50863231-TOS/MEC 08-9096

Biological Fouling
OWEZ_R_112_T1_20100114_biofouling

Survey of marine fouling on turbine support structures of the Offshore Windfarm Egmond aan Zee

Arnhem, January 14 2010

Author M.C.M. Bruijs
KEMA Technical & Operational Services

Prepared for Noordzeewind

author	: Maarten C.M. Bruijs		06-06-16	reviewed	: Henk A. Jenner	06-06-
B	36 pages	1 annex	WSc	approved	: M. de Jong	06-06-

KEMA Nederland B.V. Utrechtseweg 310, 6812 AR Arnhem P.O. Box 9035, 6800 ET Arnhem The Netherlands
T +31 26 3 56 91 11 F +31 26 3 89 24 77 contact@kema.com www.kema.com Registered Arnhem 09080262

CONTENTS

SUMMARY

This survey report on biological fouling (NZW-MEP task 1.1.2) describes the findings during the monitoring of marine fouling in the NZW windfarm during the first year of operation in 2007. This monitoring however had to be postponed until February 2008 due to less optimal weather conditions in 2007 during the planned survey period and unavailability of suitable vessels when the weather was suitable again. This has not interfered with the results.

The goal of the monitoring is to investigate if biological fouling on the OWEZ windfarm has a different pattern in time and space, compared to what can be expected based on existing knowledge. This report is a first description of the fouling in the OWEZ windfarm. The aim is to deliver information on the nature and thickness of the fouling on turbine support constructions, as a function of time. It concerns the assessment of the (succession of) species composition and the expected biomass through the successive years. The monitoring details for the biological fouling monitoring are linked to the existing inspection procedures (inspection of monopile construction) and with the inspection activities regarding the corrosion monitoring activities.

In order to characterise the biological fouling, two variables have been assessed from the video-survey recordings and are used for the comparison with recordings of existing offshore constructions:

- *Species composition*: An analysis will be made of the different species that are present and recognised on the video recordings
- *Covering percentage*: From the video it will be estimated what the total covering percentage is during the successive years.

It has been observed that there is a clear zonation in fouling communities, which is found at the three monitored monopiles of WTG-07, WTG08 and the MetMast. The upper zone is dominated by mussel fouling community down to a depth of ~7 m, which exists in a relative thick layer. Below 7 m to the bottom, the biofouling community mainly exists in soft fouling species, forming a relatively thin layer. These findings are similar to the experiences at the Shell/NAM installations, although there are differences, mainly caused by different depths, distances from the shore and local abiotic factors.

The mussel fouling may have consequences for increased drag, however, this fouling layer seems to be self regulating, i.e. in time clusters of mussels get loose from the surface. No significant effects on vibration in the masts are expected since the thickness of this layer is limited. The soft fouling community is not expected to have a significant effect on the drag.

The increase in drag coefficient of the hard fouling (*i.e.* mussel fouling) on the upper part of the monopile is calculated to be a factor of 2.4, between smooth and rough (roughness ~10 cm). The increase of effective diameter has only a small effect compared to the roughness effect. If the effective diameter increases by 45 cm, this would correspond to an increase of only 10% in the drag force. The effect of soft fouling is nihil since this layer is very thin and has a very low roughness.

There might be an influence on corrosion, if the coating is damaged due to manual/mechanical removal of fouling species that have a strong adhesion to surfaces (e.g. Japanese oyster and barnacles). During the monitoring no signs of coating damage and no significant corrosion, like tubercles, have been observed.

Acknowledgement

The Offshore wind Farm Egmond aan Zee has a subsidy from the Ministry of Economic Affairs under the CO_2 Reduction Scheme of the Netherlands.

1 INTRODUCTION

The required inspections with respect to corrosion and biological fouling for the NSW-MEP program will be performed as much as possible according to the existing reporting sheets and procedures as used in the civil O&M program. The inspections for biofouling growth on the monopiles are carried out under water. The below water inspections of the marine growth are performed on the submarine surface of the transaction piece and the monopile (figure 1) of the wind turbines by means of ROV video recording.

