WATER & ENVIRONMENT

Energi E2 A/S

Surveys of Hard Bottom Communities on Foundations in Nysted Offshore Wind Farm and Schönheiders Pulle in 2004

Report
May 2005

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0 ABSTRACT

I efteråret 2002 indledtes opsætningen af møllefundamenter og i foråret 2003 afsluttedes anlægsarbejdet inklusive udlægning af sten i fundamenter og omkring fundamenter som erosionbeskyttelse. Fotografering, videoptagelser og indsamling af kvantitative prøver af begroningssamfundene på mølleskafter og sten blev indledt i oktober 2003 og gentaget i næsten uændret omfang i oktober 2004. Desuden blev der i 2004 gennemført lignende undersøgelser på henholdsvis 4m og 6m dybde på Schönheiders Pulle med henblik at tilvejebringe materiale fra et naturligt hårdbundssamfund på et stenrev i området.

Begroningssamfundet i mølleparken domineres kvantitativt af blåmuslinger og rurer. Biomassen er forøget kraftigt siden 2003 som følge af blåmuslingernes vækst, men er stadig lavere på mølleskafter og sten end på henholdsvis målemasten fra 1997 og Schönheiders Pulle. Det forventes dog, at biomassen på mølleskafterne indenfor det næste år vil være tæt på det maksimale for området.

Strukturen i begroningssamfundet af invertebrater var ensartet omkring fundamenterne uanset retning, men varierede med dybden både på mølleskafterne og på stenene. Ændringerne skyldes, at de dominerende arter af blåmuslinger, rur og tanglopper reduceres i antal og mængde med stigende dybde og at andre arter af krebsdyr øges i antal, hvilket tilskrives dybderelaterede hydrografiske ændringer med virkning på tilførsel og bundfældning af larver, fødetilgængelighed og vækst samt ophvirvling af sediment fra bunden.

Makroalgesamfundet var domineret af rødalger og artsfattigt. Som følge af en pladskonkurrence fra blåmuslinger var alger forsvundet fra mølleskafterne i 2004 med undtagelse af transformerstationen, hvor algerne voksede på pletter med få eller ingen muslinger. Algesamfundet på Schönheiders Pulle var ensartet uanset dybden og i forhold til biomassen af algesamfundet i mølleparken var der ingen forskel. Derimod var artssammensætningen forskellig i de to områder og selvom de dominerende arter var identiske, var udbredelsen af mindre almindelige arter forskellig. Desuden var der to arter af rødalger, som ikke blev fundet i mølleparken. Det forudses, at den fremtidige udvikling af algesamfundet i mølleparken vil afhænge af blåmuslingernes vækst og pladskonkurrencen mellem planter og dyr.

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Deployment of foundations in Nysted Offshore Wind Farm started in the autumn of 2002 and the construction work including placement of stones in foundation chambers and around the foundations as scour protection ended in the spring of 2003. The first post-construction survey of the fouling community on shafts and stones was conducted in October 2003. An almost similar investigation was carried out one year later in October 2004 and supplemented with surveys at Schönheiders Pulle with the aim of providing data on a natural hard bottom community on a stone reef close to the wind farm.

Common mussels and barnacles dominated the fouling community in the wind farm in 2004. The biomass of the community has increased significantly since 2003 due to a rapid growth of the mussels. However, the biomass on shafts and stones was still below the biomass at the monitoring mast deployed in 1997 and at Schönheiders Pulle. It is

expected that the biomass on the shafts will approach the maximum level for mussel populations in the area during the next year.

The structure of the fouling community was uniform around the foundations but changed with depth on both shafts and stones. The number and biomass of the dominant species of mussels, barnacles and the amphipod *Gammarus sp*. was lower in deeper water and other species of crustaceans increased with depth. These changes in community structure were attributed to depth-related hydrographic changes, affecting the flux and settling of larvae, availability of food and growth and stirring of sediment from the seabed.

The community of macroalgae was dominated by redalgae but the number of species was low. Macroalgae has disappeared from the shafts since 2003 and excluded by the rapid growth of the mussels with the exception of the transformer station, where algae were attached to patches with no or few mussels on the shafts. The community of macroalgae at Schönheiders Pulle was similar, irrespective of the depth and similar to the community on stones in the wind farm when assessment was based on biomass. The dominant species of redalgae were the same but the species composition was different in the two areas because the distribution of the less common species varied. Two less common species of redalgae recorded at Schönheiders Pulle were not found in the wind farm. The future development of the community of macroalgae in the wind farm is expected to depend on the growth of the mussel population and the space competition between algae and invertebrates.

1 BACKGROUND

The Nysted Offshore demonstration wind farm comprises 72 turbines and one transformer station. The foundations of the turbines and the scour protection around the foundations were established during the autumn of 2002 and the spring of 2003.

The gravity foundations of concrete and the surrounding stone protections occupy about 36000 m^2 of the seabed, which consisted of sand inhabited by benthic in-fauna and epibenthic populations of common mussels (*Mytilus edulis*) /1, 2/. The total surface area of the foundations and the scour protections is about 40000 m^2.

The initial stages in colonisation of the new solid surfaces by sessile species of animals and plants and associated mobile species of invertebrates and fish were investigated in October 2003 /3/.

This report presents results of the surveys of the hard bottom (fouling) community conducted one year later in October 2004. Furthermore, it is planned to continue the surveys in the autumn of 2005. The surveys of the hard bottom community in the wind farm were almost similar in 2003 and 2004. However, surveys were also undertaken at Schönheiders Pulle with the aim of providing comparative data of a natural hard bottom community on a stone reef close to the wind farm.

2 MATERIALS AND METHODS

2.1 Location

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

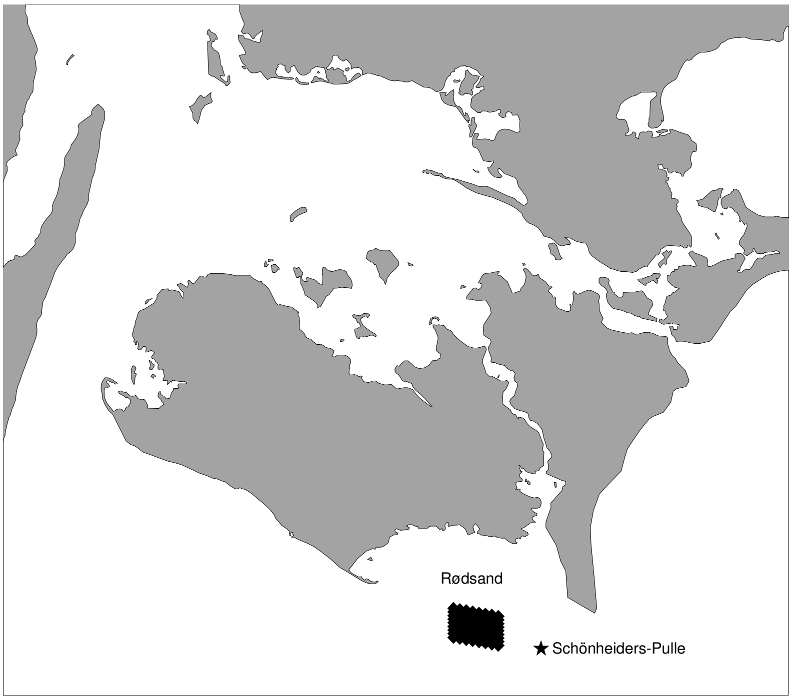

Figure 2.1 Location of the Nysted Offshore Wind farm (black area) and Schönheiders Pulle.

The water depth in the wind farm area varies between 6 and 9.5m. Winds from the western sector are the most frequent and strongest. Calculated wave heights are 3.6m at the southwest corner, 3.3m at the southeast corner and 2.6m at the north corner of the wind farm. The current velocity is highest at the south corner of the wind farm /4/.

The stone reef Schönheiders Pulle is situated about 5km southeast of the wind farm. The Forest and Nature Agency conducted a reconnaissance of the reef in 1992 and 1997 /5/.

2.2 Description of foundations and scour protection

The turbines and the transformer station are placed on gravity foundations of 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 in the cells has a nominated median diameter (d_{50}) of 70cm. At most of the turbines scour protections of stones with a nominated thickness of 110cm 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 were 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 1m outside the foundations the protections slope down to the surrounding seabed (see Figure 2.2 left)

The base of the foundations is 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 (Table 2.1). The surface of the scour protections is 1.5-2m further below (Figure 2.2 right). At turbines where the surface of the scour protection is below the natural seabed, the seabed outside the protections gradually slopes up to the natural level.

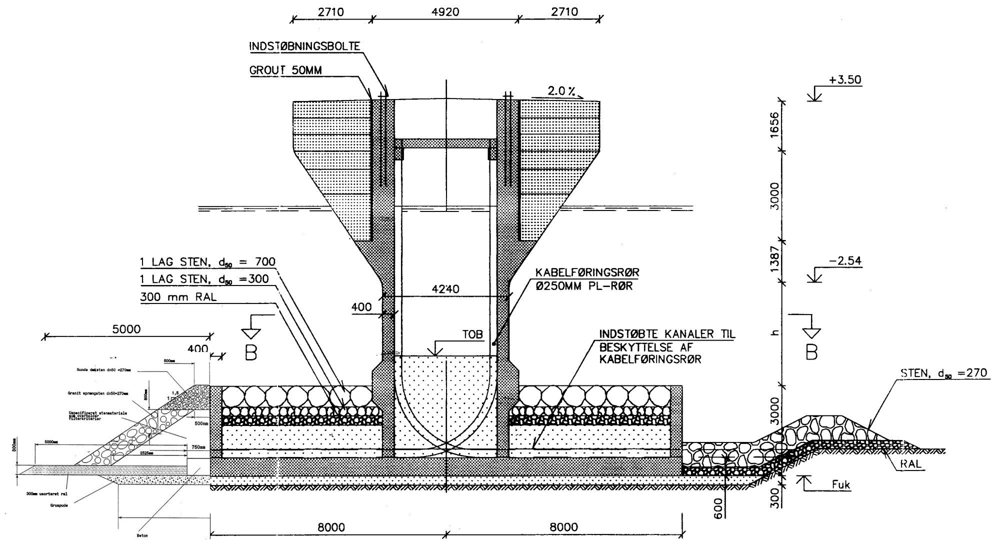

Figure 2.2 Turbine foundations in Nysted Offshore wind farm. Left: with anti collision protection. Right: with ordinary scour protection

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

The foundations were placed on the seabed during the period from October 2002 to May 2003 while the stone fill in the foundation chambers and the scour protections were placed from March to June 2003, cf. Table 2.1.

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 founda-tion	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 time lapse between deployment of the turbines and the surveys in October 2004 was 71 weeks for turbine G8 and 101 weeks for turbine B2. The stones were put in position after deployment of the turbines, and the "age" of substrate of stones varied between 66 weeks and 78 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 October 2004.

Turbine	**Time lapse in weeks between Deployment of foundations and the surveys in October 2004**	**Time lapse in weeks between Deployment of stones and the surveys in October 2004**
Turbine A7	92	76
Turbine B2*	101	79
Turbine C9	82	80
Turbine D3	82	78
Turbine E5*	80	73
Turbine G2	75	68
Turbine G8*	71	68
Transformer*	92	79
Monitoring mast*	7 years	

* Quantitative surveys

2.3 Field surveys

The field surveys in October 2004 included:

- Continued surveys in the wind farm
- Surveys at Schönheiders Pulle

2.3.1 Continued surveys in the wind farm

The scope and extent of the activities in 2004 in the wind farm including the monitoring mast are summarised in Table 2.3.

Table 2.3 Summary of investigations of fouling community at turbine foundations and scour protections and at the monitoring mast in October 2004.

Locality	Method	Parameters to be registered	Number of stations	Place of sampling	No. of photos or samples per station
Turbines	Photography	Coverage of mussels, barnacles, macro algae etc.	8 turbines (A7, B2, C9, D3, E5, G2, G8 and transformer)	Shaft	5-10 (0.24 m^2 = 40 x 60cm)
				Stones in chambers and scour protection	20 (0.24 m^2 = 40×60cm)
	Quantitative Sampling	Species list Abundance per species Biomass per species Shell length of mussels >10mm	4 turbines (B2, E5, G8 and transformer)	Shaft	6 samples: 225 cm^2 = 15×15 cm
				Stones in chambers and scour protection	12 samples: 625cm^2 = 25×25 cm
Monitoring mast	Photography	Coverage of mussels, barnacles, macro algae etc.	1	West side	8 (0,24 m^2 = 40x60 cm) Each meter depth from 1 m to 8 m
	Quantitative Sampling	Species list Abundance per species Biomass per species Shell length of mussels >10mm	1	West side	8 samples: Samples: 625 cm^2 =25×25 cm Each meter depth from 1 m to 8 m.

The foundations selected for qualitative and quantitative surveys and the position of the monitoring mast in the wind farm are shown in Figure 2.3.

