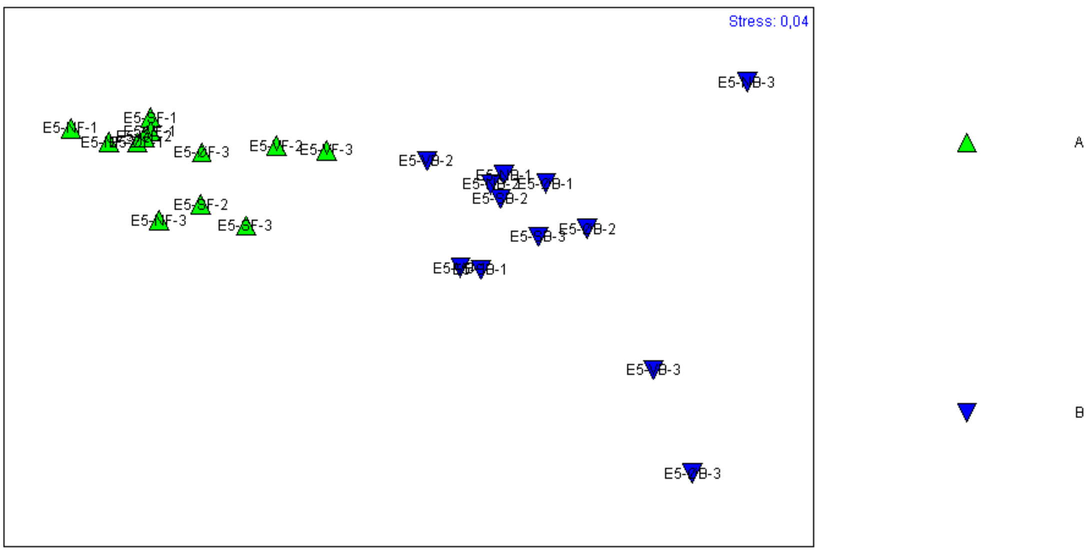
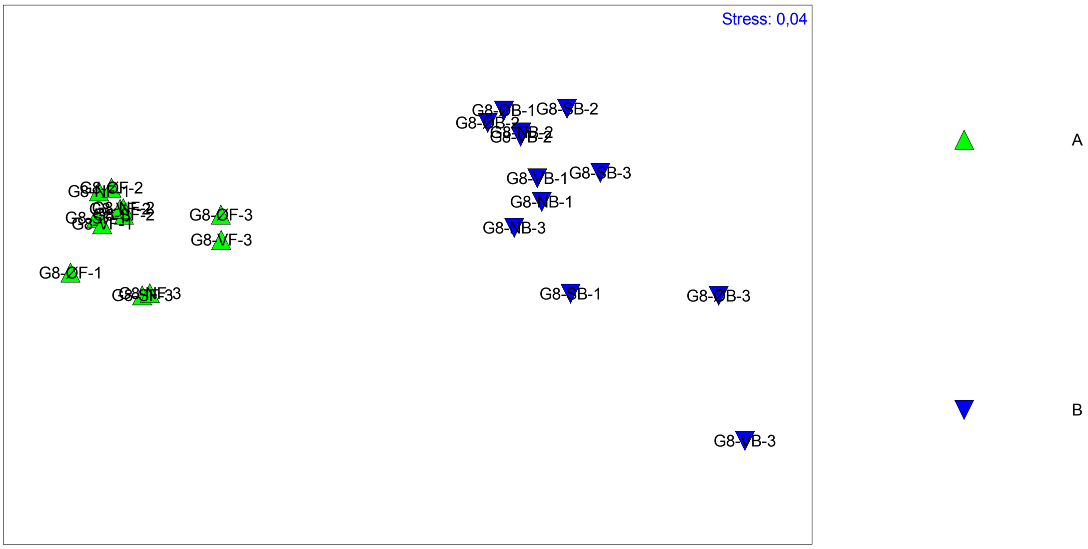


Figure 3.4a MDS- ordination based on the biomass of the fouling community on turbine B2 and E5 in 2003. A: shafts, B: stones.

G8 - biomass fauna 2003



Transformer - biomass fauna 2003

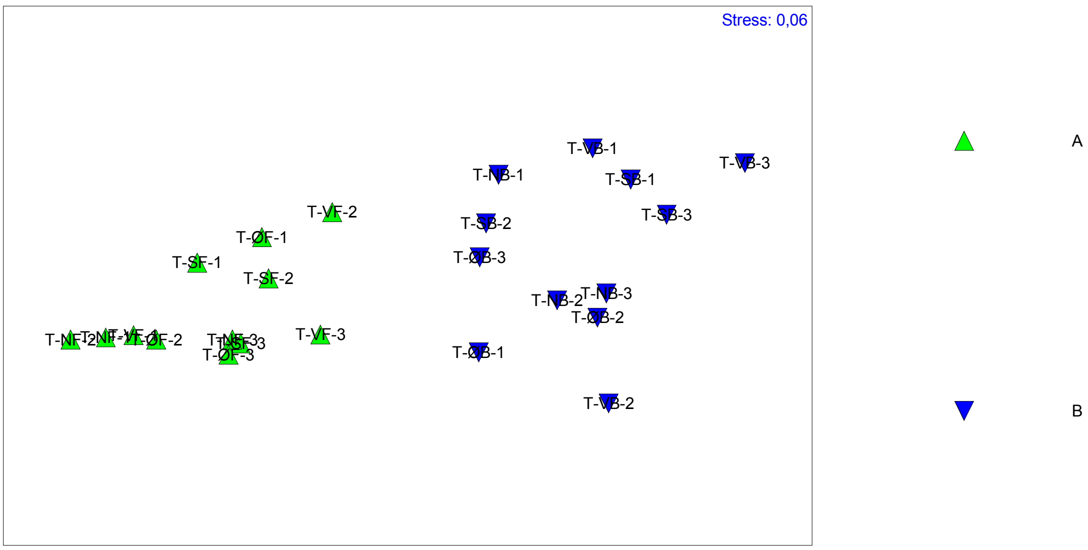
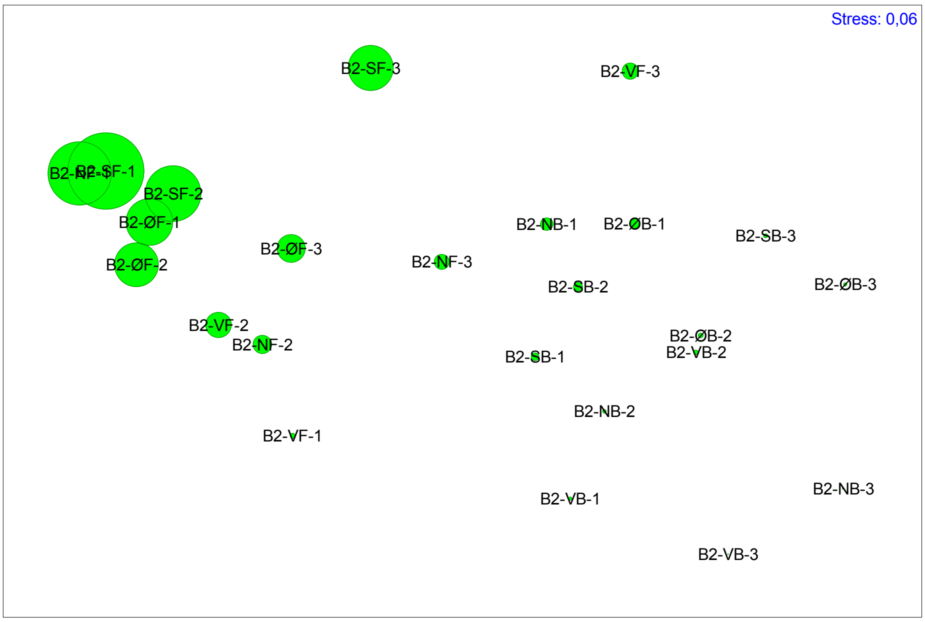


Figure 3.4b MDS- ordination based on the biomass of the fouling community on turbine G8 and transformer station in 2003. A: shafts, B: stones.