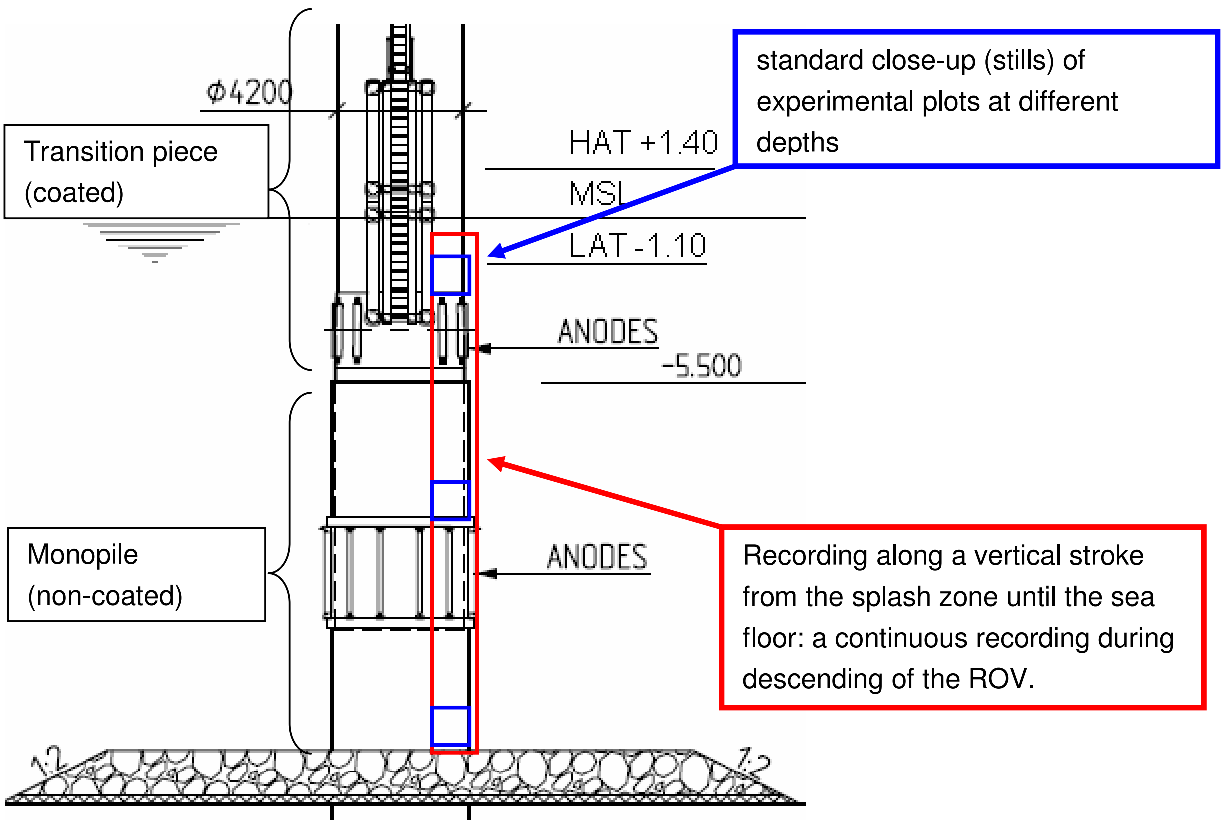


Figure 1. Schematic view on the submerged part of the monopile and OWEZ foundation. The surface to be recorded for the monitoring of biofouling, i.e. a single narrow vertical stroke that is perpendicular to the monopile axis is marked in red. The experimental plot surfaces for making close-ups / stills are marked in blue.

All the tasks for this monitoring have been carried out from the support vessel 'Coastal Digger', no activities took place from the wind masts, nor is any equipment deployed from there.

1.0 Operation of the ROV system for monitoring fouling

The ROV inspections have been carried out from the support vessel 'Coastal Digger'. The support vessel has been equipped with the appropriate surface positioning system for precise positioning of the anchors (anchor handling survey equipment). This positioning system comprises a DGPS receiver and 17" monitor for visualization.

Figure 2. The 'Coastal Digger'.

The deployment of the ROV is done with the crane of the support vessel ('Coastal Digger'). This is done to have the option to choose which side of the vessel the ROV is launched so the vessel generates lea for the ROV. When the ROV is in the water, it is disconnected from the crane. The ROV pilot starts the inspection sequence and based on his experience he decides which route of inspection will be followed taking current and waves and weather predictions into consideration. After the inspection the ROV is connected to the crane to recover the ROV.

The ROV system has been fitted with a PVC elongate to keep a set distance from the masts surface and to have a steady view on the fouling (figure 3). A grab sampler was also attached to the ROV to take samples of the fouling (figure 3).

Figure 3. The ROV with the attached PVC device (left) and the ROV control unit on board (right).

On the first day during low tide the ROV was lowered into the water for a first trial with the PVC device which was mounted on the ROV. After several attempts it was decided to shorten the elongates. Due to the turbid water, only a short distance was needed to obtain proper focussing of the camera on the surface of the masts and the marine growth. After the ROV and equipment had been 'trimmed' for proper buoyancy, the monitoring was started by lowering the ROV from the support vessel by a crane into the water. The ROV went down along the J-tube.