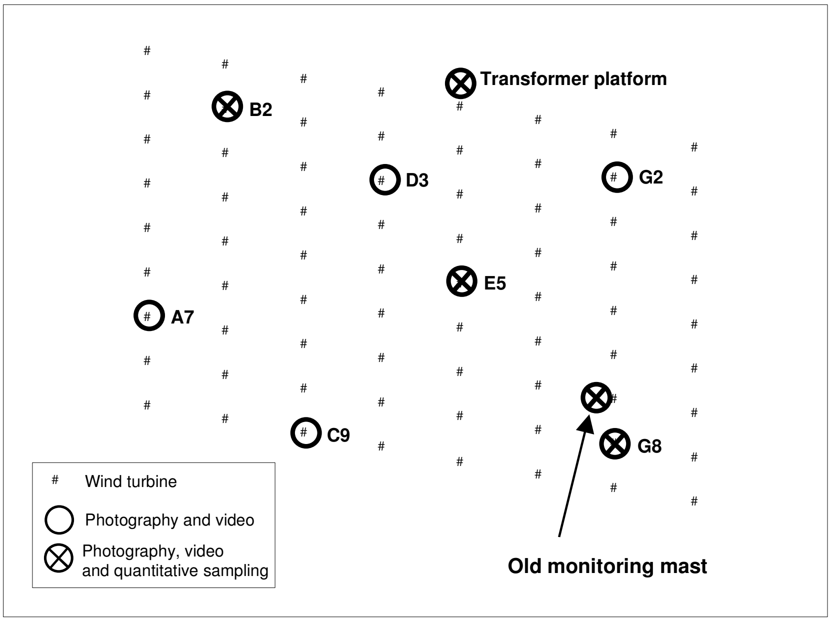

Figure 2.3 Position of foundations and monitoring mast in the wind farm surveyed in 2003 and 2004.

Photography and video

Divers carried out photography, video and quantitative sampling along four survey lines deployed south, north, west and east of each turbine. Three marked survey lines of lead were used in each direction. The first line along the shaft reached from the water surface to the stone filled chamber. The second line continued from the shaft across the surface of the stone filled chamber and beyond the edge of the foundation. The third line extended from the foundation and across the stones to the border of the scour protection.

Video recordings were carried out along the four survey lines with a handheld 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 $0.24 m^2$ (40×60 cm).

Figure 2.4 Equipment used for digital photography in the wind farm and Schönheiders Pulle in 2004.

Photos were taken in two directions (south and north) along the shafts from 0,5m below the surface and at depth intervals of 1m (1.5m, 2.5m etc.) to just above the stone fill (Figure 2.5).

Photos were taken at three positions in each of the four directions (south, north, west and south) on the stones in the chambers and at two positions on the scour protections, cf. Table 2.4 and Figure 2.5.

Table 2.4 Location of photos and quantitative samples taken on stone fill and scour protections.

Location	Photos	Quantitative samples
Stone fill in chambers	1m from the shaft	1m from the shaft
	2.5m from the shaft	
	4.5m from the shaft in the south and north direction	4.5m from the shaft in the south and north direction
	5.5m from the shaft in the west and east direction	5.5m from the shaft in the west and east direction
Scour Protection	0.5 m from the outside of the foundation	1.5m from the outside of the foun-dation
	2.5m from the outside of the foundation	

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.

The images were examined and the coverage of common mussels, barnacles and macro-algae 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 recordings also gave an indication of the presence of fish and larger invertebrates (crabs).

Quantitative sampling

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

A square steel frame was applied for the sampling. A bag of plankton net with a 300µm-mesh size 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 remove all organisms and to collect these in the net bag. The net bag was subsequently detached and closed by means of Velcro tape. The net bags were taken to the survey vessel, and the content was carefully transferred to labelled plastic bags. The samples were stored in a deep freezer for later analysis in the laboratory.

Samples were taken on the southern and northern sides of the shafts at three depths: 1m and 3m below surface and 0.5 m above the stone fill (Figure 2.5 and Table 2.4). In total, 6 samples (2×3) were taken at each shaft (Table 2.3).

On the stone fill and scour protections three samples were taken in each of the four directions. The samples were taken 1m from the shaft, 1m inside the outer edge of the hexagonal basement and 1.5m outside the basement (Figure 2.5 and Table 2.4). Thus, a total of 12 samples were taken on the stone fill and the scour protection at each turbine.

The sample size was 0.0225m^2 (15×15 cm) on the shafts and 0.0625m^2 (25×25 cm) on the stones. The smaller sample size on the shafts was justified by a higher density of sessile organisms on the smooth concrete surfaces than on the rough and irregular stones.

At 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 in 1991 and 2001 suggested that the thickness of the fouling layer was uniform around the circular steel foundation of the mast. The samples collected in the uppermost 5 m in 2003 and 2004 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.

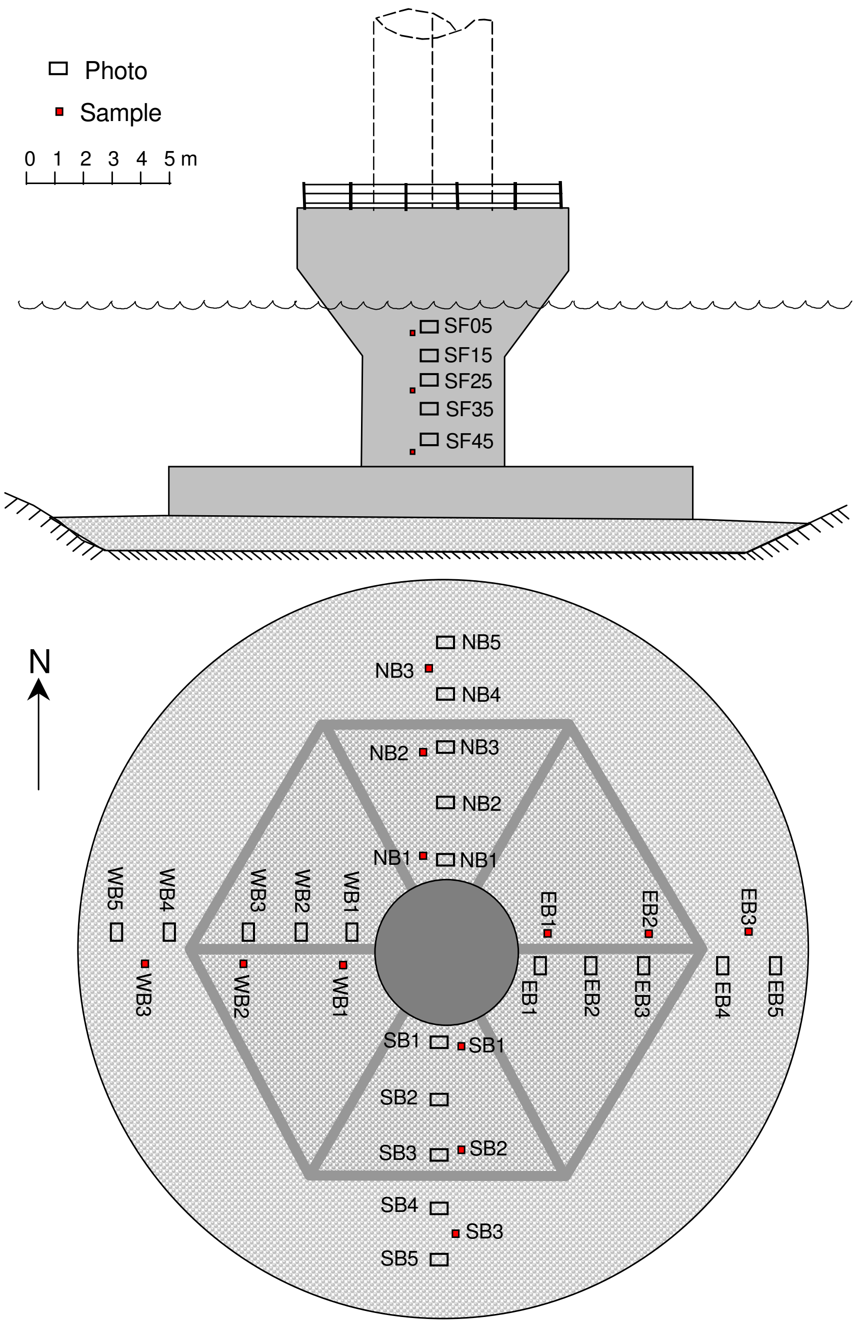

Figure 2.5 *Investigation of the fouling community on turbine foundations and scour protections in the Nysted Offshore Wind Farm. Top: Side view. Bottom: Top view. Sample and image codes are indicated.*

2.3.2 Schönheiders Pulle

Is a natural stone reef southeast of the wind farm, cf. Figure 2.1. The water depth is between 4-11 metres. According to the Forest and Nature Agency the shallowest part of the reef was surveyed in September 1992 and the deeper part in September 1997. The density of stones was high until a depth of 7m and decreased rapidly with greater depth. The coverage of common mussel (*Mytilus edulis*) was high in shallow water and declined with increasing depth. The diversity of macroalgae was modest due to the low salinity, and the community consisted of filamentous and encrusting red- and brown algae /5/.

Surveys were conducted at station 1 and station 3, which were inspected in 1992. Stones should be plenty and covered by dense epi-benthic communities of mussels and macroalgae according to the previous surveys. The water depth was approximately 4m and 6m, respectively.

The surveys at station 1 and station 3 included:

- Video-recording in four directions (south, north, west and east) from the centre of the station and to a distance of 5m.

- Photography in four directions and stations at 1m intervals from the centre and to a distance of 5m. The total number of photos were 4 x 5 = 20 at each station.

- Collection of quantitative samples in four directions. The samples (625 cm^2) were collected 1m and 2m from the centre of each station. The total number of samples were 2 x 4 = 8 samples at each station.

The analysis of photos and quantitative samples was carried out as described for similar samples collected in the wind farm.

2.4 Laboratory treatment and statistical analysis

2.4.1 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 the species were determined.

The common mussel (*Mytilus edulis*) and the barnacle *Balanus improvisus* were by far the most dominant sessile organisms. Mussels were very abundant and further treatment of the samples was based on a separation of the mussels in three size classes (<3.5mm, 3.5-10mm and >10mm) using sieves with different mesh sizes. The biomass of each size class was determined.

The number of mussels <3.5mm and 3.5-10mm was estimated on the basis of the wet weight of counted sub-samples. The number of mussels >10mm was counted in all samples. The number of mussels >10mm was large in most samples and it was therefore not possible to measure the shell length of the mussels in all samples with the available resources. The shell length of the mussels >10mm was measured in one sample collected in each direction on shafts and stones. The shell length was also determined in one sample collected in each direction at station 1 and station 3 at Schönheiders Pulle, cf. Annex 5.

The species composition of macroalgae was determined in the samples and the biomass of red algae, brown algae and green algae was measured as dry weight.

2.4.2 Statistical analysis

Common mussels, barnacles and a few associated mobile species of crustaceans and polychaetes dominated the hard bottom community in 2003 and 2004. The structure of the community of invertebrates and attached macroalgae was analysed using multivariate techniques based on the PRIMER software /6/. Classification and ordination was based on fourth root-transformed abundance and biomass data (dry weight) and calculation of Bray-Curtis similarity.

The analysis was initially performed 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 a separate analysis was conducted for the vertical shaft of concrete and the stones. Moreover, aggregated data for shaft and stones from the turbines (B2, E5, G and transformer) were subject to similar multivariate analysis. Results of aggregated analysis for stones in the wind farm were compared with results from Schönheiders Pulle.

3 RESULTS OF PHOTO AND VIDEO

3.1 Epi-fauna and macroalgae

Common mussels (*Mytilus edulis*), barnacles (*Balanus improvisus*) and filamentous redalgae dominated the fouling community. The distribution and coverage of the conspicuous species were different on the shafts, on the stones in the foundation chambers and on the scour protection stones around the foundations (Annex 1).

The shafts were completely covered by a dense layer of common mussels (*Mytilus edulis*) except for a narrow barnacle zone closest to the surface. The uppermost part of the barnacle zone originated from the primary settling in 2003 and the lowest part consisted of barnacles settled on mussels in 2004 (Figure 3.1). The cover of mussels was 100% between the barnacle zone and the lowest part of the shafts with the exception of the transformer, where the primary settling of barnacles was still not covered by mussels in deeper parts of the shaft. Macroalgae were absent or very scarce on the shafts. However, tufts of redalgae were present on the shaft of the transformer in patches with barnacles not covered by mussels.

Dense populations of mussels also covered the stones in the foundation chambers and the abundance of mussels appeared in general to be highest on stones closest to the shafts. Barnacles and tufts of macroalgae were common especially on edges and sides of the stones with few mussels.

Barnacles were abundant on the vertical external walls of the foundations and also abundant on the scour protection stones around the foundations. Tufts of redalgae were also common on scour protection stones but mussels were scattered (Figure 3.2). Intrusion of sand between scour protection stones and stones partly covered by sand was seen around some foundations. Specimens of large common mussels on scour protection stones and accumulations of empty shells of *Mytilus* between the stones at turbine A7 must originate from the local mussel population on the seabed.