B2 - Mytilus edulis 2003



E5 - Mytilus edulis 2003

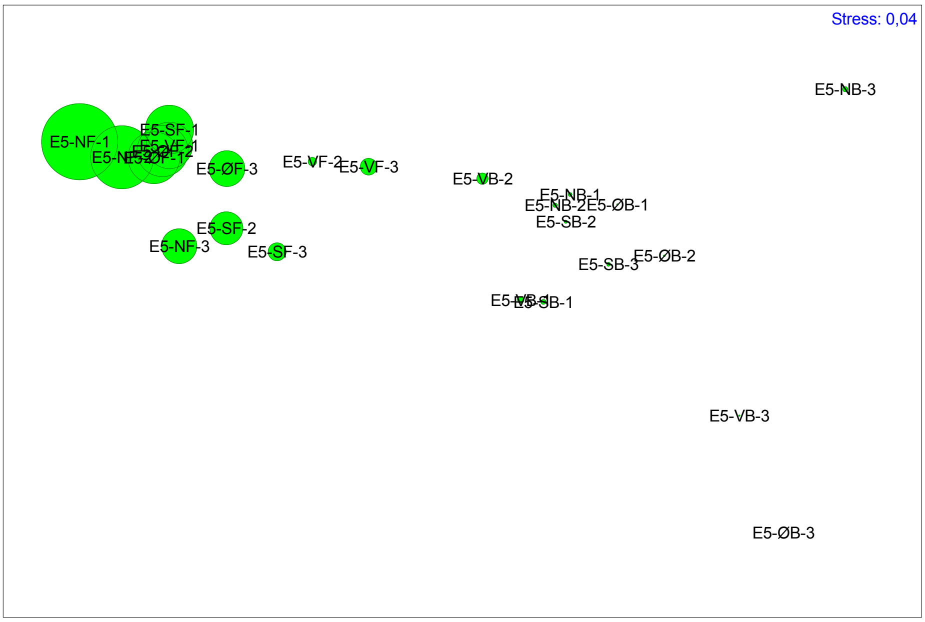
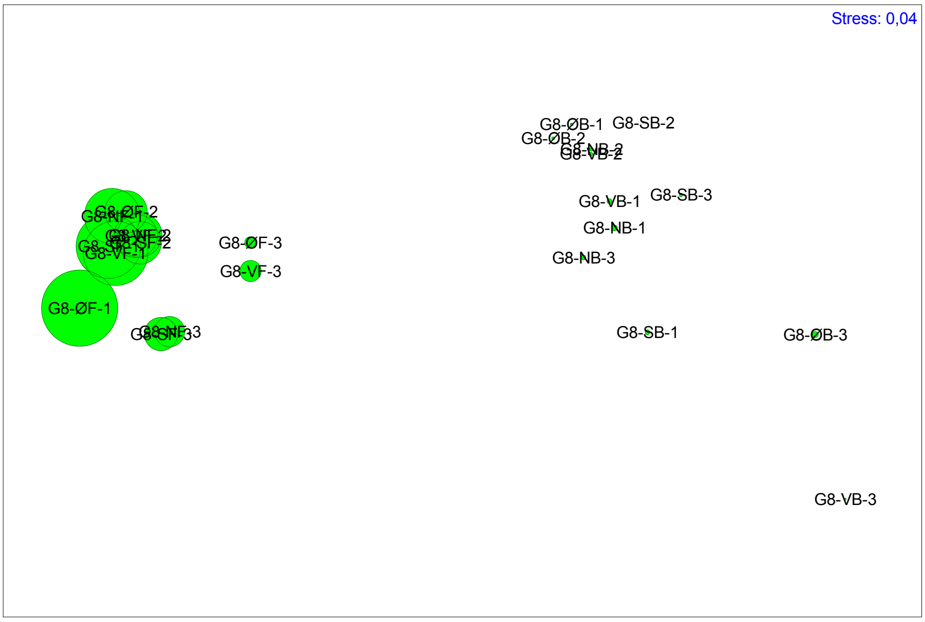


Figure 3.5a MDS- ordination based on the biomass of common mussels (Mytilus edulis) on turbine B2 and E5 in 2003. The circles are proportional to the biomass.

G8 - Mytilus edulis 2003



Transformer - Mytilus edulis 2003

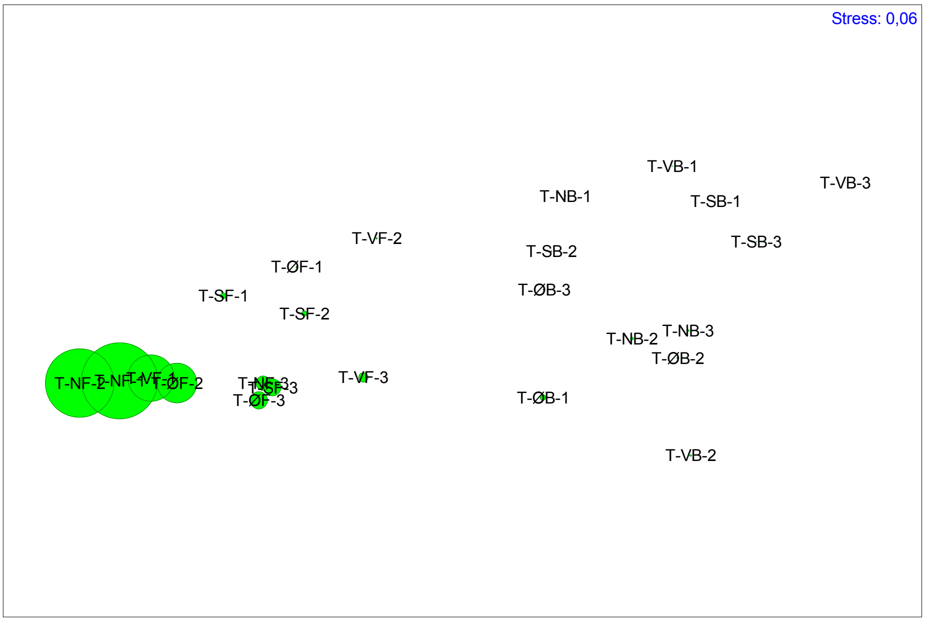
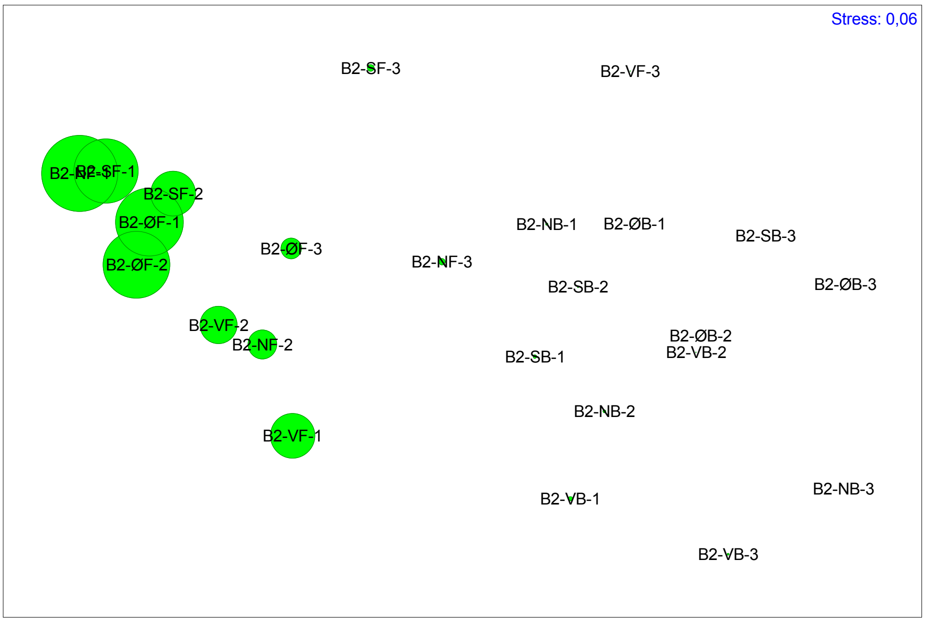