A continuous recording of the video images took place (in colour) by means of a digital camera mounted on the ROV (DOE 18:1 optical zoom high resolution colour camera, PAL/NTSC > 470 lines – 1/3'CCD, 1 Lux @ f1.4, viewing angle 7º - 58º, camera tilt ± 90º). The light applied was a Tungsten-halogen 2 x 250 Watt (3 settings), fitted with a filter in order to provide a diffuse light field to prevent reflection. The window covered by the camera (height x width) is approximately 60 x 60 – 30 x 30 and varies depending on the distance from the object (monopile surface). The images were recorded on the hard disc of a DVDrecorder. At several depths, where significant changes in fouling where visually observed or other interesting and notable observations were made, the ROV was held still for a few minutes to get a still-view at one location. The stills as mentioned in Figure 1 are made as well. After reaching the bottom, the ROV was raised again with continuous recording of the images.

The depth recorded is the water column above the ROV. During the monitoring it appeared that the depth on the screen, and as recorded on the DVD, was not correct. Therefore the depth at specific clock times in the recording was noted manually in the logbook. During viewing of the DVD images, the depth could be assessed and compared with the notes and remarks in the logbook.

In order to characterise the biological fouling, two main variables have been assessed from the video-survey recordings and have been used for the comparison with recordings of existing offshore constructions:

- *Species composition*: An analyses will be made of the different species that are present and recognised on the video recordings
- *Covering percentage*: From the video it will be estimated what the total covering percentage is during the successive years.

Coverage and thickness are estimated by means of expert judgement of the footage material (video analyses). It was not possible to make video images around the entire circumference of the monopile, as the water velocity from the tidal current did not allow to steer the ROV fully around the monopile. However, during lowering of the ROV, in general 25 – 50 % of the masts circumference along the vertical stroke could be observed. No significant differences in fouling are found in this area and it is therefore assumed that the images of the observed area are representative for the fouling around the monopile. At the OWEZ wind farm, the direction of water velocities will have influence on the fouling. As this differs in time, during different types of weather and the tidal schemes, flow conditions will be relatively similar around the masts. However, a main flow direction during the tidal scheme is present, resulting in higher flow rates on the ‘sides’ of the mast, perpendicular to the flow direction. Also, the video recording is largely dependent on the turbidity. To get a proper sharp view of the fouling, the camera needs to be very close to the surface of the monopile. At longer distances the image did not show any recognisable details. The estimate is based on the surface that was videoed.

The main differences in species composition and structure in the fouling community exists between different depths, i.e. depth zonation of fouling. Whomersly & Picken (2003) observed different factors that determined the composition and structure of the fouling community. For example, the mussel zone (at the shallowest depths) was probably structured by wave action. Other structuring forces such as predation were unlikely, since few predators (e.g. *Asterias rubens* Linnaeus) were observed in their study. The middle zones on all the platforms were dominated by M. senile. No physical disturbance was observed or recorded here, and so the factors structuring this zone were thought to be primarily biological, including competition for space and food. The deepest zone was the most diverse on all of the platforms and was possibly structured by physical factors such as scour, and a reduction in the efficiency of filter feeding mechanisms because of re-suspended sediments near the seabed. The structural complexity and composition of the substratum may also have an effect on the structuring of fouling communities.

The thickness of the biological fouling is estimated by expert judgement according to the images. The shell size of the mussels and the formation of colonies give an idea of the thickness. The thickness is given in a range, not in exact measurements. The size of the mussels was checked by the mussels that had been sampled by means of the grab sampler.

The depth of the fouling and the changes in fouling community structure are different at each monopile. The data provides information about the extent of different fouling communities, i.e. zonation. It is then possible to compare the results of each monopile.

Only three samples were taken at locations where it seemed interesting to get more details of the observed specimens. The grab sampler is mounted on the ROV but due to movement in the water current it is rather difficult to position the ROV against the monopile and remove all specimens from the surface in a specific area. The grab sampler does not fully clean the surface where it takes the sample, only a small part of the fouling was removed and most specimens remained on the surface. Also, the dimension of the sampled area is therefore difficult to estimate.

An overview of the different fouling species is provided as well, refer to annex A. The species tell a lot about the specifications of the fouling community and potential effects. There is seasonal succession in fouling in time. Each fouling species has a specific habitat, morphology and strategy for settlement. For example, mussels form large clumps in colonies that make thick layers, other species like *Jassia* form a relatively thin layer. In a few years, the biodiversity may have changed completely due to competition and/or changing environmental conditions, resulting in a different fouling community. This is important to monitor. Also, each species has a specific manner in which it settles and attaches to surfaces. For example, mussels use byssus threads and the Japanese oyster and barnacles cement themselves to a surface. This may have consequences for removal of the biological fouling and the protection against corrosion as well, as parts of the coating may be removed with the fouling species due to attachment. The list of species is therefore relevant. When the adhesion of the coating to the monopile surface is stronger than the attachment of the fouling species, the coating will remain on the monopile. NB, only at WTG-07 and WTG-08 is a coating is applied on the monopile, the MetMast has no coating. During the monitoring attention was paid to the specific areas where the patches of fouling had fallen from the surface to check if these bare areas showed damage and/or corrosion. Only the uncoated MetMast has been manually cleaned so far. The observation on damages and corrosion was depending on the quality of the images produced by means of the camera, *i.e.* depending on the general visibility and video image quality. It was observed that the coating showed no damages and no signs of corrosion. The fouling species observed by the ROV video recording are checked with the results of the monitoring of WTG-07 by means of divers as performed by Bureau Waardenburg (BuWa, 2008).