Dense populations of mussels covered the monitoring mast (Figure 3.3). Barnacles attached to the surface of large mussels appeared to be more abundant on mussels in deeper water (6-8m) than in more shallow water (1-5m). Macroalgae were scarce and confined to the uppermost 5m of the mast.

3.2 Fish and larger invertebrates

The semi- pelagic two-spotted Gobi (*Coryphopterus flavescens*) was common close to the stones and abundant in the lee areas behind the shafts and the vertical wall of the foundations. Goldsinny-wrasse (*Ctenolabrus rupestris*) was fairly common close to the stones and in crevices of the three-dimensional stone layers. The common crab (*Carcinus maenas*) was common and more specimens were probably hiding in the numerous spaces in the mosaic of stones.

Figure 3.1 *Barnacles settled on the shells of common mussels (Mytilus edulis) in the lowest part of the barnacle zone near the surface (Turbine A7, October 2004).*

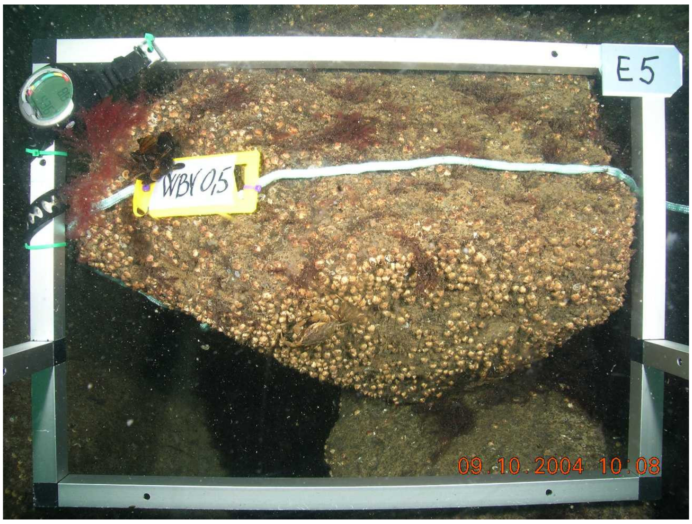

Figure 3.2 *Scour protection stone with barnacles and filamentous redalgae.*

Figure 3.3 Dense populations of Mytilus edulis with barnacles on the shells at the monitoring mast in October 2004.

3.3 Interpretation of photos

The interpretation of photos was 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 with the deeper stones. The photos focus on the top stones and therefore the assessment was confined to the top stones. The coverage of the top stones within the photo frame was assessed. The coverage of sessile animals and macroalgae was expressed as a percentage of the of top stones and not related to the area of the photo frame.

Short tufts of macroalgae and settling of fine sediment make its difficult to assess the coverage of barnacles and mussels. Barnacles were mostly visible at the edges of the stones. Dense tufts of short macroalgae may have favoured deposits of silt and this also hampered an assessment of presence and coverage of barnacles and mussels. Barnacles and small mussels are therefore underestimated on the stones.

4 RESULTS OF SURVEYS OF INVERTEBRATES

4.1 Biomass and abundance of the hard bottom community

4.1.1 Biomass

The average total biomass of the hard bottom community of sessile and mobile invertebrates on the foundations varied roughly between 3600 gDW/m^2 and 5400 g/DW/m^2 on the **Shafts** and between 1100 gDW/m^2 and 2300 gDW/m^2 on the **Stones** (Table 4.1). The biomass of the fouling community on the shafts was in general 2 to 3 times higher than the biomass on the stones.

The biomass on the foundations was still lower than the average biomass on the monitoring mast (7900 gDW/m^2). The biomass on stones in the chambers of the foundations and the scour protection was lower than the biomass at Schönheiders Pulle (Annex 2).

Table 4.1 Total biomass of the hard bottom community and biomass of common mussels (Mytilus edulis), barnacles (Balanus improvisus) and remaining taxa on shafts and stones at the turbines (B2, E5, G8 and transformer), the monitoring mast and Schönheiders Pulle in 2004. Rounded average values.

Locality	**Total biomass**		***Mytilus edulis***		***Balanus improvisus***		**Remaining 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	5400	1900	4900	1700	520	200	13	2
E5	5000	2300	4700	2100	295	140	8	3
G8	5000	2300	4400	2100	600	190	13	4
Transformer	3600	1100	2900	880	700	190	9	2
Monitoring Mast	7900		7400		450		21	
Sch. Pulle st.1		3500		3450		35		10
Sch. Pulle st.3		2950		2900		50		6

The biomass of the fouling community on shafts and stones respectively was rather similar at turbine B2, E5 and G8 and higher than the biomass of the community on shafts and stones at the transformer station.

The total biomass of the fouling community on shafts and stones was not related to the age of the substrates, the position of the turbines in the wind farm or the water depth, cf. Table 2.1 and Table 2.2.

Common mussels (*Mytilus edulis*) and the barnacle *Balanus improvisus* were the dominant species of the fouling community. The biomass of the remaining species including mobile crustaceans, polychaetes and other taxa was low (Table 4.1 and Annex 2).

The average biomass of common mussels accounted for 80-94% of the total biomass on the shafts and 82%-94% of the biomass on the stones. Barnacles accounted for 5%-12% of the total biomass on shafts and stones at turbine B2, E5 and G8 but 18-20% of the biomass on shaft and stones at the transformer station.

4.1.2 Abundance

The total average abundance of the fouling community ranged between 88000/m² and 162000/m² on the shafts and between 51000/m² and 229000/m² on the stones (Table 4.2).

The total abundance of invertebrates on the shafts was of the same magnitude as on the monitoring mast. The total abundance on the stones was in general lower than the abundance on stones at Schönheiders Pulle except for the transformer, where the abundance was very high due to heavy settling of small (<3.5mm) mussels, cf. Annex 3.

Table 4.2 Total abundance of the hard bottom community and abundance of common mussels (Mytilus edulis), barnacles (Balanus improvisus) and remaining taxa on shafts and stones at the turbines (B2, E5, G8 and transformer), the monitoring mast and Schönheiders Pulle in 2004. Rounded average values.

Locality	Total abundance		*Mytilus edulis*		*Balanus improvisus*		Remaining taxa	
	Shafts	Stones	Shafts	Stones	Shafts	Stones	Shafts	Stones
	Ind./m²	Ind./m²	Ind./m²	Ind./m²	Ind./m²	Ind./m²	Ind./m²	Ind./m²
B2	162000	108000	152000	101000	2970	1420	7540	5270
E5	99000	66000	89000	58000	1420	1090	8860	6900
G8	133000	51000	115000	43000	2930	1290	15400	7000
Transformer	88000	229000	77000	224000	3360	1040	7900	3500
Mast	115000		89000		5450		21000	
Sch.Pulle st.1		144000		130000		1510		13000
Sch.Pulle st.3		148000		141000		2020		5000

Common mussels accounted for 84-94% of the total abundance on shafts and stones. The density of barnacles was between 1400/m² and 3400/m² on the shafts and a little lower (1000/m² - 1400/m²) on the stones. The density of barnacles in 2004 was much lower than in 2003 /3/. Barnacles are pioneer organisms on hard surfaces and covered shafts and stones with dense populations at the initial stage of the colonisation in 2003. The initial encrusting layer of barnacles has mostly been covered and killed by a dense layer of mussels. Most of the barnacles recorded in 2004 were new recruits settled on the shells of larger mussels, cf. Figure 3.1.

The abundance of barnacles on shafts and stones was still lower than at the monitoring mast and at Schönheiders Pulle. The difference in density of barnacles is attributed to the fact that the mussels are larger at the monitoring mast and at Schönheiders Pulle and therefore offer a more suitable substrate for settling of barnacles, cf. Annex 5.

The species composition and abundance of other taxa of organisms besides common mussels and barnacles are shown in Annex 4. Crustaceans were the most diverse taxonomic group and 10 species were identified. The amphipod *Gammarus spp.*, was by far the most abundant species on both shaft and stones. The amphipod *Microdeutopus sp.* was abundant on stones. The crustacean *Corophium sp.* was common in 2004 but the abundance was far less than in 2003, where this tube building species was numerous especially on the deeper parts of the shafts /3/.

A few other species of crustaceans (e.g. *Jaera albifrons*) and the polychaete *Nereis succinea* were fairly abundant in some samples from shafts and stones. Typically in-fauna bivalves like *Cerastoderma sp.* and *Mya arenaria* present in 2003 were absent in 2004 and the same was the case with the gastropod *Rissoa albella*. The gastropod *Rissoa al-*

bella is normally associated with vegetation and the absence may be related to the scarcity of vegetation in 2004.

The abundance of the associated fauna was high and totally dominated by the amphipod *Gammarus sp.* at the monitoring mast. *Gammarus sp.* was also the dominant mobile species at Schönheiders Pulle. However, the associated fauna was in general a little more diverse at Schönheiders Pulle than the fauna at the foundations. Some species of crustaceans (*Cyathura carinata* and *Melita sp.*) was in general more common and abundant at Schönheiders Pulle than at the foundations and the mud snail (*Hydrobia sp.*) was abundant in some samples at station 1 (Annex 4).

4.1.3 Shell length of common mussels

The shell length of most mussels were <3.5mm and 3.5-10mm (Annex 5). However, mussels larger than 10mm, which were almost absent in 2003, accounted for 16-24% of the total abundance on shafts and between 10-26% on stones with the exception of the transformer, where a heavy spatfall in 2004 reduced the percentage of larger mussels.

The size distribution of measured populations of mussels with a shell length equal to or larger than 10mm was characterised by median length, average length, standard deviation and maximum length. The results of measurements and calculations in Annex 5 are summarised in Table 4.3.

Table 4.3 Average, median and maximum shell length of common mussels (Mytilus edulis) larger to or equal to 10mm on shafts and stones of the turbines (B2, E5, G8 and transformer), the monitoring mast and Schönheiders Pulle in 2004. Rounded average values.

Locality	Average length		Median length		Maximum length		Number measured	
	Shafts	Stones	Shafts	Stones	Shafts	Stones	Shafts	Stones
	Mm	Mm	mm	Mm	mm	mm		
B2	15-16	12-14	15	12-13	27-29	20-25	550-632	263-1663
E5	18-19	14-16	18-19	14-15	30-33	28-32	439-497	875-1394
G8	16-19	14-16	15-19	14-15	31-32	27-33	421-514	670-1156
Transformer	13-21	11-12	12-21	11-12	19-31	13-18	353-392	35-150
Monitoring mast	20		17		50-55		948-1450	
Sch. Pulle st.1		16-19		15-17		39-40		643-808
Sch. Pulle st.3		15-18		14-16		33-45		527-887

The average and median length of the mussels is highly correlated. The mussels on the shafts are significantly larger than the mussels on the stones. Both the growth rate and the density of mussels are higher on the shafts than on the stones and this contributed to a faster current and water renewal in the surface water and a higher availability of plankton food.

The average and especially the maximum length of mussels on the shafts are still lower than the length of the mussels at the monitoring mast. The mussels on stones have not yet reached the maximum size of the mussels at Schönheiders Pulle.

4.1.4 Development of common mussels at the monitoring mast

The biomass and density of common mussels was surveyed in 1999 and 2001 at the top 5 metres of the monitoring mast. The results of the surveys in 2004 are compared with the previous results in Table 4.4.

Table 4.4 Biomass and abundance of common mussels (Mytilus edulis) at the top 5 metres of the monitoring mast in 1999, 2001, 2003 and 2004.

Depth	Biomass (kg wet weight/m^2)				Abundance (Ind./m2)			
	1999	2001	2003	2004	1999	2001	2003	2004
1m	7.0	14.5	9.6	20.3	17000	53000	109000	216000
2m	7.4	14.9	13.2	17.4	42000	23000	45000	70000
3m	8.4	17.1	12.8	12.1	26000	41000	68000	65000
4m	8.9	19.5	11.9	13.4	18000	33000	35000	47000
5m	10.0	15.5	9.7	12.3	19000	24000	74000	54000
Range	**7-10**	**15-20**	**10-13**	**12-20**	**17000-42000**	**23000-53000**	**35000-109000**	**47000-216000**

The biomass of mussels in 2004 has increased since 2003 and has almost reached the maximum level measured in 2001. The number of small mussels (<3.5mm) was similar in 2003 and 2004, but the number and weight of larger mussels (3.5-10mm) and especially mussels larger than 10mm have increased since 2003 (Annex 2). The maximum length of mussels was 50-58mm in 1999-2003 and almost the same in 2004 (50-55mm). The maximum length of the mussels at the monitoring mast was already reached two years after the mast was established. This length is probably close to the maximum size for mussels under favourable growth conditions in this part of the Baltic Sea.

4.2 The structure of the hard bottom community in 2004

4.2.1 Structure on shafts and stones

Analysis based on biomass and abundance data (including and excluding *Mytilus* and *Balanus*) showed that the similarity of the hard bottom community differed significantly on the shafts and stones (Table 4.5). Abundance of the fauna showed the most pronounced differences in the similarity between shafts and stones (Figure 4.1 to Figure 4.4).

Table 4.5 Similarity of the hard bottom community on the shafts versus the stones in 2004. Results of one-way ANOSIM test based on biomass and abundance data.