Figure 3.5b MDS- ordination based on the biomass of common mussels (Mytilus edulis) on turbine G8 and transformer station in 2003. The circles are proportional to the biomass.

B2 - *Balanus improvisus 2003*



E5 - *Balanus improvisus 2003*

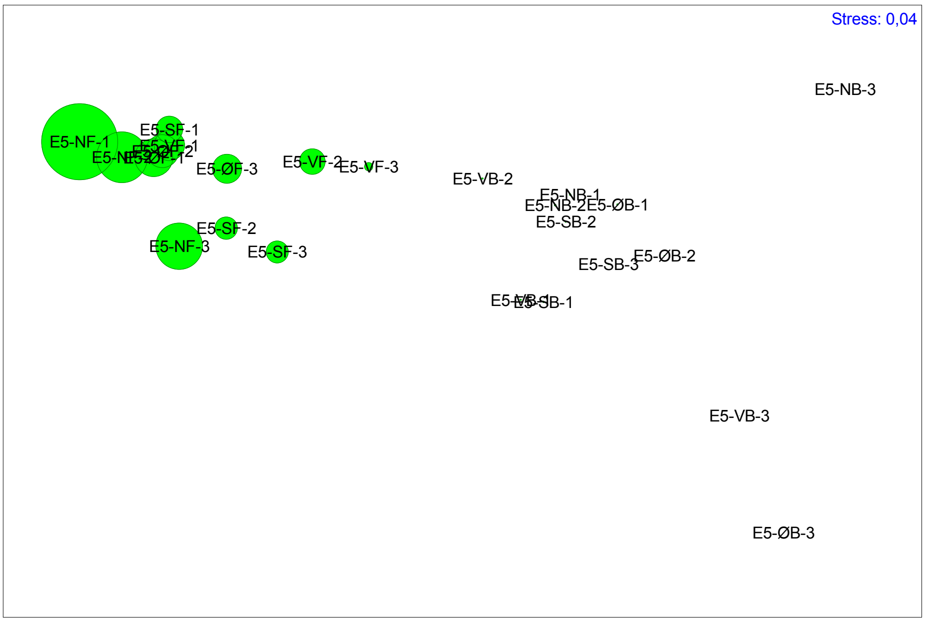
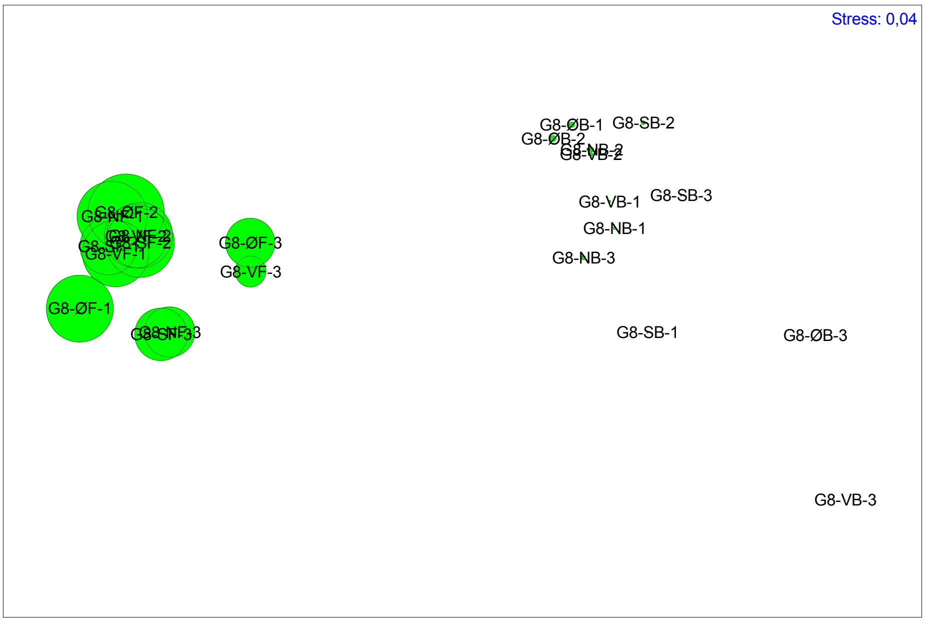


Figure 3.6a MDS-ordination based on the biomass of barnacles (Balanus improvisus) on turbine B2 and E5 in 2003. The circles are proportional to the biomass.

G8 - Balanus improvisus 2003



Transformer - Balanus improvisus 2003

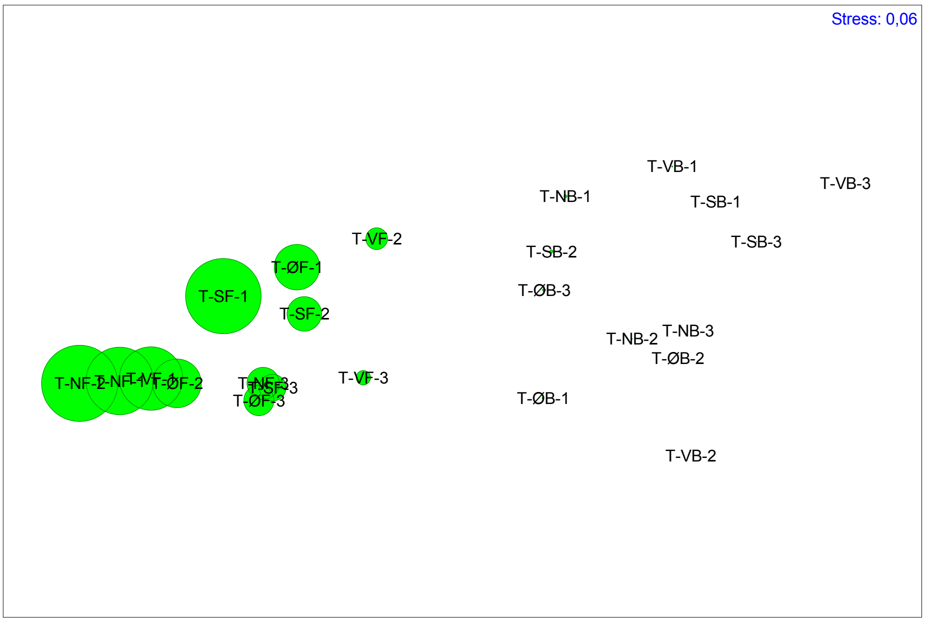


Figure 3.6b MDS-ordination based on the biomass of barnacles (Balanus improvisus) on turbine G8 and transformer station in 2003. The circles are proportional to the biomass

The aim of the following analysis was to examine the community structure in relation to the **direction** (North, South, East and West) and the **water depth** of the sampling stations, respectively. Data from shafts and stones were subject to separate analysis due to the different structure of the fouling community. The analysis was done for each foundation on the basis of biomass and on aggregated data for all foundations on the basis of biomass and abundance of the fouling community on the shafts. The results of the ANOSIM tests were summarised in Annex 9.