1.1 Planned monitoring campaign for 1.1.2 biological fouling

Table 1 below provides an update of the performed activities and the planned activities.

Table 1. Planned monitoring campaign for 1.1.2 biological fouling.

	2006				2007 *				2008				2009				2010			
Pre survey																				
Survey									**											
Analyses											***									
Report																				

* first operational year of the wind farm

** the first monitoring for 2007 took place during February 2008.

*** the monitoring for 2008 took place during the first week of July 2008 (reported separately).

The monitoring during the first year of operation (2007) had to be postponed due to bad weather conditions and availability of support vessels. Although the monitoring for 2007 took place during early 2008, the observations made are expected to be similar as would have been during the end of the summer in 2007. After the summer, during autumn and winter, no new fouling organisms will settle and growth will be low due to low temperatures.

2 MONITORING BY KEMA, FEBRUARY 2008

2.0 Wednesday February 13 2008: monitoring WTG-07

On Wednesday February 13, the ROV monitoring of the turbine monopile WTG-07 took place. At low tide the ROV was lowered into the water for a first trial with the PVC device which was mounted on the ROV to keep distance from the mast surface (figure 4). After several attempts it was decided to shorten the elongates. Due to the turbid water a short distance from the camera to the monopile surface was needed to obtain proper focussing of the camera on the surface and marine growth. The depth recorded is the water column above the ROV.

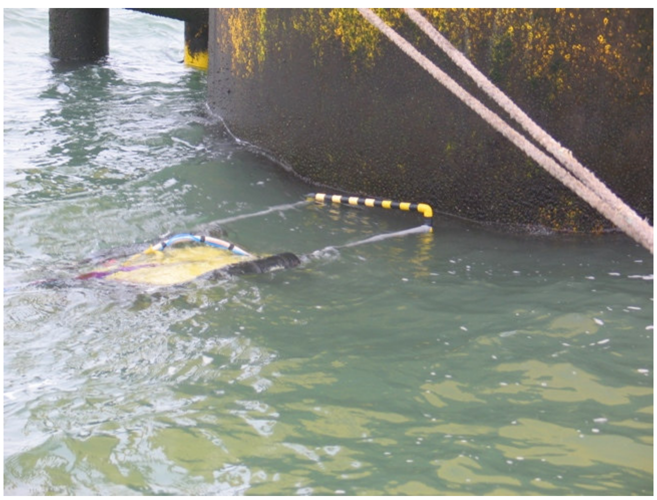


Figure 4. The ROV approaching the WTG-07. At his moment the PVC elongates were still at full length, but needed to be shortened in order to obtain a proper view of the fouling.

After alteration the ROV was lowered into the water to start the monitoring. In the range from the water line along the J-tube to a depth of 7 metres, the surface was estimated to be covered with mussels for ~90% (figure 6). The mussel species were *Mytilus edulis* and *Mytilus galloprovincialis* and formed a layer of about 5 – 15 cm in thickness with a roughness of 10 cm. Yellow patches of the coating of the transition piece were visible where clumps of mussels have fallen of the monopile surface. On the mussels, common starfish (*Asterias rubens*) were foraging on the mussels. The ROV was then lowered to a depth of 9 m to the upper ridge of the second anode ring. Between 7 – 9 metres, more fouling species were observed including plumose and other anemones (small clusters and individuals randomly spread over the surface), bryozoans, barnacles, hydroids, tube worms and some oysters (specifically the Japanese oyster, *Crassostrea gigas*). However, less mussels were present here with only small clusters scattered over the surface. It was however not possible to distinguish between the two mussel species based on the video images as the images did not allow observation of the specific features of each species. In principle the total surface was covered by this fouling community (with the tube worms and hydroids as the main species) and no fouling-free surfaces were observed. The thickness was estimated between 1 and 5 cm, depending on the species (roughness is very limited).

In the area below 12 – 13 metres, (the lower ridge of the anode ring) the same fouling community as at a depth of 7 – 9 m was observed, covering the monopile surface 100% (roughness is very limited).At lower depth the water was very turbid and the view on the fouling community was not optimal. The total depth was 15 metres down to the scour protection stones.