Foundations	Biomass		Abundance inclusive *Mytilus* and *Balanus*		Abundance exclusive *Mytilus* and *Balanus*	
	Global R	Significance level	Global R	Significance level	Global R	Significance level
B2	0,205	**4.4%**	0,384	**0.6%**	0,478	**0.1%**
E5	0,372	**1.3%**	0,439	**0.2%**	0,424	**0.4%**
G8	0,224	**4.8%**	0,439	**0.2%**	0,409	**0.4%**
Transformer	0,199	5.3%	0,352	**0.5%**	0,291	**2.2**

Bold indicates a significant level (5%)

The community structure based on biomass and abundance (including *Mytilus* and *Balanus*) was determined by the predominance of mussels and barnacles. Examples are shown in Figure 4.5 and Figure 4.6.

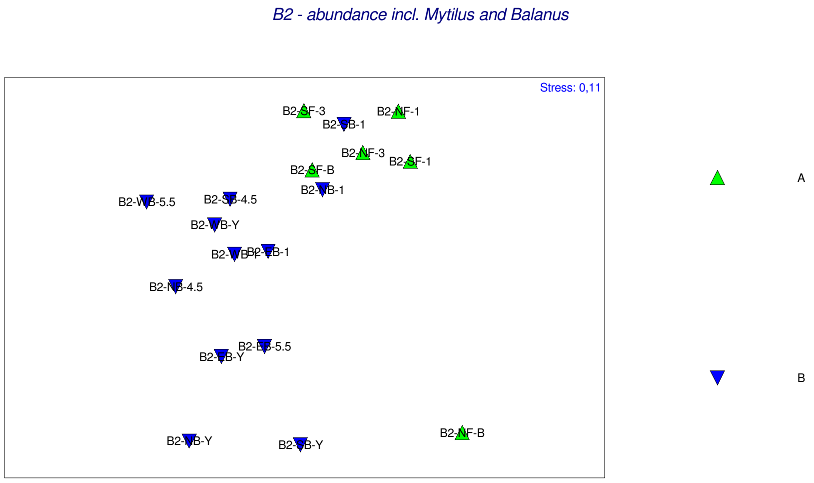

Figure 4.1 *MDS-ordination based on the abundance of the fouling community (incl. Mytilus and Balanus) at turbine B2 in 2004. A: shafts, B: stones.*

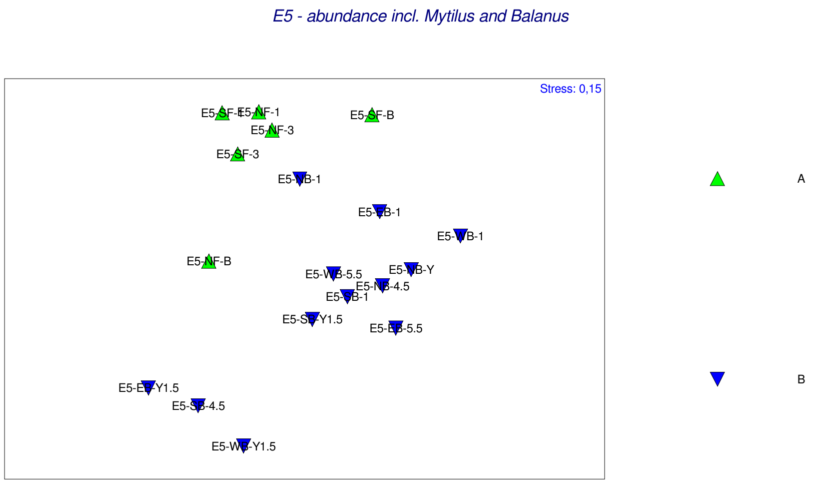

Figure 4.2 *MDS-ordination based on the abundance of the fouling community (incl. Mytilus and Balanus) at turbine E5 in 2004. A: shafts, B: stones.*

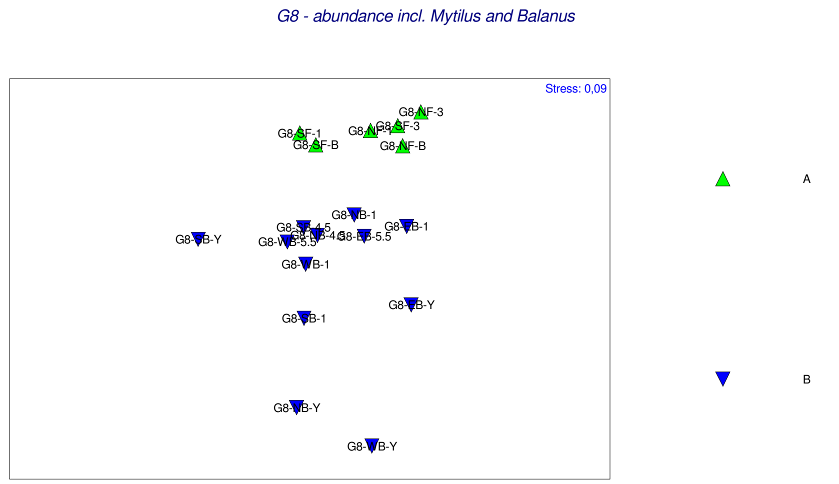

Figure 4.3 *MDS- ordination based on the abundance of the fouling community (incl. Mytilus and Balanus) at turbine G8 in 2004. A: shafts, B: stones.*

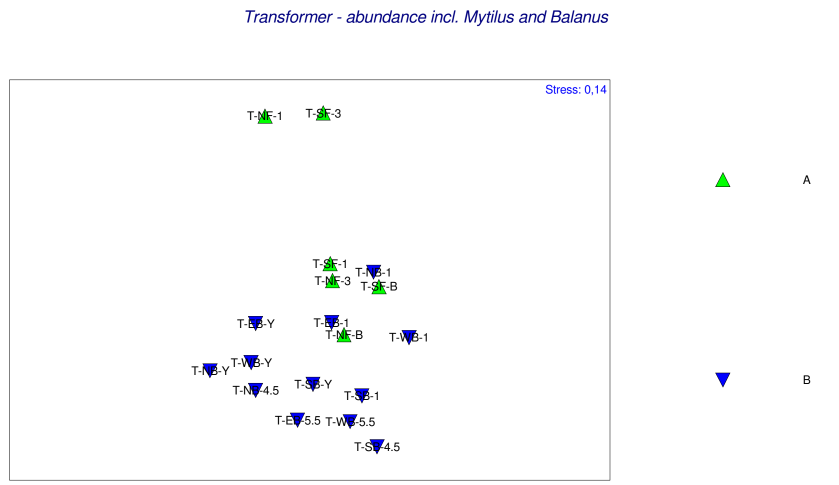

Figure 4.4 *MDS- ordination based on the abundance of the fouling community (incl. Mytilus and Balanus) at the transformer station in 2004. A: shafts, B: stones.*

G8 - abundance Mytilus edulis

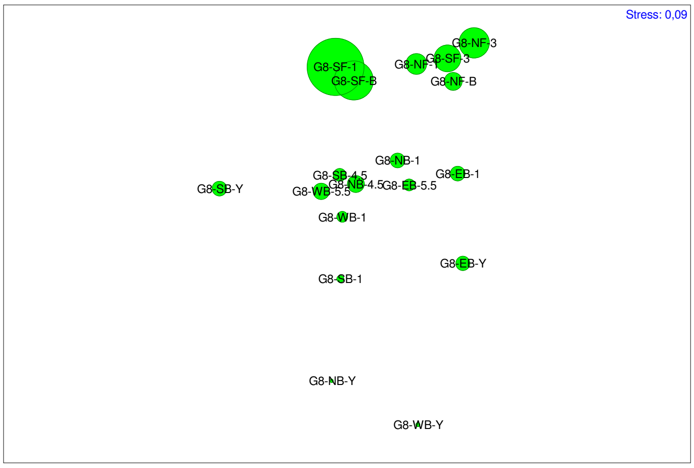

Figure 4.5 *MDS-ordination based on abundance of common mussels (Mytilus edulis) at turbine G8 in 2004. The circles are proportional to the abundance.*

G8 - abundance Balanus improvisus

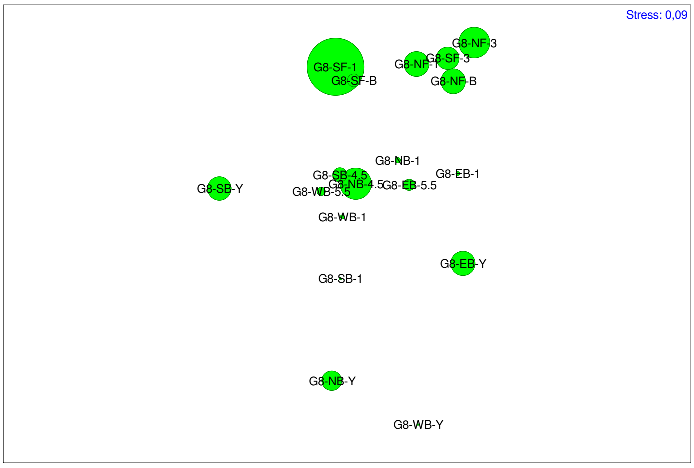

Figure 4.6 *MDS-ordination based on the abundance of barnacles (Balanus improvisus) at turbine G8 and E5 in 2004. The circles are proportional to the abundance.*

The colonisation on the shafts in 2003 was characterised by barnacles partly succeeded and covered by common mussels. This initial stage was attributed to a combination of high influx of larvae, availability of plankton (food) due to a rapid current velocity in the surface water and less competition from macroalgae during settling /3/. The biomass and predominance of mussels on the shafts have increased in 2004 due to the fast growth rate of the mussels and renewed settling of barnacles on the surface of the larger mussels. The biomass and abundance of mussels and barnacles have increased on stones since 2003.

4.2.2 Structure of the fouling community in relation to direction, water depth and distance

The aim of the analysis was to examine the structure of the hard bottom community in relation to the **direction** (south, north, west and east), **water depth** (only shafts) and **distance** from the shaft of the sampling stations across stones in the foundations chambers and scour protection (only stones).

Data from shafts and stones were subject to separate analysis due to the different structure of the fouling community. The analysis was performed both for the foundations individually and for aggregated data combining all foundations and on the basis of biomass and abundance (including and excluding *Mytilus* and *Balanus*). The results of the ANOSIM tests are summarised in Annex 8.

Structure on shafts and stones in relation to direction

The structure of the fouling community was similar on the south and north faces of the **shafts** with the exception of a significant difference in biomass (but not in abundance) at turbine G8. However, the power of the one-way ANOSIM test at individual foundations is rather weak and 10% is the maximum level of significance because the number of possible permutations is limited to ten. An analysis based on aggregated data, which allows more permutations, is stronger, and according to this analysis the community was similar on the south and north faces of the shafts. A similar conclusion was reached on the basis of an analysis of the data in 2003 /3/. As a consequence the sampling on shafts was therefore reduced from four to two directions in 2004.

The community structure on **stones** was independent of direction when the analysis was based on biomass (Annex 8). Analysis based on abundance showed significant difference at turbine B2 (N vs W and W vs E) and at turbine G8 (S vs E) but none at turbine E5 and the transformer. However, a stronger analysis based on aggregated data showed that the community structure on stones was independent of direction (Annex 8).

Structure on shafts in relation to water depth

Analysis of the structure of the hard bottom community in relation to water depth is weak at the individual turbines, but there are significant differences between different levels on the shafts. An analysis based on aggregated data showed that 1m and 3m below surface the community was uniform but that 3m below surface the structure and the lowest station on the shafts 0.5m above the stones differed significantly both in analysis based on biomass and abundance (Annex 8). The abundance incl. *Mytilus* and *Balanus* at the station 0.5m above the shaft was also different from the station 1m below the surface (Figure 4.7).

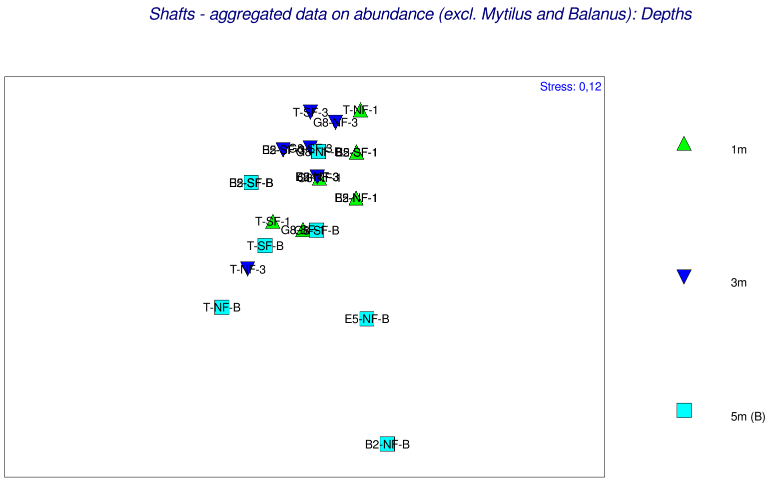

Figure 4.7 MDS-ordination based on aggregated abundance data (excluding Mytilus and Balanus) at different depths along the shafts in 2004.