Structure on shafts and stones in relation to direction: The structure of the fouling community on the **shafts** was similar in the four directions (North, South, East and West) based on biomass data from individual foundations and also based on analysis of aggregated data of both biomass and abundance. The power of the one-way analysis at individual foundations was rather weak and 10% is the maximum level of significance because the number of possible permutations is limited to ten. The community structure on **stones** was also independent of direction except on turbine E5, where the community was different in the directions south and east, cf. Annex 9.

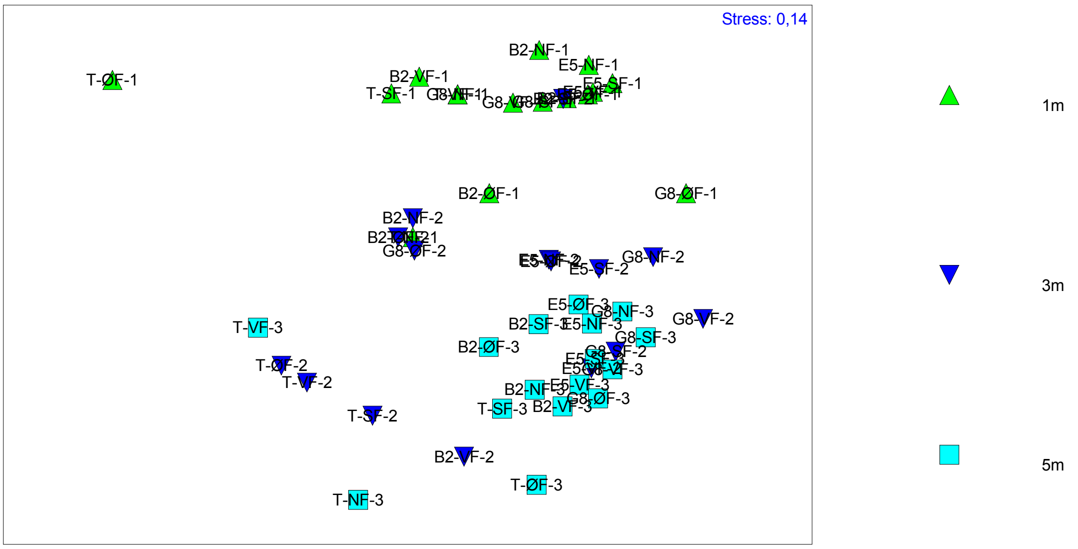
Structure on shafts in relation to water depth: The fouling community changed significantly with the water depth of the sampling stations on the shafts of turbines and the transformer. The fouling community was normally similar at the two uppermost stations 1m and 3m below the surface whereas the community 1m and 5m below the surface was significantly different at the turbines and the transformer. The vertical zonation was even more pronounced at turbine B2 and G8 where the community changed significantly between 3m and 5m below the surface.

The analysis of aggregated data from the shafts based on biomass confirm that the community was uniform 1m and 3m below the surface but different from the community 5m below the surface. The result of an analysis based on abundance data inclusive *Mytilus edulis* and *Balanus improvisus* was basically similar. A predominance of mussels and barnacles near the surface and a decline in biomass and number of the species in deeper water explain the vertical zonation (Figure 3.5a, Figure 3.5b, Figure 3.6a and Figure 3.6b). The vertical zonation on the shafts was even more pronounced for the abundance of the non-sessile species, where the community changed significantly for each sampling interval below the surface, cf. Annex 9 and the MDS-plot in Figure 3.7a and Figure 3.7b.

The free-swimming amphipod *Gammarus spp*. was most abundant near the water surface whereas the other species of amphipods (*Microdeutopus sp*. and *Corophium insidiosum*) were most common in deeper water (Figure 3.7b). This zonation is probably caused by a decrease in wave exposure with greater depth and a simultaneous increase in coverage of macroalgae and deposit of silt in the mats of algae.

Structure in relation to distance of stations on stones: Sampling station 1 and 2 on stones are located on top of the fill and station 3 on the surrounding scour protection. The fouling community was similar at station 1 and station 2 on the stone fill at the turbines and the transformer. However, station 2 on top of the stones and station 3 on the scour protection differed at turbine B2 and G8 and was close to the level of significance at turbine E5, cf. Annex 9. This may be attributed to a difference in water depth, which is about 2m higher at the stone protection, cf. Table 2.1. In addition, the scour protection stones are more likely to be affected by natural re-suspension of the ambient sediment.

Shaft-abundance-excl. Mytilus+Balanus (B2,E5,G8,transformer): Depth



Shaft-abundance of Gammarus spp.

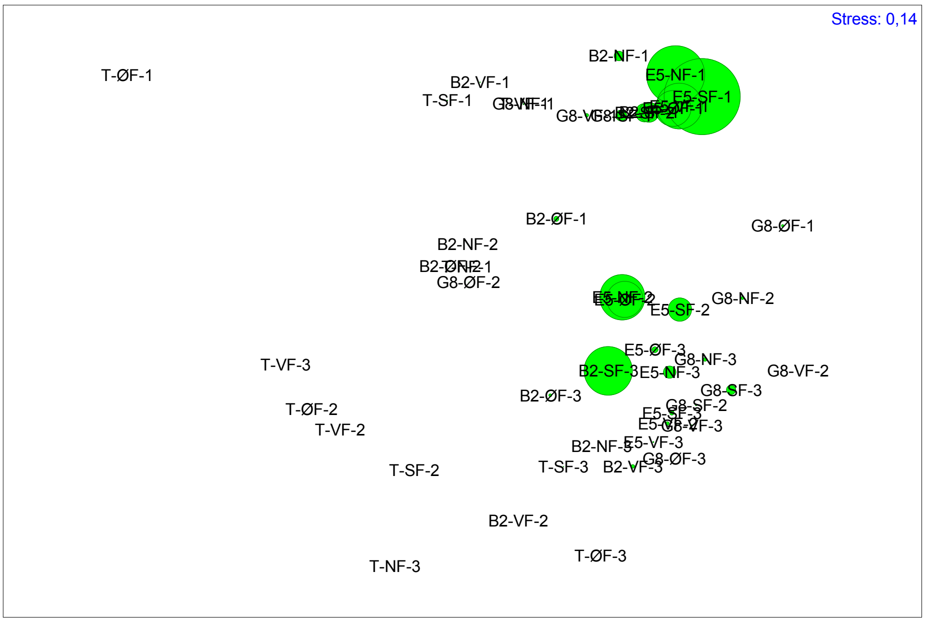
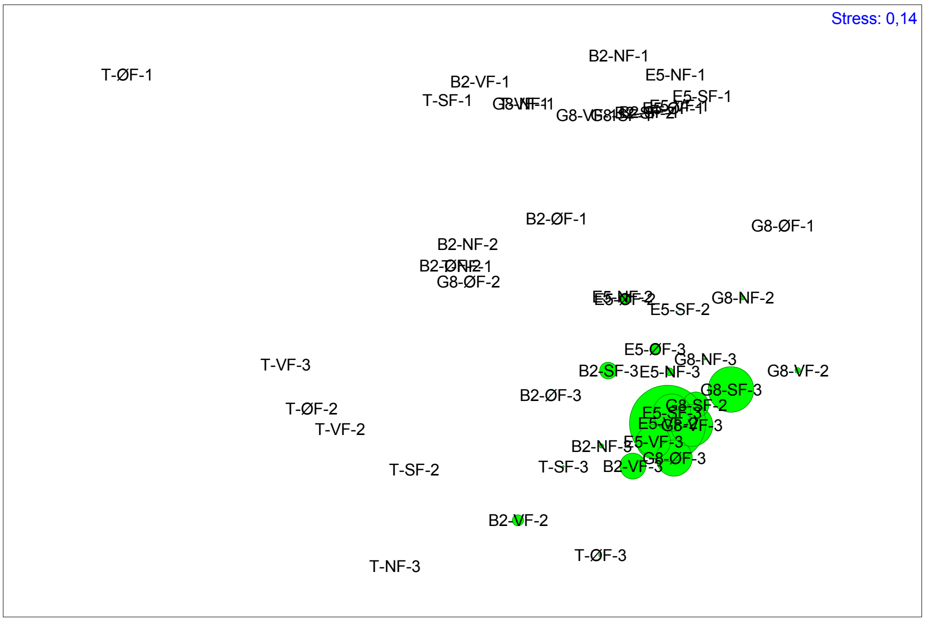