By means of an automated grab-sampler (figure 5), a few samples of fouling where taken from the surface at several depths. These samples have been analysed by Bureau Waardenburg. The species that have been identified are:

- 3x blue mussel *Mytilus edilus*
- 1 x barnacle (species unknown)
- 2x hydroid polyps
- 1 x tube worms
- 1 x bristle worm
- 1 x common starfish (*Asterias rubens*)
- 5 x plumose anemone (‘zeeanjelier’) (*Metridium senile*)
- 10 x orange anemone (‘golfbreker anemoon’) (*Diadumene cincta*)
- 1 x unknown anemone (probably ‘slibanemoon’)
- Several hundreds of jassid amphipod crustaceans (‘slijkgarnalen’) (*Jassa* spp)

Annex A shows an additional list of species determined by Bureau Waardenburg (BuWa) at WTG-07. These samples were taken during the monitoring and sampling by divers for MEP-NSW (BuWa, 2008). The average number of organisms on the monopile of WTG-07 as found by BuWa, was 3,263 individuals per m^2 comparable, but on this monopile mussels were most abundant (average 2,042 individuals per m^2 with a total biomass of 505 g afdw per m^2 (ash-free dry weights)) followed by anemones (average 828 individuals per m^2) and Jassa spp. (average 353 individuals per m^2).

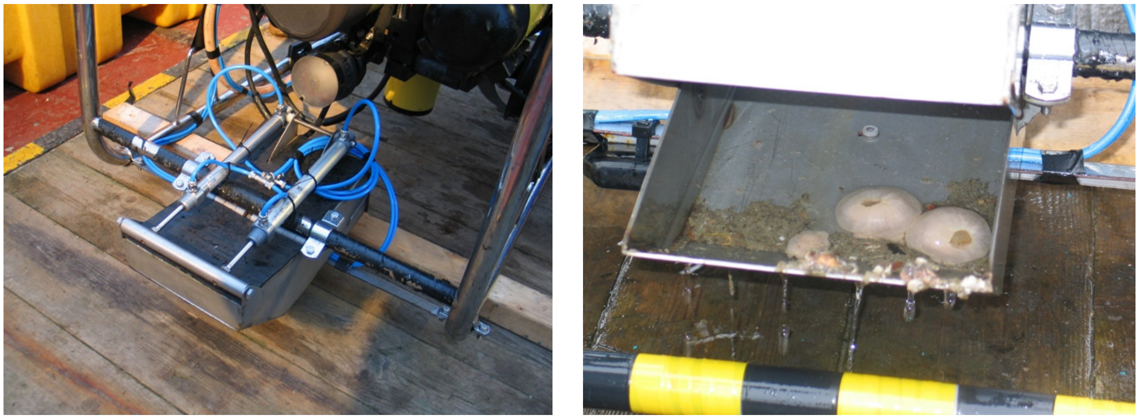


Figure 5. The grab sampler mounted on the ROV (left) and the fouling grabbed from the surface of WTG-07 (right).

Figure 6 below shows the stills at WTG-07 at different depths (recorded as the water column above the ROV during inspection) with specific fouling communities as described above. A summary of the observations at WTG-07 is provided in figure 7. The red line indicates the transition between hard and soft fouling communities as observed at all monopiles and mentioned in the last paragraph. The coverage percentage and layer thickness correspond to the depth layer as indicated by the brackets. This also holds for the figures 9 – 10 (MetMast) and 13 – 14 (WTG-08) in the following paragraphs.