The overall similarity of the fouling community is high because of the predominance of *Mytilus* and *Balanus* with respect to biomass and the predominance of *Mytilus* and *Gammarus* with respect to abundance. The dissimilarity between different depths is low due to a decline in biomass or abundance of the three dominant species (*Mytilus*, *Balanus* and *Gammarus*) with increasing depth and an increase with depth of sub-dominant species of crustacean e.g. *Microdeutopus sp*.

The mobile amphipod *Gammarus spp*. was most abundant near the water surface whereas other and less abundant species of amphipods (*Microdeutopus sp*. and *Corophium insidiosum*) were most common in deeper water (Figure 4.8 and Figure 4.9). This zonation is probably caused by a decrease in wave exposure with greater depth and deposition of silt.

Shafts - aggregated data on abundance of Gammarus sp.: Depths

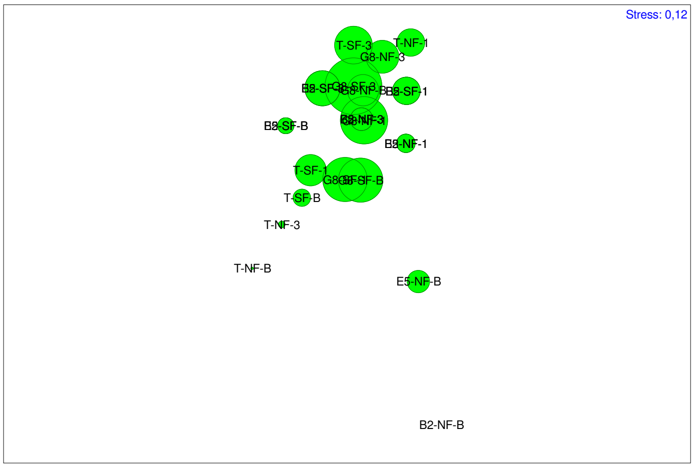

Figure 4.8 MDS-ordination based on aggregated abundance data of Gammarus sp. at different depths along the shafts in 2004. The circles are proportional to the abundance of the species.

Shafts - aggregated data on abundance of Microdeutopus sp.: Depths

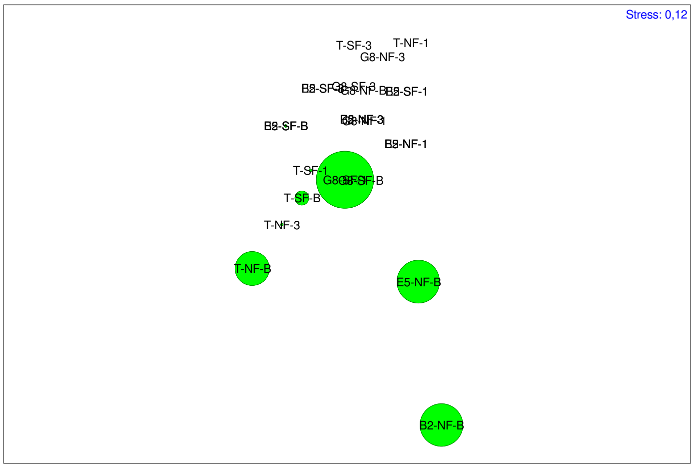

Figure 4.9 MDS-ordination based on aggregated abundance data of Microdeutopus sp. at different depths along the shafts in 2004. The circles are proportional to the abundance of the species.

Structure in relation to distance of stations on stones

Sampling stations 1 and 2 on stones are located on top of the stone fill in the foundation chambers. Station 3 is located on the scour protection stones around the foundations.

The fouling community was similar at stations 1 and 2 on the stone fill in the chambers. However, station 1 on the stone fill and station 3 on the scour protection differed at turbine B2 and the transformer and was also close to the level of significance at turbine G8, cf. Annex 8. Stations 2 and 3 were different at turbine G8 in the analysis based on biomass.

Analysis of aggregated data showed that the structure of the fouling community was similar on the stones in the foundations chambers (stations 1 and 2) and that these stations were both significantly different from the community on the scour protection stones (station 3), cf. Figure 4.10 and Annex 8.

The community on stones in the chambers (stations 1 and 2) has a higher biomass and abundance of the dominant species (*Mytilus*, *Balanus* and *Gammarus*) than the community on scour protection stones at station 3. Some subdominant species of crustaceans (*Microdeutopus sp*. and *Jaera albifrons*) were almost equally abundant at the stations and the crustacean *Corophium* was most abundant on the scour protection stones (Figure 4.11, Figure 4.12 and Figure 4.13).

The community on stones in the chambers is similar and has a higher biomass and abundance than the community on the scour protection stones and a possible explanation for this is that the stones in the chambers are elevated 1-2m above the seabed. The community on the stones in the chambers is likely to be more protected from stirred sediment and sediment scouring during rough weather, which may hamper the development of the hard bottom community on the scour protection stones.

Stones - aggregated data on abundance (excl. Mytilus and Balanus): Direction

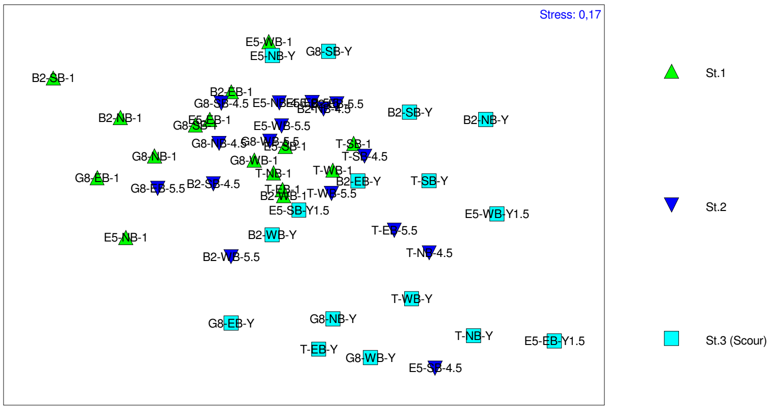

Figure 4.10 MDS-ordination based on aggregated abundance data (excluding Mytilus and Balanus) at different distance on stones in 2004.

Stones - aggregated data on abundance of Gammarus sp. : Direction

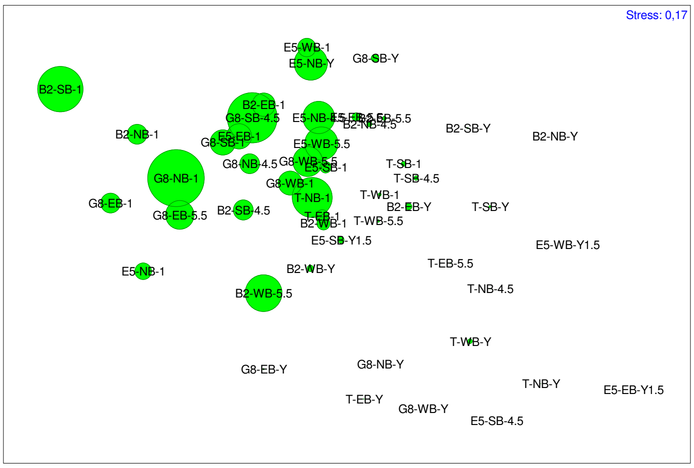

Figure 4.11 MDS-ordination based on aggregated abundance data of Gammarus sp. at different distance on stones in 2004.

Stones - aggregated data on abundance of Microdeutopus sp.: Direction

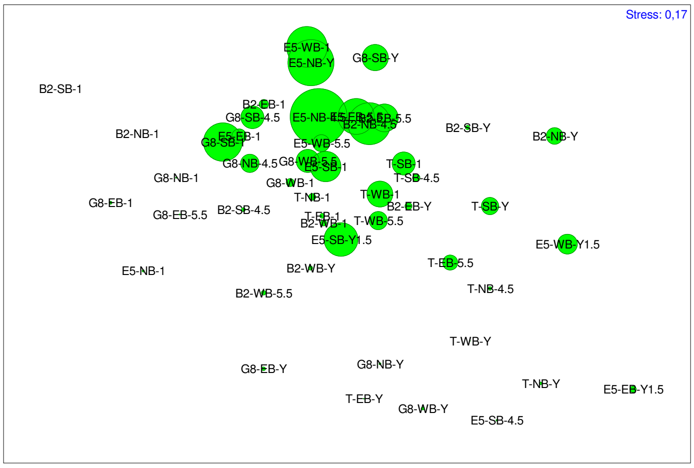

Figure 4.12 MDS-ordination based on aggregated abundance data of Microdeutopus sp. at different distance on stones in 2004.

Stones - aggregated data on abundance of Jaera albifrons: Direction

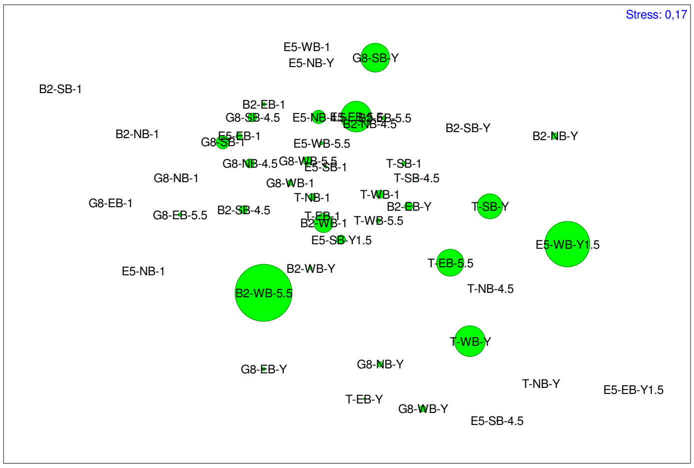

Figure 4.13 MDS-ordination based on aggregated abundance data of Jaera albifrons at different distance on stones in 2004.

4.2.3 Comparison with Schönheiders Pulle

The hard bottom community is similar at stations 1 and 3 surveyed at Schönheiders Pulle according to ANOSIM-tests based on both biomass and abundance (including and excluding *Mytilus* and *Balanus*). The similarity between the stations is more than 80% and 60-70% for analysis based on biomass and abundance, respectively.

Therefore the two stations are treated together in the analysis where Schönheiders Pulle and the hard bottom community on stones in the wind farm is compared.

The community structure on stones in the wind farm and Schönheiders Pulle is different at 5% and 0.1% significance levels for analysis based on biomass and abundance, respectively (Table 4.6).

Table 4.6 Similarity of the hard bottom community on turbine stones in the wind farm versus stones at Schönheiders Pulle in 2004. Results of One-way ANOSIM test based on aggregated biomass and abundance data.

Biomass		**Abundance Inclusive Mytilus and Balanus**		**Abundance exclusive Mytilus and Balanus**	
Global R	Significance level	Global R	Significance level	Global R	Significance level
0,126	**5%**	0,423	**0.1%**	0,468	**0.1%**

The community at Schönheiders Pulle is more similar than the community on the stones in the wind farm (Figure 4.14). The dissimilarity between the two areas is mainly determined by the fact that the biomass and abundance of the two dominant species (*Mytilus edulis* and *Gammarus sp*.) were higher at Schönheiders Pulle than in the wind farm. The dissimilarity in abundance (excluding *Mytilus* and *Balanus*) is determined by differences in abundance of *Gammarus sp*. (most abundant at Schönheiders Pulle) and a few subdominant species (*Microdeutopus sp*. and *Corophium sp*.), which were most abundant on stones in the wind farm, cf. Figure 4.15, Figure 4.16 and Figure 4.17.

Abundance (excl. Mytilus and Balanus) on Turbine stones and Schönheiders Pulle

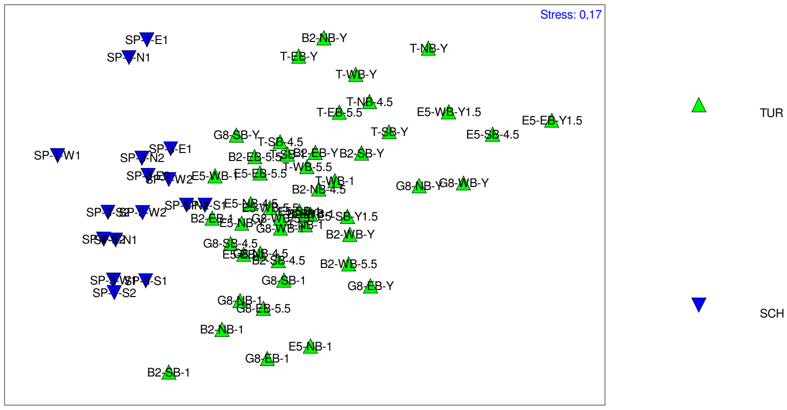

Figure 4.14 MDS-ordination based on aggregated data of abundance (excluding Mytilus and Balanus) on turbine stones (TUR) in the wind farm and Schönheiders Pulle (SCH) in 2004.