Figure 3.7a MDS- ordination based on abundance of non-sessile species in relation to the depth on shafts of B2, E5, G8 and transformer. The size of the circles is proportional to the abundance of the species.

Shaft-abundance of Microdeutopus sp.



Shaft-abundance of Corophium insidiosum

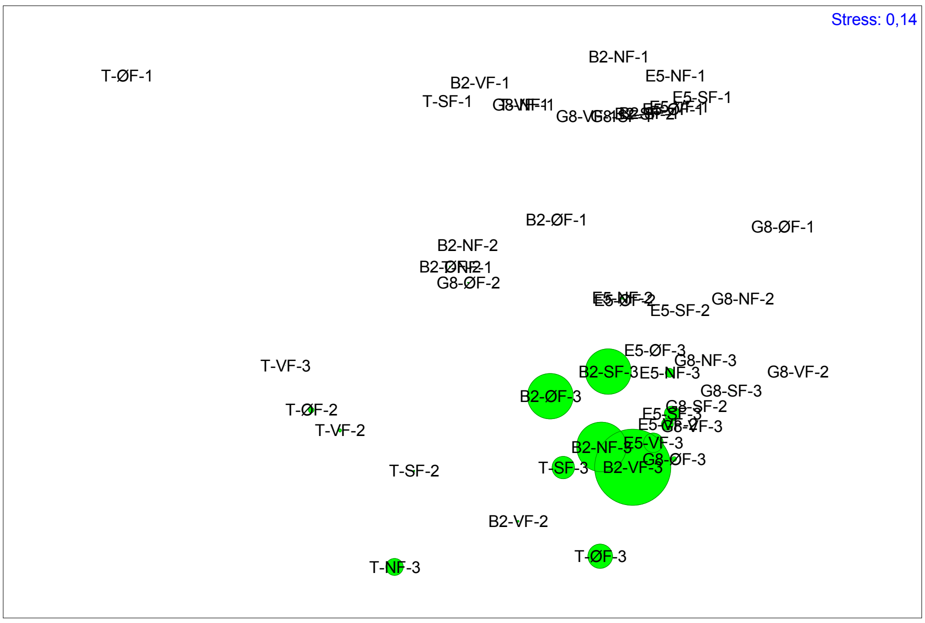


Figure 3.7b MDS- ordination based on abundance of non-sessile species in relation to the depth on shafts of B2, E5, G8 and transformer. The size of the circles is proportional to the abundance of the species.

The changes in the fouling community on **stones** at the transformer station deviated from the turbines. In contrast to the turbines the fouling community was similar at stations 1 and 2 on the top of the stones and station 3 on the scour protection, cf. Annex 9. The reduced and more uniform community of sessile and mobile invertebrates on shaft and stones may be result of more intensive seabed work and activity and the expected higher sediment load around the transformer station.

3.3 Macroalgae

3.3.1 Biomass and species composition

The average biomass of macroalgae varied between 1.6 gDW/m^2 and 12.5 gDW/m^2 on the shafts and between 5.5 gDW/m^2 and 18.9 gDW/m^2 on the stones (Annex 7 and Table 3.5). The biomass was in general 2 times higher on stones than on shafts. The ratio was 1.5 to 5 at the individual foundations. The biomass was highest on turbine B2 and lowest on the transformer station.

Table 3.5 Total biomass and biomass of redalgae, brownalgae and greenalgae. Rounded average values for shaft and stones.

Foundation	Total biomass		Redalgae		Brownalgae		Greenalgae	
	Shaft	Stones	Shaft	Stones	Shaft	Stones	Shaft	Stones
	gDW/m^2	gDW/m^2	gDW/m^2	gDW/m^2	gDW/m^2	gDW/m^2	gDW/m^2	gDW/m^2
B2	12.5	18.9	8.0	16.8	4.5	1.9	<0.1	0.8
E5	4.4	9.6	3.6	9.1	0.8	0.2	<0.1	0.3
G8	1.6	9.2	1.5	6.8	0.1	2.3	0	0.1
Transformer	1.7	5.5	1.4	5.4	0.3	<0.1	<0.1	<0.1
Mast	2.6		2.6		0		0	

The community was dominated by redalgae both in respect to biomass and diversity. The diversity of the community was low and the predominant species was the redalgae *Ceramium tenuicorne*, *Polysiphonia fibrillosa*, *Polysiphonia fucoides, Callithamnion/Aglaothamnion* and filamentous brown algae belonging to the Genus *Ectocarpus/Pilayella* (Annex 8). Greenalgae (*Cladophora sp*. and *Enteromorpha sp*.) was mostly absent from the shafts and the distribution on stones was patchy. The diversity and biomass of macroalgae are subject to seasonal changes. The biomass of the annual filamentous brown algae is highest in late spring and summer and a decline in autumn probably explains the low biomass at the sampling time in October.

The biomass of macroalgae was higher on stones than on shafts and this difference may be explained by less competition for space from barnacles and mussels and the less exposure from waves in deeper water.

The community of algae on the monitoring mast was scarce and the average biomass was low (2.6 gDW/m^2). The predominant species was the redalgae *Ceramium tenuicorne*. Brown- and greenalgae were absent from the mast. The dense fouling layer dominated by mussels is probably a less suitable substrate than stones for development of macroalgae. Exposure for waves and the time of sampling contribute to the observed absence of brown- and greenalgae.

The community of macroalgae developed during the first year on shafts and stones was less diverse and the biomass was lower than the community of macroalgae developed on natural stones in the Lagoon of Rødsand in 2001 /4/. However, an increase in diversity and biomass of perennial species of macroalgae is expected on the stones in the coming years.

3.3.2 The structure of the community

The structure of the community of macroalgae differed significantly on shafts and stones because of a higher diversity and biomass on stones. This appears from the MDS ordinations in Figure 3.8a and Figure 3.8b and confirmed by the results of ANOSIM tests summarised in Table 3.6. The predominance of redalgae on the stones is shown in Figure 3.9a and Figure 3.9b.

Table 3.6 Results of a One-way analysis of the similarity of the community of macroalgae on the shafts versus the stones in 2003.