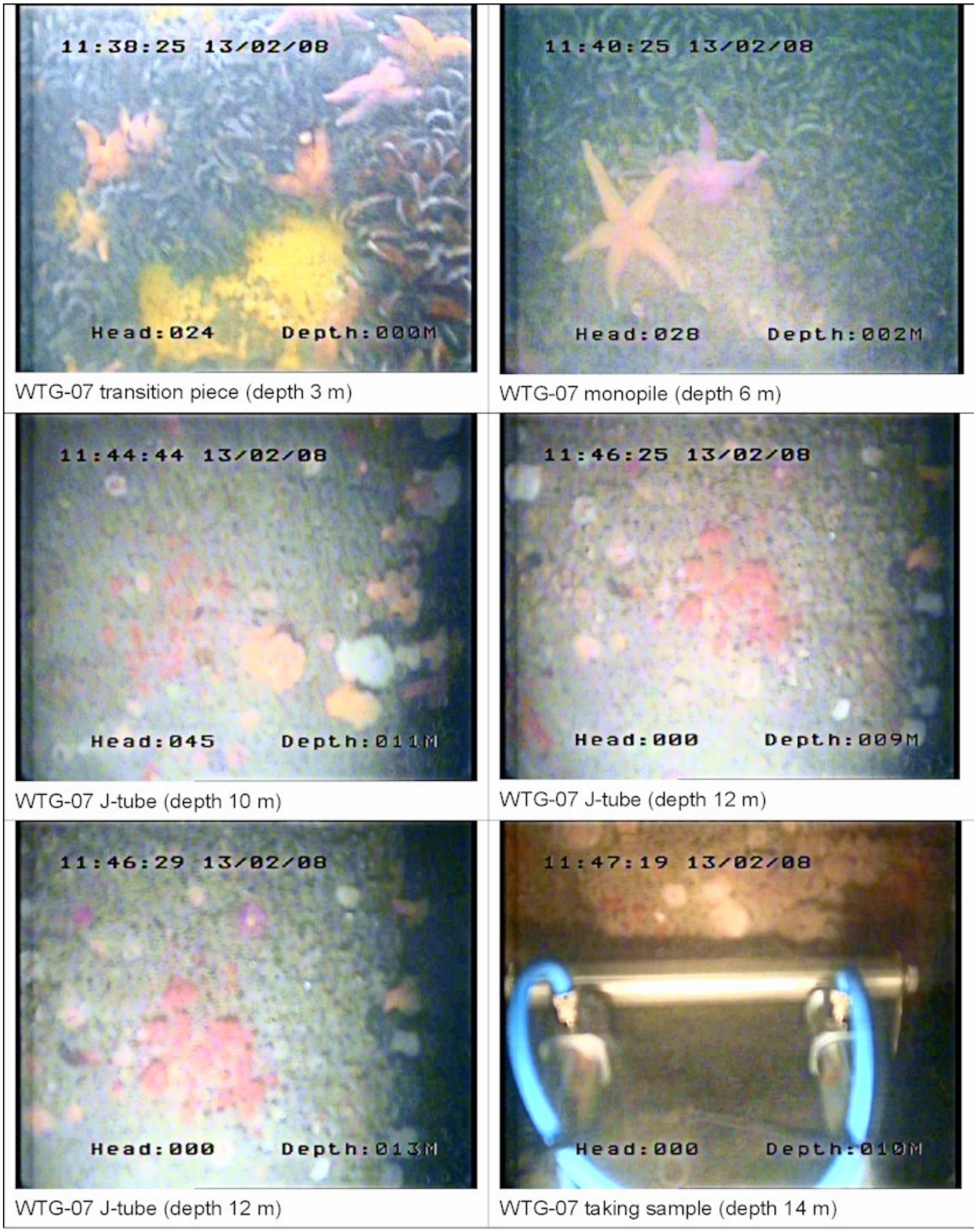
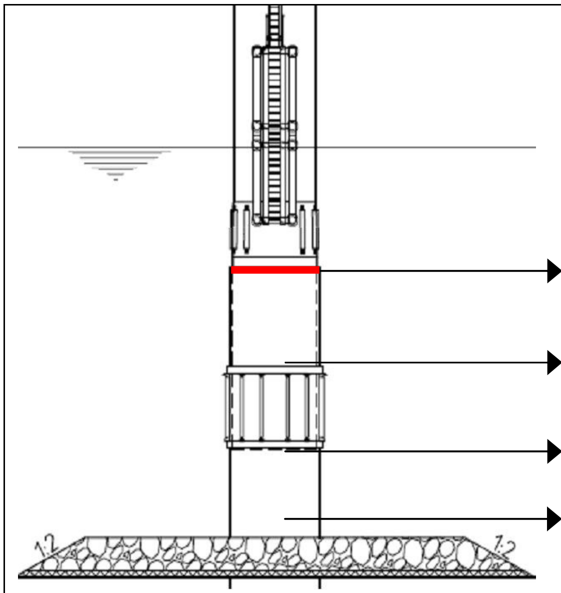


Figure 6. Pictures of the fouling by means of the ROV recording at WTG-07.



Depth (m)	Coverage (%)	Layer thickness (cm)	Remarks
0	~90	5 – 15	Mussels + starfish
6 – 7	100	1 – 5	Plumose and other anemones, bryozoa, barnacles, hydroids, tube worms and some oysters
9			
12 – 13	100	1 – 5	
15			

Figure 7. Summary marine growth at the WTG-07.

2.1 Thursday February 14 2008: monitoring MetMast

On Thursday February 14, the ROV monitoring of the MetMast and the WTG-08 was performed. Several changes had been made to the ROV, based on experience during the day before. These changes included shortening of the PVC elongates, so that proper functioning of the grab sampler was allowed. Also, a light-filter was placed on the lamp, in order to obtain a diffuse light field. This prevented a strong reflection of the light on the particles in the water and hence a better focus of the camera was possible.

Figure 8. The ROV approaching the MetMast.