Abundance of Gammarus sp. on Turbine stones and Schönheiders Pulle

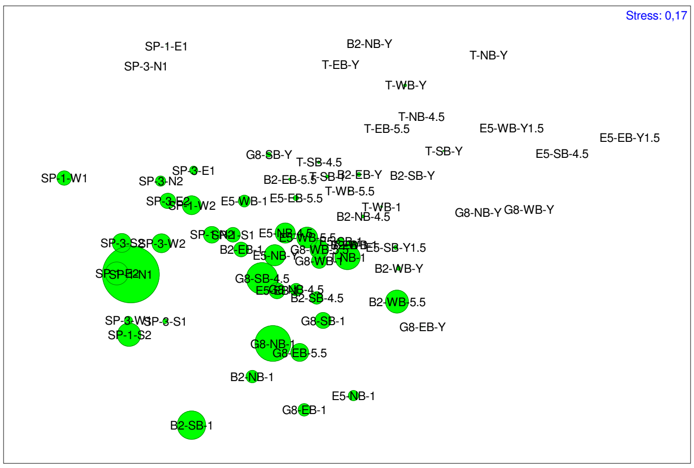

Figure 4.15 MDS-ordination based on aggregated data of abundance of Gammarus sp. on stones in the wind farm (TUR) and Schönheiders Pulle (SCH) in 2004.

Abundance of Microdeutopus sp. on Turbine stones and Schönheiders Pulle

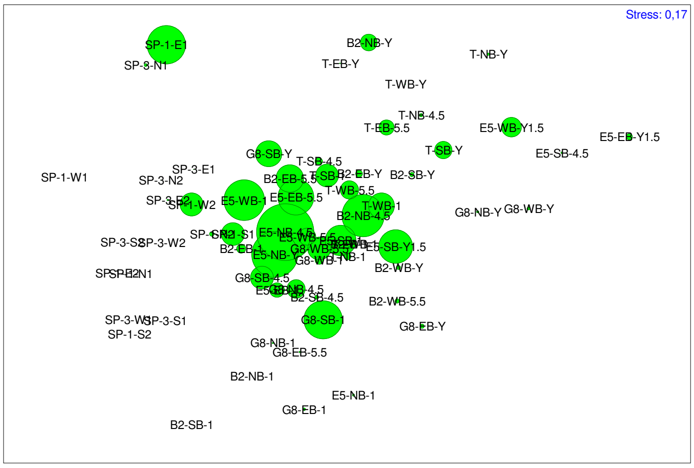

Figure 4.16 MDS-ordination based on aggregated abundance data of Microdeutopus sp. on stones in the wind farm (TUR) and Schönheiders Pulle (SCH) in 2004.

Abundance of Corophium sp. on Turbine stones and Schönheiders Pulle

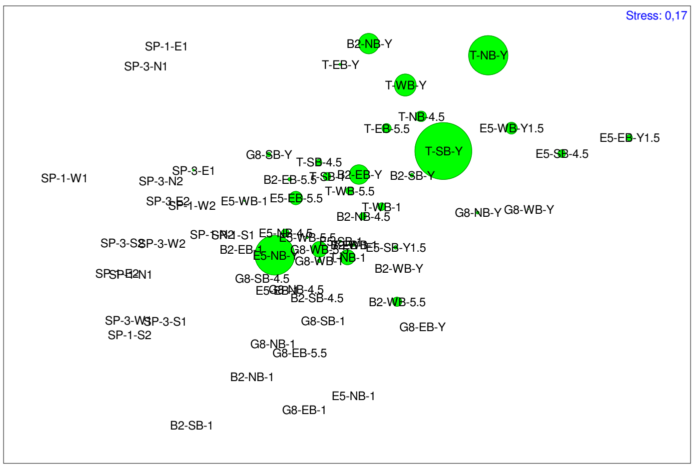

Figure 4.17 MDS-ordination based on aggregated data of abundance of Corophium sp. on stones in the wind farm (TUR) and Schönheiders Pulle (SCH) in 2004.

4.3 Changes in the hard bottom community since 2003

4.3.1 Changes in biomass and abundance

The total biomass of the fouling community has increased 4-8 times on the shafts and more than 20 times on the stones during one year (Table 4.7). The increase in biomass was 35 times on the transformer stones. However, the total biomass and the biomass of *Mytilus edulis* were still lowest at the transformer also in 2004.

Table 4.7 Total biomass of the hard bottom community and biomass of common mussels (Mytilus edulis) on shafts and stones in 2003 and 2004. Rounded average values.

Foundation	**Total biomass (g DW/m²)**				**Biomass of *Mytilus edulis* (g DW/m²)**			
	Shafts		Stones		Shafts		Stones	
	2003	2004	2003	2004	2003	2004	2003	2004
B2	713	5400	78	1900	401	4900	62	1700
E5	1425	5000	99	2300	671	4700	71	2100
G8	1334	5000	90	2300	536	4400	49	2100
Transformer	688	3600	30	1100	181	2900	13	880

Table 4.8 Total abundance of the hard bottom community and abundance of common mussels (Mytilus edulis) on shafts and stones in 2003 and 2004. Rounded average values.

Foundation	**Total abundance (Ind./m²)**				**Abundance of *Mytilus edulis* (Ind./m²)**			
	Shafts		Stones		Shafts		Stones	
	2003	2004	2003	2004	2003	2004	2003	2004
B2	222000	162000	83000	108000	178000	152000	77000	101000
E5	386000	99000	91000	66000	361000	89000	88000	58000
G8	300000	133000	60000	51000	278000	115000	57000	43000
Transformer	77000	88000	18000	229000	66000	77000	17000	224000

In general the total abundance and the abundance of *Mytilus edulis* have decreased on the shafts of turbines B2, E5 and G8 but increased at the transformer. The abundance on stones has increased in 2004 at turbines B2 and the transformer and decreased on turbines E5 and G8.

4.3.2 Changes in community structure

The profound changes in biomass and abundance since 2003 have changed the community structure significantly on both shafts and stones (Figure 4.18, Figure 4.19, Figure 4.20 and Figure 4.21).

The dissimilarity in abundance in 2003 and 2004 was mainly caused by a 4-8 times increase of the density of *Gammarus* on both shafts and stones. An increase of the crustaceans *Microdeutopus* and *Jaera albifrons* (on stones) and a decrease of *Corophium* (on both shaft and stones) also contributed to the dissimilarity in 2003 and 2004 (Figure 4.22, Figure 4.23, Figure 4.24 and Figure 4.25).

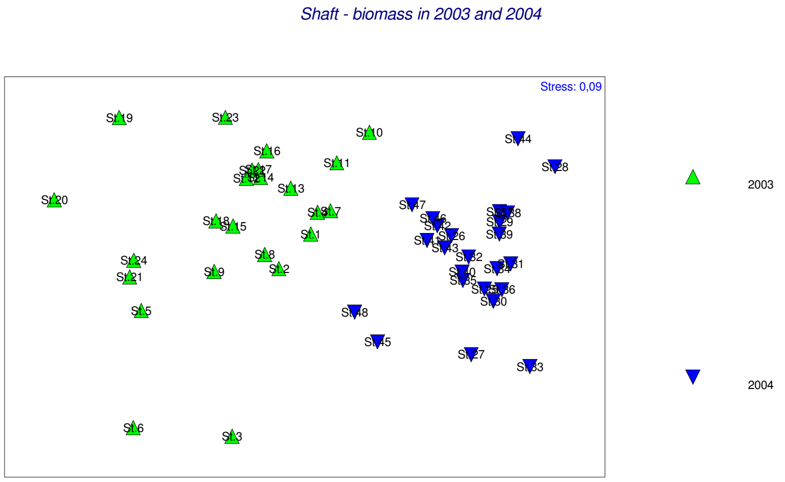

Figure 4.18 MDS-ordination based on the biomass of the hard bottom community on shafts in 2003 and 2004.

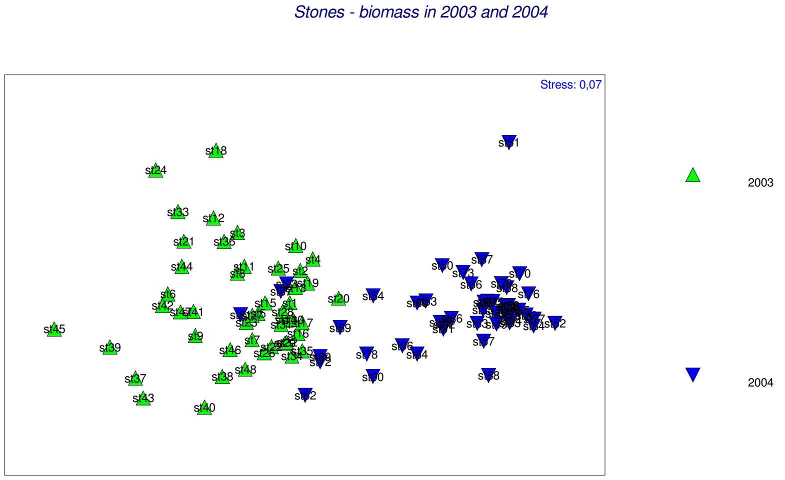

Figure 4.19 MDS-ordination based on the biomass of the hard bottom community on stones in 2003 and 2004.

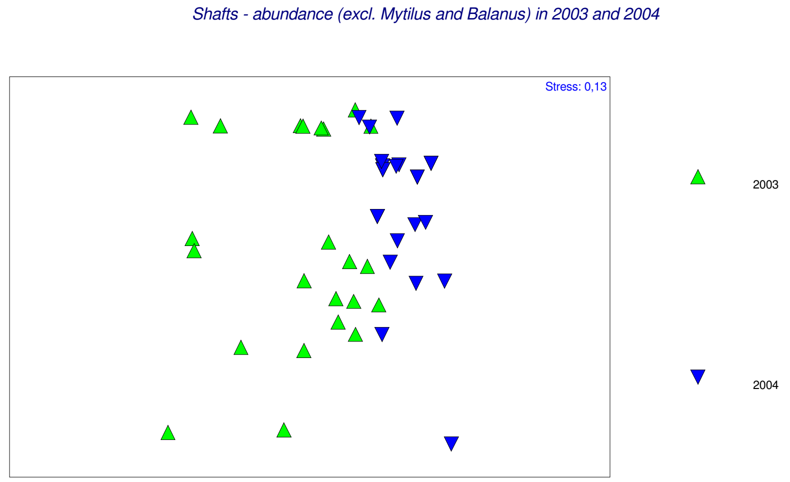

Figure 4.20 *MDS-ordination based on the abundance (excluding Mytilus and Balanus) on shafts in 2003 and 2004.*

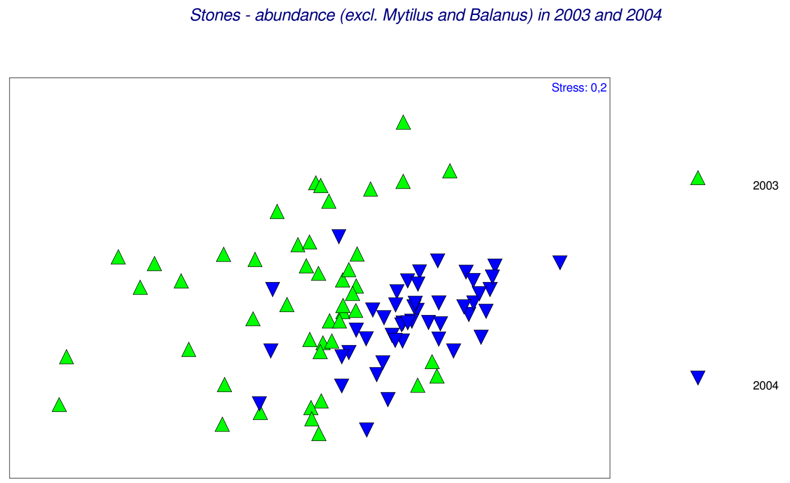

Figure 4.21 *MDS-ordination based on the abundance (excluding Mytilus and Balanus) on stones in 2003 and 2004.*

Stones - abundance of Gammarus sp. in 2003 and 2004

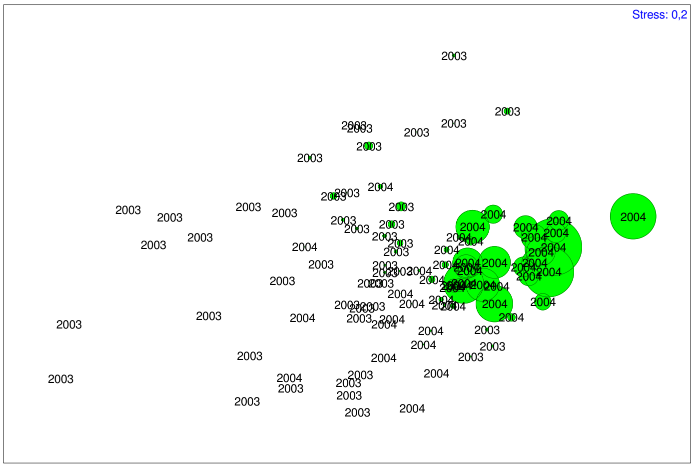

Figure 4.22 MDS-ordination based on the abundance of Gammarus sp. on stones in 2003 and 2004.