Foundation	Sample statistic (Global R)	Significance level of sample statistic
B2	0.376	0.1%
E5	0.562	0.1%
G8	0.633	0.1%
Transformer	0.183	1.2%

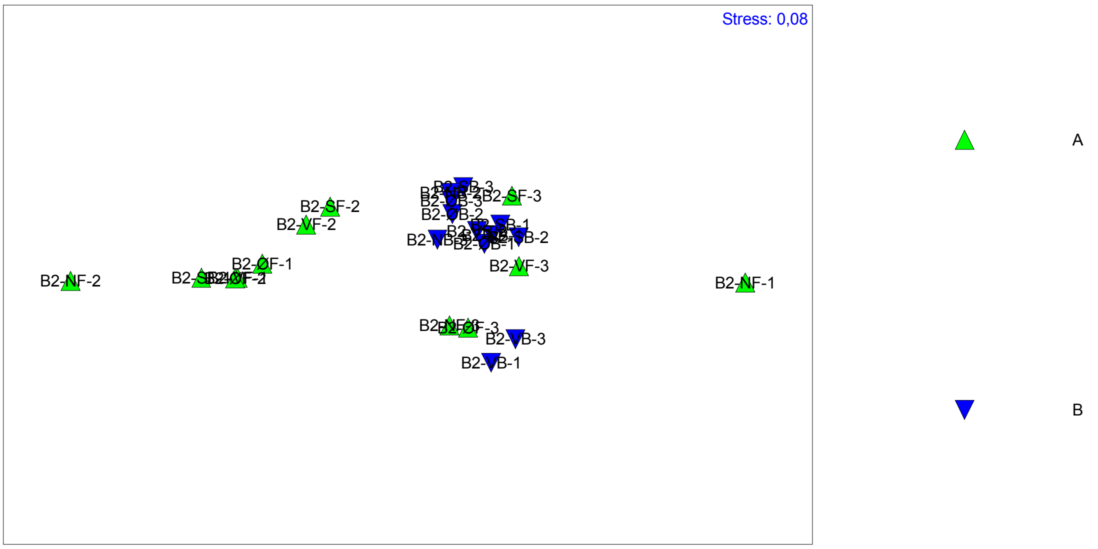
The aim of the further analysis was to examine the importance of **direction** (North, South, East and West) and **depth** on the shafts and the direction and **distance** of the sampling stations on the stones. The analysis was based on data from each turbine and the transformer station and also on aggregated data for all foundations. The results of the ANOSIM tests are summarised in Annex 10.

Structure on shafts and stones in relation to direction: As mentioned earlier the power of the analysis of direction in relation to the individual foundations is rather weak because of the limited number of possible permutations and this must be taken into account when considering the results of the analyses. Macroalgae were absent in 3m depth in some directions of the shafts and this further reduced the number of possible permutations and the power.

The biomass of macroalgae on the **shafts** was not affected by the direction. An exception was the transformer station where the community on the North and South faces differed significantly and this was also confirmed by analysis by aggregated data. The biomass of macroalgae was highest on the South face and shading of the transformer could contribute to a lower biomass on the North face of the shaft.

The community of macroalgae on **stones** was not affected by direction at turbine E5 but one or more directions were significant around the other foundations. The biomass on stones North of G8 was different from all other directions. The community on stones North and East of the transformer was also different. West and East were different at B2.

B2 - biomass algae 2003



E5 - biomass algae 2003

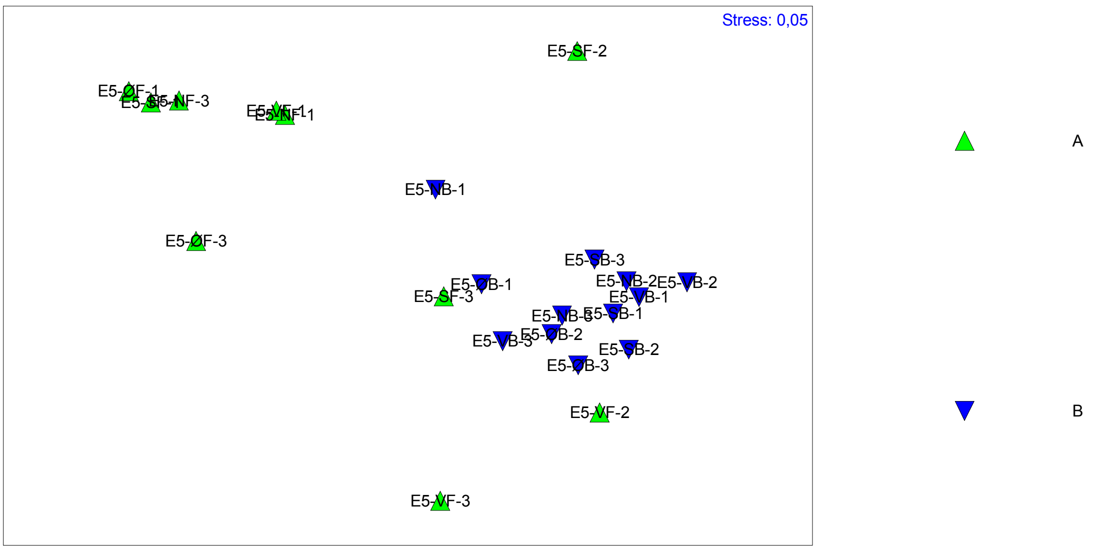
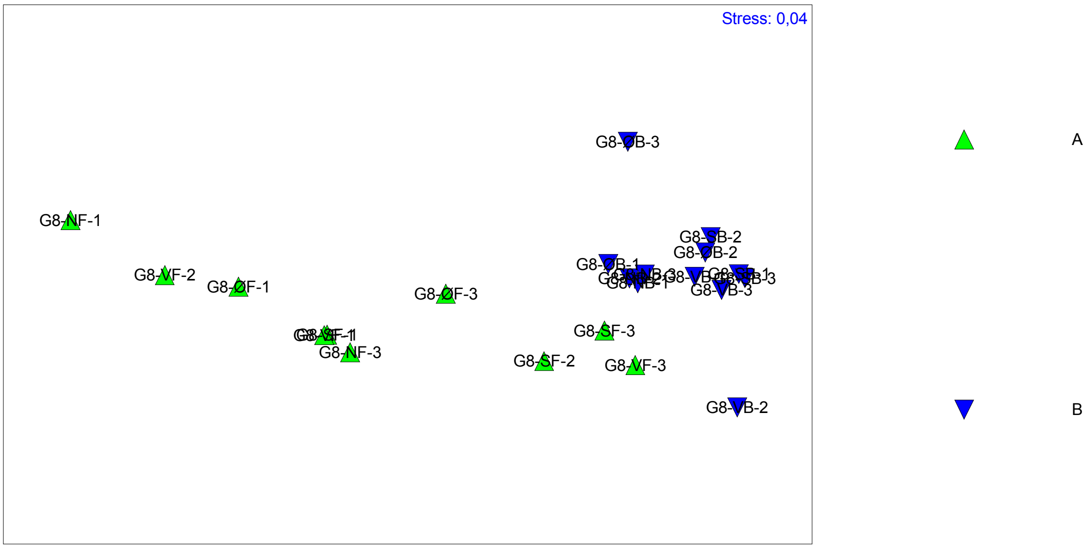


Figure 3.8a MDS- ordination based on the biomass of macroalgae on shafts and stones of turbine B2 and E5 in 2003. A: shafts, B: stones.