At low tide the ROV was lowered into the water and the recording of the MetMast began. At the transition piece, the fouling mainly consisted of young mussels, covering the yellow coated surface for about 40 - 70% at the surface layer and up to 90% in deeper layers (figure 9). It was noted that the transition piece at the surface depth had previously partially been cleaned, so this is the reason that mainly young mussels were present. This cleaning took place because of J tube maintenance. Many starfish were found foraging here and also sea urchins were observed. The thickness of the mussel fouling was estimated between 5 – 10 cm.

When reaching the ridge between the transition piece and the monopile (down to 4 m), it was found that the growth significantly changed. The fouling formed thick patches of mussel clusters and in between the surface of the coated transition piece was visible (60 – 80% coverage of the surface), with some growth of barnacles. At the location of the anodes, the fouling species mussels, anemones, barnacles and also sea urchins were observed. The thickness of the mussel fouling was estimated between 5 – 10 cm.

Below the anode ring (6 – 12 m), the surface of the monopile was very clean (welding ridges were visible), showing very little marine growth (10 – 20%), only small clusters of mussels and some anemones. A rather strange pattern of some kind of ‘ridges’ (figure 9) on the surface was also observed. The thickness of the mussel fouling was estimated between 1 – 5 cm. In the area below (12 – 18 metres, lower ridge of the anode ring) the same fouling community was observed, covering the monopile surface ~10 – 20%. The total depth was 21.5 metres onto the scour protection stones.

MetMast monopile 2 (depth 3 m)

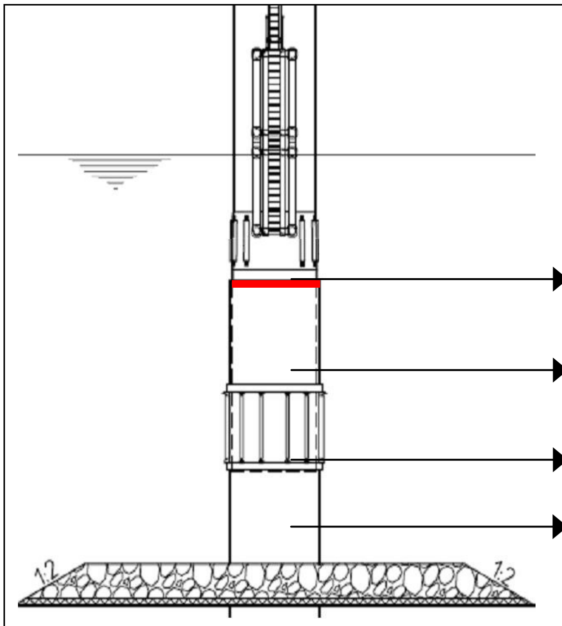
MetMast monopile transition crossing (4 m)

MetMast anode 1 (depth 6 m)

MetMast anode 2 (depth 12 m)

MetMast monopile 1 (depth 14 m)

Figure 9. Pictures of the fouling by means of the ROV recording at different depths.



Depth (m)	Coverage (%)	Layer thickness (cm)	Remarks
0			
	40 – 70	5 – 10	Mussels + starfish + sea urchins
4	60 – 80	5 – 10	
12			Some mussels, plumose and other anemones, barnacles and hydroids
	10 – 20	1 – 5	
14			
	10 – 20	1 – 5	
21.5			

Figure 10. Summary marine growth at the MetMast.

2.2 Thursday February 14 2008: monitoring WTG-08

On Thursday February 14, the ROV monitoring of the turbine mast WTG-08 took place.

Figure 11. The ROV approaching WTG-08.

The marine growth at WTG-08 was found to be nearly similar to the marine growth at WTG-07, both in species observed and in the growth pattern.

To a depth of 7 metres the fouling was mainly adult mussels and foraging starfish. In this range the surface was estimated to be covered with mussels for ~90% (figure 12). The mussel species form a layer of about 5 – 15 cm. Yellow patches of the coating of the transition piece were visible. Common starfish (*Asterias rubens*) were foraging on the mussels.

The ROV was then lowered to a depth of 9 m (upper ridge of the anode ring) along the surface of the monopile. Between 7 – 9 metres, more fouling species were observed, among others plumose and other anemones, bryozoa, barnacles, hydroids, tube worms and mussels. It was however not possible to determine the species. The total surface was covered by this fouling community and no clean surface areas were found. The thickness of the mussel fouling was estimated between 1 – 5 cm.

Figure 12. Detail of the fouling near the splash zone of WTG-08.

In the area below (12 – 15 metres, lower ridge of the anode ring to the bottom) the same fouling community was observed, covering the monopile surface 100%. The total depth was 16 metres onto the scour protection stones.