Stones - abundance of Microdeutopus sp. in 2003 and 2004

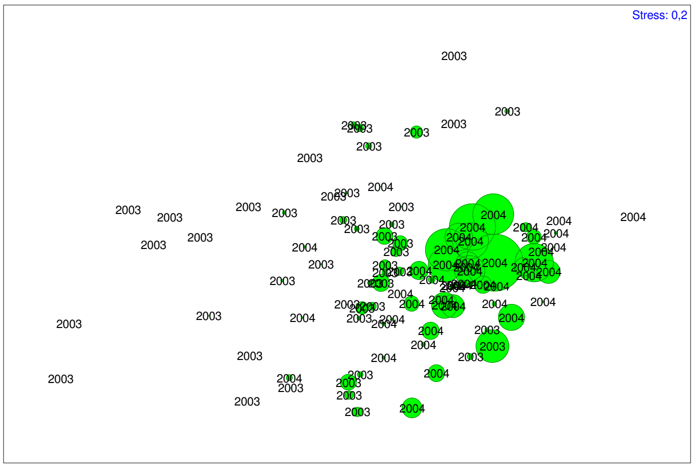

Figure 4.23 MDS-ordination based on the abundance of Microdeutopus sp. on stones in 2003 and 2004.

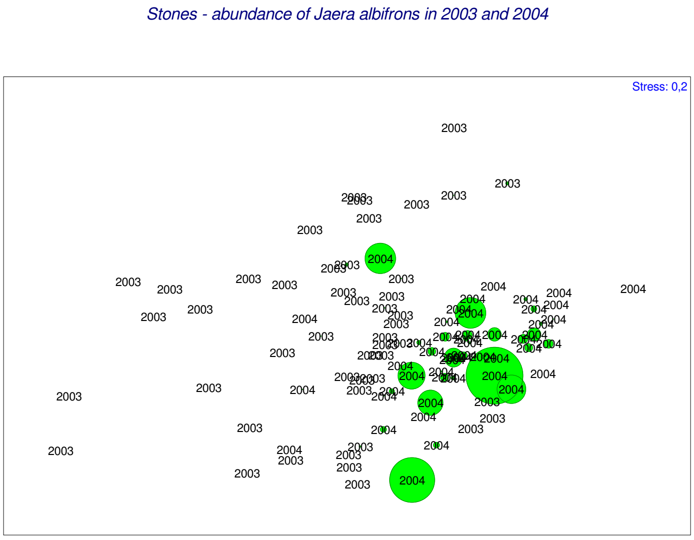

Figure 4.24 MDS-ordination based on the abundance of Jaera albifrons on stones in 2003 and 2004.

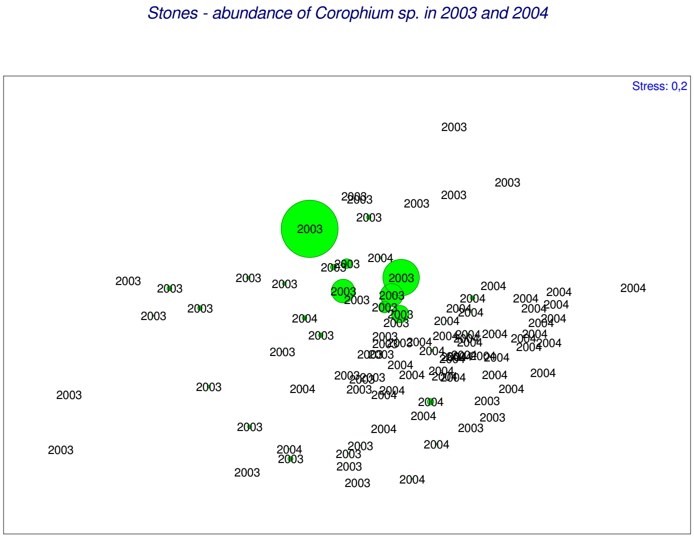

Figure 4.25 MDS-ordination based on the abundance of Corophium sp. on stones in 2003 and 2004.

5 RESULTS OF SURVEYS OF MACROALGAE

5.1 Biomass and species composition in 2004

The average biomass of macroalgae was between zero and less than 4 gDW/m^2 on the shafts, and between <1 gDW/m^2 and 29 gDW/m^2 on the stones (Table 5.1 and Annex 6). Algae was almost absent from the shafts except for the transformer. The biomass of algae on stones was highest at the transformer and turbine B2 and lowest at turbine E5 and G8.

Table 5.1 Total biomass and biomass of redalgae, brownalgae and greenalgae at turbines, monitoring mast and Schönheiders Pulle. Rounded average values for shaft and stones.

Locality	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	0.003	18.9	0.003	18.9	0	0	0	0
E5	0	0.6	0	0.6	0	0	0	0.0007
G8	0	2.7	0	2.7	0	0.003	0	0
Transformer	3.9	28.9	3.9	28.9	0	0	0	0
Monitoring Mast	0.3		0.3		0		0	
Sch, Pulle St. 1		21.0		21.0		0		0
Sch. Pulle St. 3		21.3		21.3		0		0

The community was dominated by redalgae both in respect to biomass and number of species. There were only single records of brownalgae (*Pilayella/Ectocarpus*) and greenalgae (*Cladophora sp.*) on stones at turbine E5 and G8.

The diversity of the community of macroalgae was low and the dominant species was *Polysiphonia fucoides. Callithamnion/Aglaothamnion*, *Ceramium tenuicorne* and *Polysiphonia fibrillosa* were also fairly common, but the remaining species of redalgae were scarce on stones in the wind farm (Annex 7).

Algae was scarce at the monitoring mast and only small populations of *Ceramium tenuicorne* were observed on the mast 1m to 3m below the water surface.

The average biomass of algae was about 20 gDW/m^2 at both stations at Schönheiders Pulle. Brown- and greenalgae were not recorded. The dominant species of redalgae were *Ceramium tenuicorne* at station 1 and *Polysiphonia fucoides* at station 3. *Ceramium nodulosum* and *Polysiphonia fibrillosa* was also common (Annex 7).

5.2 The structure of the community

Due to the absence or scarcity of algae on the shafts at turbines B2, E5 and G8 comparison of macroalgae was only possible at the transformer, where the community structure on shaft and stones differed significantly according to an ANOSOM-test (Global R= 0,548, Level of significance: 0.4%).

Structure on stones in relation to direction and distance
Further analysis on the importance of **direction** (south, north, west and east) and **distance** of the sampling stations was confined to aggregated biomass data of algae on the stones at turbine B2, E5, G8 and transformer.

According to the results of the ANOSIM tests direction or distance of the sampling stations to the stones did not affect the structure of macroalgae community (Annex 9).

5.3 Comparison with Schönheiders Pulle

An ANOSIM-test based on biomass data showed that the community of algae was similar at station 1 and station 3 and the data was therefore combined.

The similarity of the biomass of algae at turbine stones and Schönheiders Pulle was high (more than 50%) and the community of macroalgae was uniform in the two areas according to an ANOSIM test (Global R=-0,033, Level of significance: 75%). However, an analysis based on presence/absence data proved that the species composition on stones in the wind farm and at Schönheiders Pulle was different (Global R=0,448, Level of significance: 0.1%), cf. Figure 5.1.

Species like *Polysiphonia fucoides* and *Ceramium tenuicorne* were common and dominant in both areas (Figure 5.2). The dissimilarity of the species composition in the two areas was attributed to the fact that some species e.g. *Callithamnion/Aglaothamnion* were most common on turbine stones (Figure 5.3) while others species like *Ceramium nodulosum* was most common at Schönheiders Pulle (Figure 5.4). Two less frequent species of red algae (*Rhodomela confervoides* and *Furcellaria lumbricalis*) were only recorded at Schönheiders Pulle.

Species of macroalgae on turbine stones and Schönheiders Pulle

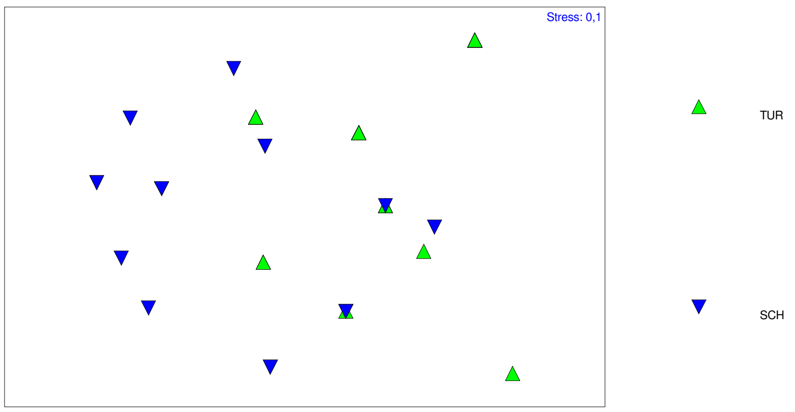

Figure 5.1 *MDS-ordination based on presence/absence of macroalgae species on stones in the wind farm (TUR) and Schönheiders Pulle (SCH) in 2004.*

Ceramium tenuicorne on turbine stones and Schönheiders Pulle

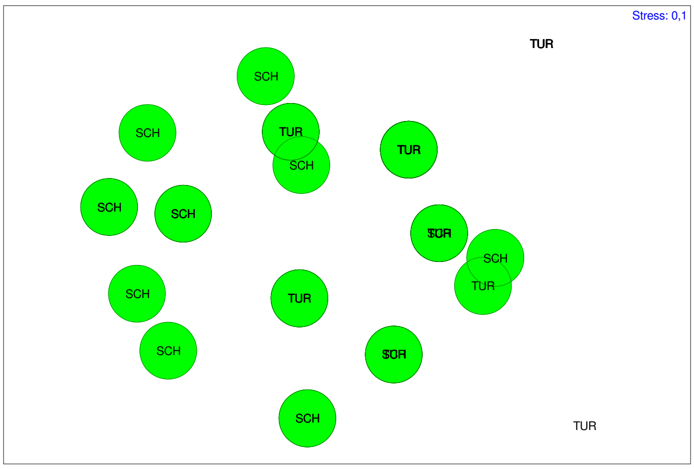

Figure 5.2 *MDS-ordination based on presence/absence of Ceramium tenuicorne on stones in the wind farm (TUR) and Schönheiders Pulle (SCH) in 2004.*

Callithamnion/Aglaothamnion on turbine stones and Schönheiders Pulle

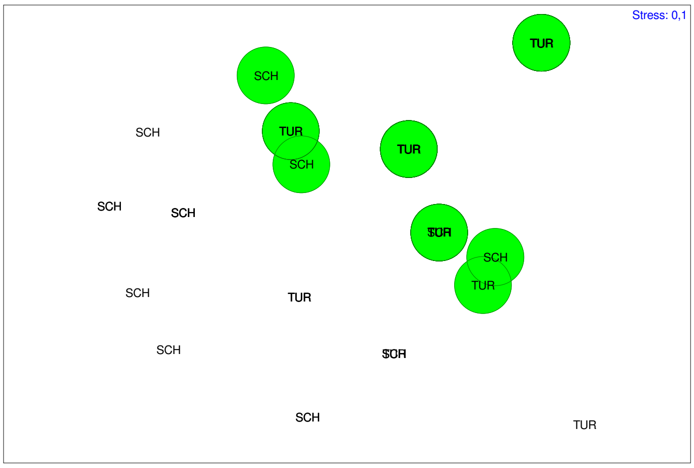

Figure 5.3 *MDS-ordination based on presence/absence of Callithamnion/Aglaothamnion on stones in the wind farm (TUR) and Schönheiders Pulle (SCH) in 2004.*

Ceramium nodulosum on turbine stones and Schönheiders Pulle

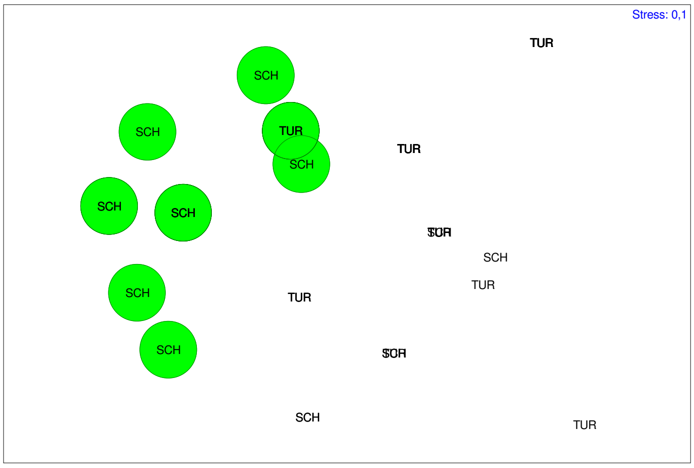

Figure 5.4 *MDS-ordination based on presence/absence of Ceramium nodulosum on stones in the wind farm (TUR) and Schönheiders Pulle (SCH) in 2004.*

5.4 Changes in algae since 2003

5.4.1 Biomass

The algae has almost disappeared on the shafts in 2004 with the exception of the transformer, where the biomass was about two times higher than in 2003. The biomass of algae on stones was unchanged at turbine B2, reduced at turbines E5 and G8 and higher at the transformer in 2004 compared with 2003 (Table 5.2).