G8 - biomass algae 2003



Transformer - biomass algae 2003

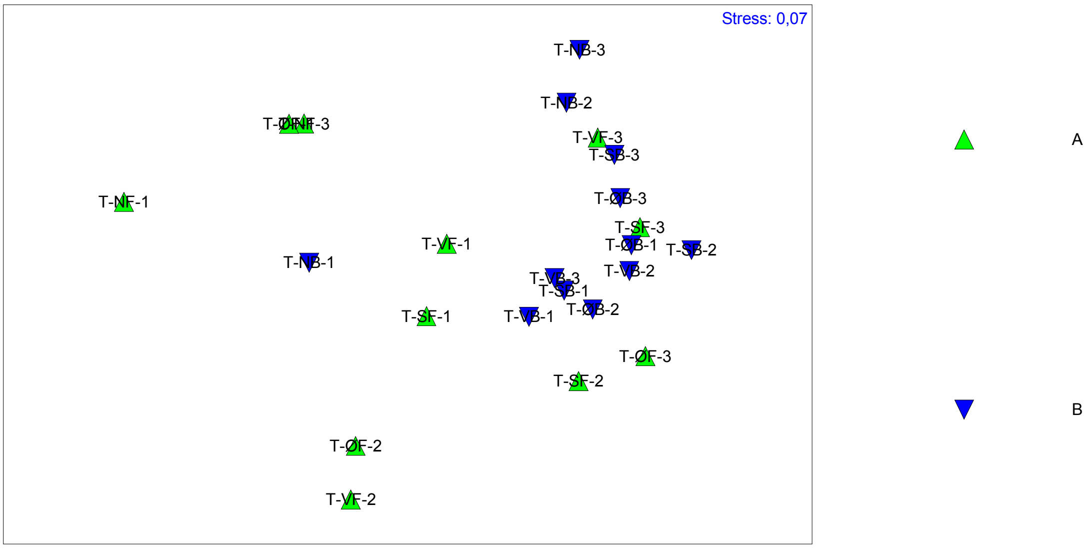


Figure 3.8b MDS- ordination based on the biomass of macroalgae on shafts and stones of turbine G8 and transformer station in 2003. A: shafts, B: stones.

The biomass of algae was lower on stones North of turbine G8 than in the other directions. At the transformer station the biomass was higher on the North than on the East face. The importance of direction on the biomass of macroalgae on stones was therefore not consistent at this early stage of development of the community of macroalgae and interpretation is not feasible.

Structure on shafts in relation to water depth: The community was similar at the 2 uppermost sampling stations of the **shafts** of the foundations but changed significantly at greater depth at turbine B2 and G8. According to the analysis of the aggregated data the community of macroalgae differed significantly between 1m and 3m and between 1m and 5m but not between 3m and 5m (Annex 10). Analysis of individual and aggregated data is not consistent but it is believed that a combination of competition for space, exposure for waves and light are the main regulating factors.

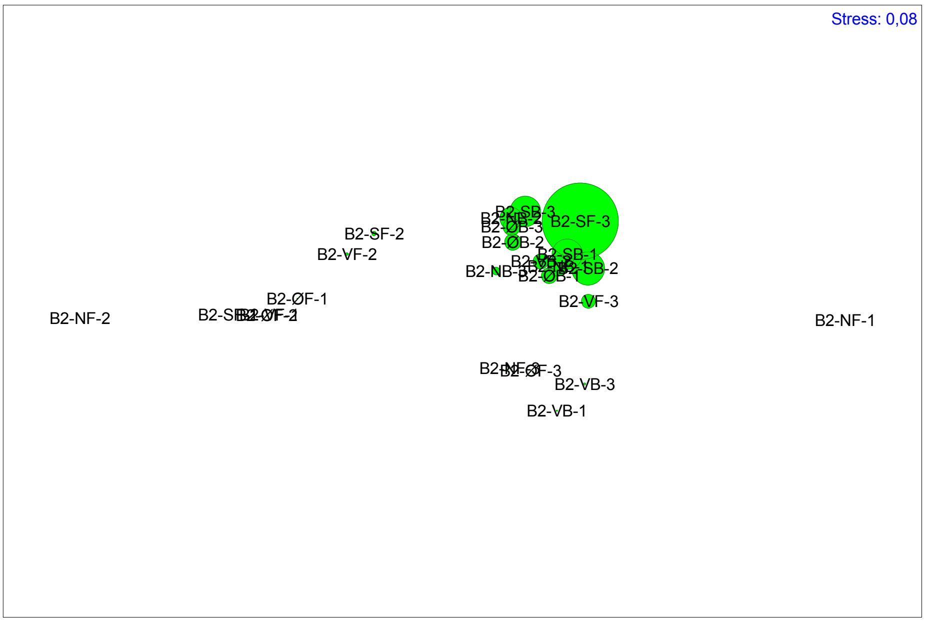
Physical factors of potential importance for development of macroalgae are light and exposure for waves. The lower biomass North of G8 could be a shadowing effect of the turbine but this explanation is not supported by the result of biomass around the transformer station. Exposure for waves and currents may be a potential regulating factor but the impact may be opposite in rough and benign weather. The drag forces will potentially reduce the biomass of filamentous algae in rough weather but the water movement in benign weather may increase the flux of nutrients and enhance the growth and biomass.

The maximum wave high in the wind farm depends on the wind direction and the position of the turbines in the wind farm. The highest waves comes from Southwest and West and the lowest from North /5/. The wave high in all wind directions is in general reduced in the wind farm from South to North due to the decreasing water depth in this direction and the lee effect of the sand bars in the Lagoon of Rødsand.

Analysis of aggregate data showed that the structure of the community of macroalgae on stones of the North and West faces of the turbines was different and exposure may be a contributing factor.

Structure in relation to distance of stations on stones: The community of macroalgae was similar on stations 1 and 2 on top of the stones and at station 3 on the scour protection both on individual foundations and also based on aggregated data for the turbines and the transformer station.

B2 - Redalgae 2003



E5 - Redalgae 2003

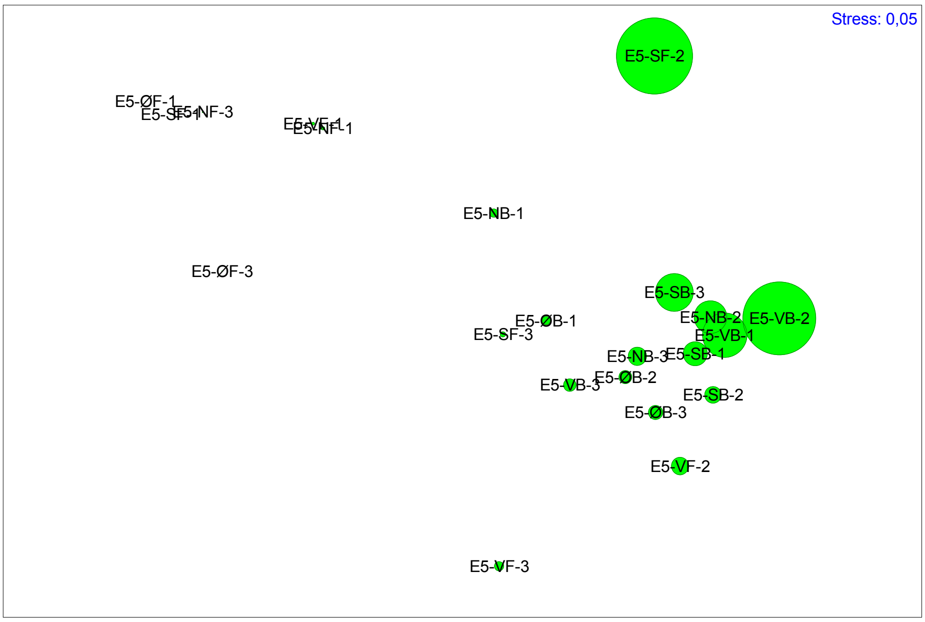
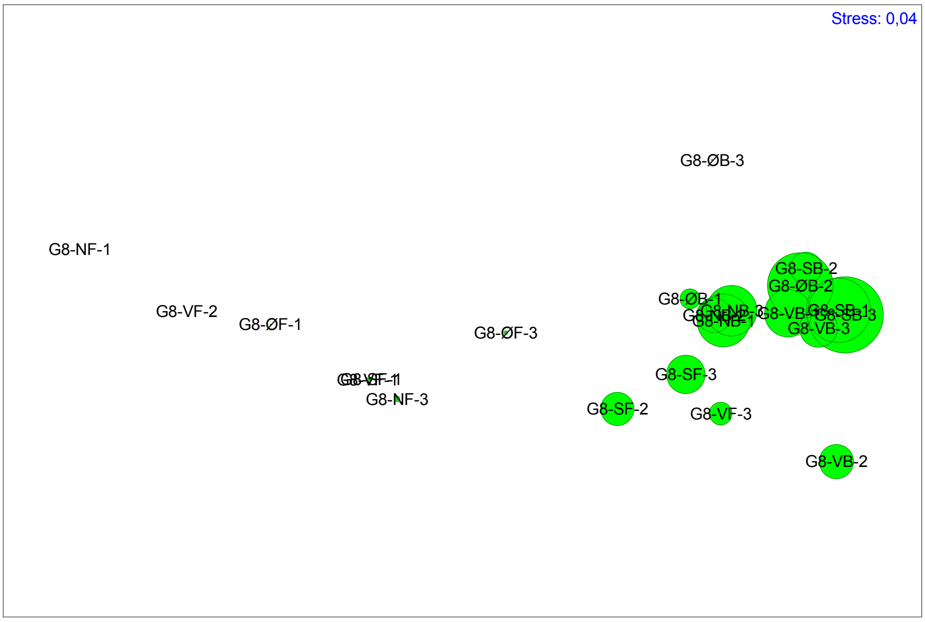