Table 5.2 Total biomass and biomass of redalgae, brownalgae and greenalgae in 2003 and 2004. Rounded average values for shaft and stones.

Location	Total biomass (gDW/m^2)				Redalgae (gDW/m^2)			
	Shaft		Stones		Shaft		Stones	
	2003	2004	2003	2004	2003	2004	2003	2004
B2	12.5	0.003	18.9	18.9	8.0	0.003	16.8	18.9
E5	4.4	0	9.6	0.6	3.6	0	9.1	0.6
G8	1.6	0	9.2	2.7	1.5	0	6.8	2.7
Transformer	1.7	3.9	5.5	28.9	1.4	3.9	5.4	28.9
Monitoring mast	2.6	0.3			2.6			

5.4.2 Species composition and community structure

The same species of red algae (*Ceramium tenuicorne* and *Polysiphonia fucoides*) was dominant in both 2003 and 2004. The community of algae on stones was significantly dissimilar in 2003 and 2004 mostly because brown algae and green algae were almost absent in 2004 (Figure 5.5 and Figure 5.6). However, the community of red algae was also different because both dominant and subdominant species like *Polysiphonia fibrillosa* and *Ceramium nodulosum* were much more common on stones in 2003 than in 2004.

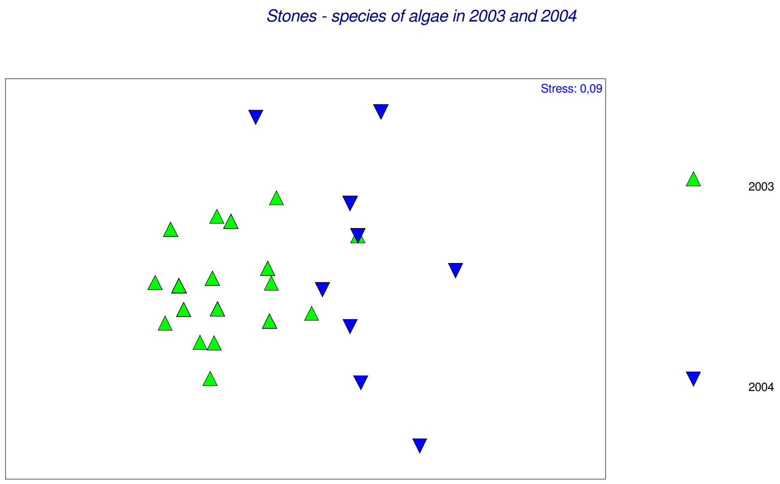

Figure 5.5 *MDS-ordination based on presence/absence of algae on stones in the wind farm in 2003 and 2004.*

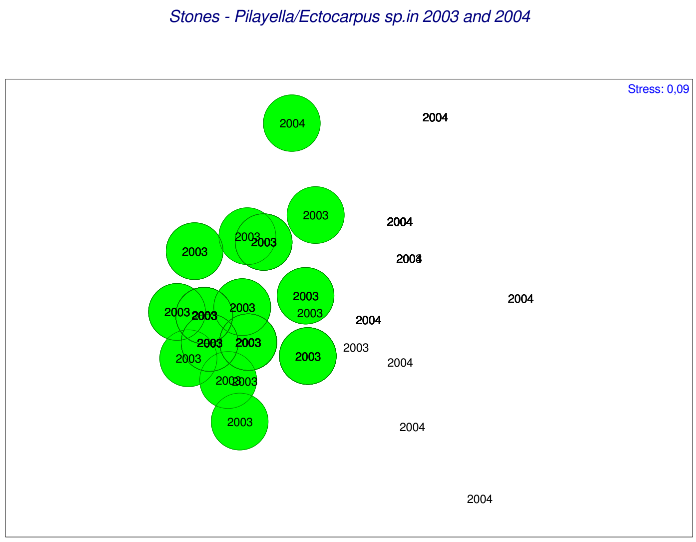

Figure 5.6 *MDS-ordination based on presence/absence of brownalgae (Pilayella/Ectocarpus sp.) on stones in the wind farm in 2003 and 2004.*

6 DISCUSSION

6.1 Invertebrates

Surveys of the fouling community of sessile and mobile invertebrates and attached macroalgae were conducted in October 2004 one year after the first post-construction survey in October 2003. The "age" of the foundations was 71-101 weeks, and the stones were placed in the foundation chambers and around the foundations as scour protection 66-78 weeks prior to the surveys in 2004.

Common mussels (*Mytilus edulis*), barnacles (*Balanus improvisus*) and crustaceans (*Gammarus spp*., *Microdeutopus sp*. and *Corophium sp*.) dominated the hard bottom community on foundations, monitoring mast and Schönheiders Pulle.

The average total biomass of the fouling community was 3.6-5.4 kgDW/m^2 on the shafts and 1.1-2.3 kgDW/m^2 on the foundation stones in 2004. Common mussels accounted for 80-94% and barnacles for 5-12% of the average biomass of the community on the foundations. The biomass has increased 4-8 times on the shafts and 20 times on the stones during one year.

Common mussels were also the most abundant component of the fouling community in 2004. The total abundance of mussels has mostly decreased since 2003 but mussels with a shell length larger than 10mm, which were almost absent in 2003, accounted for 10-25% of the number of mussels on shaft and stones in 2004. Both the density of mussels larger than 10mm and the growth rate of the mussels was highest on the shafts, probably because the faster current in the surface water increases the availability of plankton for the suspension feeding populations of mussels (and barnacles).

The changes in the biomass of the fouling community since 2003 were most profound at the transformer station but the biomass on shafts and stones was still lower than at turbines B2, E5 and G8 in 2004. More intense traffic around the transformer and expected sediment stirring and higher concentrations of sediment in the surrounding water were believed to have contributed to a reduced settling of mussels in 2003 /3/. The heavy settling of mussels on the stones in 2004 suggests that smothering of substrate and newly settled mussels might have contributed to the reduced recruitment of mussels in 2003.

The delayed colonisation of mussel at the transformer station means that the primary settling layer of barnacles on the shaft is not entirely covered by mussels. Patches of barnacles remain on the shaft and the biomass of barnacles is higher and accounts for more (18-20%) of the total biomass than at the other turbines.

The structure of the fouling community was uniform on the south and north faces of the shafts and also uniforms on stones in all directions (south, north, west and east). The calculated wave heights in the corners of the wind farm differ about 1m but a different exposure for waves has not affected the structure of the fouling community in different directions around the foundations.

The structure of the fouling community was different on shafts and stones. The community on the uppermost parts of the shafts was similar but dissimilar from the community on the lowest part of the shafts. The community on fill stones in the chambers was similar but dissimilar from the community on scour protection stones.

The dissimilarity of the fouling community on shafts and stones was attributed to a higher biomass and abundance of the dominant species (*Mytilus*, *Balanus* and *Gammarus*) on the shafts and a predominance of subdominant species of crustaceans (e.g. *Corophium*) on stones.

Waves and currents are probably important hydrodynamic factors structuring the community due to depth-related impacts on flux of larvae, availability of plankton (food), sedimentation of organic matter and stirring of sediment from the seabed. The water movement in the water column is more rapid than on stones and this favours settling and growth of mussels and barnacles on the shafts. Abundance of mobile crustaceans (*Gammarus*) is related to the habitat created by large mussels and this explains that the results of analysis of community structure based on biomass and abundance (also abundance exclusive *Mytilus*) are similar.

A decrease in abundance and biomass of the dominant species and an increase of subdominant crustaceans (*Microdeutopus*) with increasing depth contribute to the significant dissimilarity in community structure between the uppermost and lower part of the shafts. Decreasing current velocity with depth is probably a limiting factor for the mussel populations. The predominance of *Microdeutopus* on the lower parts of the shafts and on stones may be a combined effect of increased sedimentation of organic matter and less exposure to waves and currents in deeper water.

The fouling community on scour protection stones is significantly different and impoverished in biomass and abundance of both dominant species (*Mytilus*, *Balanus* and *Gammarus*) and some subdominant species (*Microdeutopus* and *Jaera albifrons*) compared to the community on stones in the chambers. The low abundant crustacean *Corophium* is the only species most common on scour protection stones. However, the density of *Corophium* in 2004 was far below the density on the stones in 2003 /3/.

The water depth in the wind farm is shallow and sand ripples in the seabed are indicative of sediment movements. Possible intrusion of sand between scour protection stones and settling of sand on the stones suggest that stirring and scouring of sediment during rough weather are factors that may delay and hamper development of the fouling community on the scour protection stones.

Indications of similar sediment movements and potential abrasive effects on biota on stones were observed at station 3 at Schönheiders Pulle. However, the abundance and biomass of the community at station 3 was higher than on the scour protection stones. Therefore, a further development of the hard bottom community is expected in the wind farm.

The average biomass (7 kgDW/m^2), abundance (90000/m^2) and maximum shell length (55-58mm) of common mussels at the monitoring mast are probably close to the carrying capacity of the population under optimal growth condition in this part of the Baltic Sea. The maximum biomass and size of mussels were reached two years after the monitoring mast was deployed. Colonisation of common mussels on artificial reefs in the

Pomeranian Bay in the southern Baltic was stabilised some 2 years after deployment at a density level about 40-50000 individuals m^{-2} /7/.

The biomass and maximum shell length of common mussels on the shafts approach the values at the monitoring mast. The fast growth rate and the rapid increase in biomass during the last year suggest that the biomass of the fouling community on the shafts will stabilise close to the expected maximum level for populations of common mussels in the area during the next year.

6.2 Macroalgae

Macroalgae were absent or scarce on the shafts with the exception of the transformer where the average biomass was 4 gDW/m^2. The average biomass of macroalgae on stones was between <1 gDW/m^2 and 29 gDW/m^2. The biomass was highest on both shaft and stones at the transformer.

Macroalgae has disappeared from the shafts of turbines B2, E5 and G8 since 2003. The biomass on stones was unaltered at turbine B2, reduced at turbines E5 and G8 and has increased on shaft and stones at the transformer during the past year. The changes in distribution and biomass of macroalgae are related to the increasing coverage and biomass of common mussels on shaft and stones. Dense layers of fast growing mussels exclude macroalgae, which is confined to patches of barnacles on the shaft of the transformer and stones with scarce populations of mussels.

The diversity of the community was low and dominated by a few species of redalgae (*Polysiphonia fucoides* and *Ceramium tenuicorne*) in 2003 and 2004. Brown- and greenalgae were absent or scarce in 2004.

The biomass of macroalgae and the structure of the community were uniform in different directions around the foundation and similar on stones in the chambers and the scour protection stones.

The average biomass of macroalgae was 20 gDW/m^2 at Schönheiders Pulle, and the community was similar at the two stations. An analysis based on the biomass of macroalgae proved that the community structure was similar at Schönheiders Pulle and the wind farm but the species composition was significantly different in the two areas. The dominant species of redalgae was common but distribution of subdominant species was different.

The low diversity and dominance of redalgae in the wind farm and Schönheiders Pulle are determined by the salinity in the area. Less common species recorded at Schönheiders Pulle may also become established in the wind farm. However, future changes in macroalgae in the wind farm depend on the growth of common mussels and the competition for space.

7 CONCLUSIONS

- The biomass of the fouling community dominated by common mussels and barnacles has increased several times on both shafts and stones due to a rapid growth of common mussels during the past year. The biomass of the community on shaft and stones is still lower than the biomass at the monitoring mast and Schönheiders Pulle. However, the rapid increase in biomass suggests that the biomass of the fouling community on the shafts will stabilise close to the expected maximum level for populations of common mussels in the area during the next year.

- The structure of the fouling community is different on shaft and stones and change significantly with increasing depth on both shaft and stones due to changes in biomass and abundance of both dominant and subdominant species of invertebrates. The community is uniform in different directions around the foundations.

- The structure of the invertebrate community at Schönheiders Pulle is similar at the two stations but different from the community on stones in the wind farm. The dissimilarity between the areas is attributed to a higher abundance and biomass of the same dominant species of mussels and amphipods (*Gammarus spp.*) at Schönheiders Pulle and a lower abundance of crustaceans (*Microdeutopus sp.* and *Corophium sp.*) characteristic for the wind farm.

- The rapid growth of common mussels has excluded macroalgae from shafts and stones with dense layers of mussels due to competition for space. The biomass of macroalgae has increased at the transformer because a delayed and incomplete colonisation of mussels has left patches available for attachment of algae on both shaft and stones.

- Direction or depth in relation to the foundations does not affect the structure of the community of macroalgae on stones.

- The community of macroalgae at Schönheiders Pulle was similar at the two stations. The structure of the community at Schönheiders Pulle and the wind farm was similar with respect to biomass but the species composition was significantly different in the two areas. The dominant species of redalgae were the same but distribution of subdominant species was different.

- The low diversity and dominance of redalgae in the wind farm and Schönheiders Pulle are determined by the salinity in the area. Less common species of redalgae only recorded at Schönheiders Pulle may also become established in the wind farm. However, future changes in the community of macroalgae in the wind farm depend on the growth of common mussels and competition for space.

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