Figure 3.9a MDS-ordination based on the biomass of redalgae on turbine B2 and E5 in 2003. The circles are proportional to the biomass.

G8 - Redalgae 2003



Transformer - Redalgae 2003

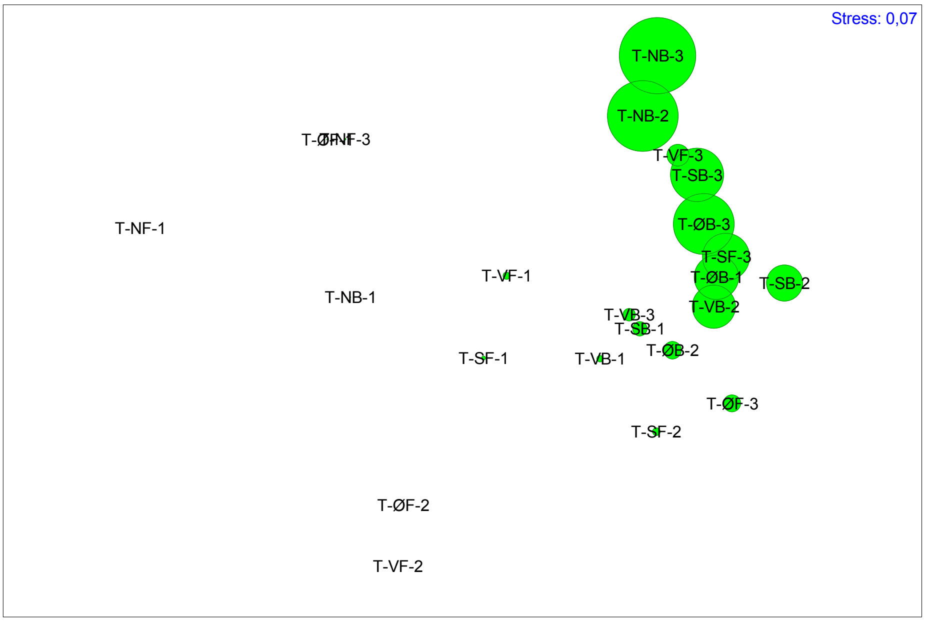


Figure 3.9b MDS-ordination based on the biomass of redalgae on turbine G8 and transformer station in 2003. The circles are proportional to the biomass.

4 SUMMARY AND CONCLUSIONS

4.1 Invertebrates

Surveys of the fouling community of sessile and mobile invertebrates and attached macroalgae was conducted in October 2003 19-49 weeks after deployment of the foundations and 16-28 weeks after the stones was placed in the chambers of the foundations and around the foundations as scour protection.

A dense layer of small common mussels (*Mytilus edulis*) covered the shafts (the vertical cylindrical and smooth concrete surfaces of the foundations). The shell length of the mussels was mostly below 10mm and the mussels covered a layer of barnacles (*Balanus improvisus*) except for narrow barnacle zone close to the water surface.

The biomass of mussels and barnacles on the shafts was about ten times higher than on the stones. A few species of amphipods were also abundant on shafts and stones but the density and biomass of mobile species was far below the density and biomass of the sessile species. The biomass on shafts and stones was not affected by the age of the substrates because the settling has been limited on foundations deployed late in 2002 after the end of the reproductive season.

The structure of the invertebrate fouling community on the shafts and stones was different due to the higher biomass on the shafts. The fouling community on shafts and on stones was similar in different directions (North, South, East and West) around the foundations. There was only one exception. The community was dissimilar South and East of turbine E5.

The fouling community changed with depth on the shafts and except for the transformer station also on the stones. The community was similar in the uppermost sampling stations on the shafts due to the predominance of mussels and barnacles closest to the surface. The sessile species decreased in deeper water and mobile species of amphipods (*Microdeutopus sp*. and *Corophium insidiosum*) increased in number. A reduction in wave action and a simultaneous increase of macroalgae and deposit of silt may have contributed to the observed changes.

A thick and dense layer of mussels covered the monitoring mast deployed in 1997. The biomass of common mussels on the mast was about four times higher than the maximum biomass of mussels developed on shafts of the turbines in 2003. The maximum shell length of mussels on the mast was similar in 1999-2003. The biomass of mussels in 2003 was lower than in 2001. The biomass in 2001 was probably close to the maximum attainable in the area and it is believed that erosion of the old fouling layer has given space for a renewed settling of mussels.

4.2 Macroalgae

Macroalgae were scarce on the uppermost part of the shafts and the coverage and biomass increased with depth. The biomass of macroalgae on stones was about two times higher than on the shafts. A few species of redalgae dominated the community but the diversity and biomass was far below these population attributes measured on natural stones in the Lagoon of Rødsand in 2001.

The community of macroalgae on shafts and stones was different. Analysis of the importance of direction on macroalgae around individual turbines was inconclusive. Analysis based of aggregated biomass data indicated that the community on North and South faces of shafts was different and that North and West faces of stones differed. However, firm conclusion must await further surveys of the development of the fouling community of macroalgae.

4.3 Conclusions

- A fouling community of common mussels, barnacles and macroalgae have developed on turbines and the transformer station on concrete foundations and stones introduced in the wind farm in late 2002 and early 2003. The fouling community was not affected by the age of the substrates during the first reproductive season in 2003.

- A further growth, development and succession of sessile communities of invertebrates and macroalgae and mobile invertebrate species and fish are envisioned in the next years. The expectation is based on measurements of the fouling community on the monitoring mast in the wind farm deployed in 1997 and surveys of the natural community of macroalgae on stones in the Lagoon of Rødsand close to the wind farm.

- The biomass and abundance of invertebrates and the biomass of macroalgae on the shaft and stones was reduced at the transformer station compared to the turbines. The seabed work and the traffic have been more intense around the transformer due to additional deployment of connecting cables on the seabed. The associated sediment spill of the extra earthwork and re-suspension of sediment caused by the propellers of the ships may have hampered the settling and growth of organisms and reduced the biomass and abundance of the fouling community in the first reproductive season.

5 REFERENCES

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