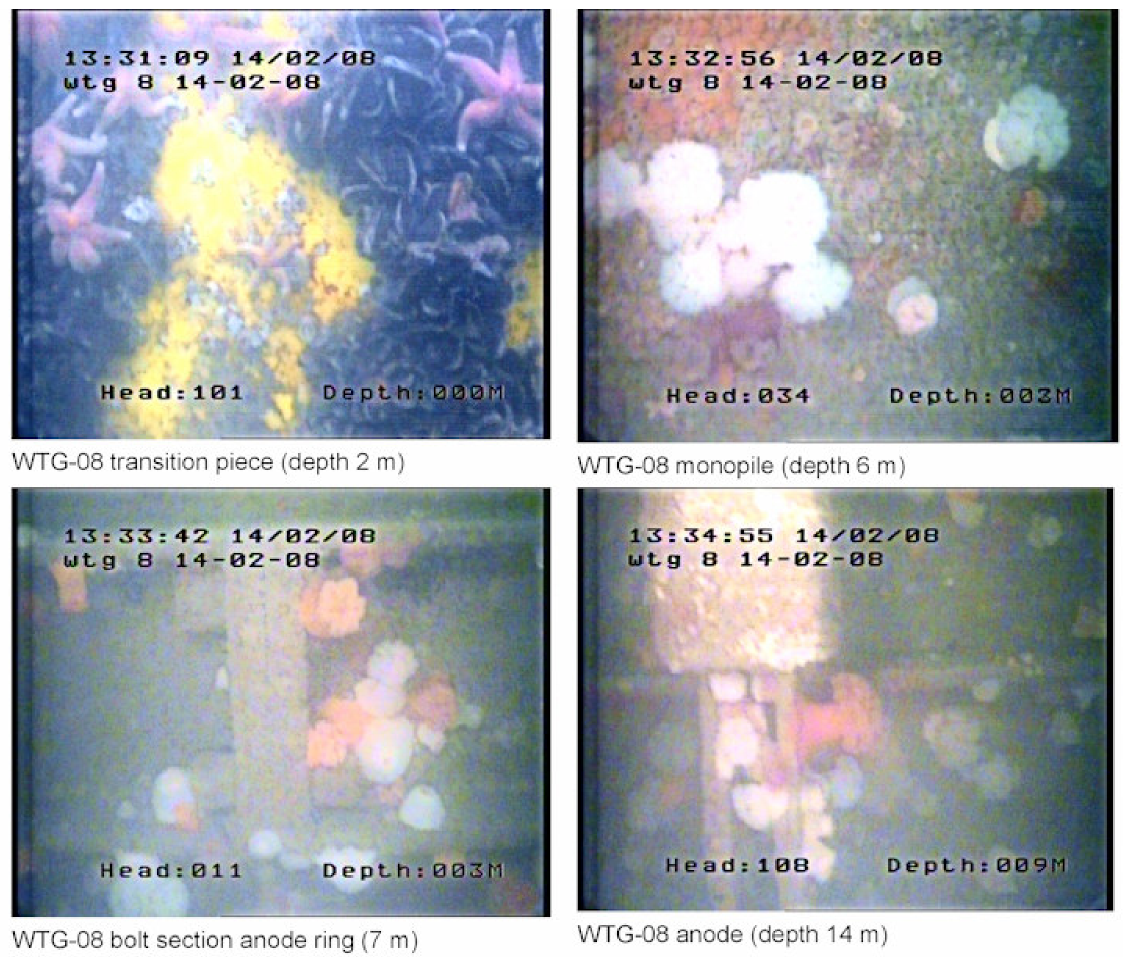


Figure 13. Pictures of the fouling by means of the ROV recording at different depths.

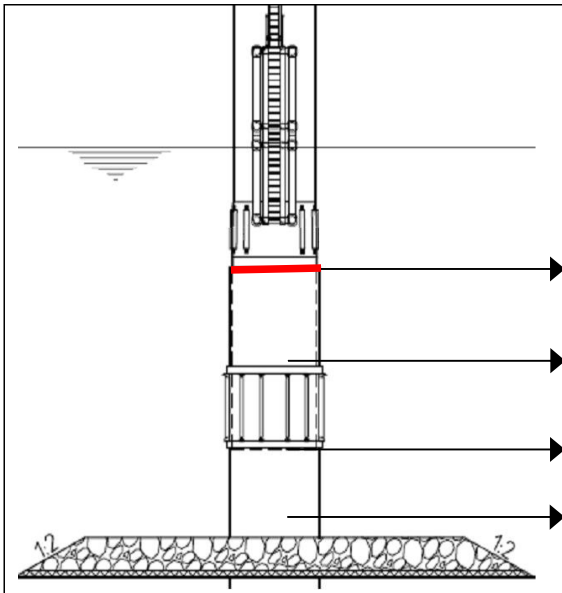
	Depth (m)	Coverage (%)	Layer thickness (cm)	Remarks
	0	~90	5 – 15	Mussels + starfish + some sea urchins
	4			
	9	100	1 – 5	Plumose and other anemones, bryozoa, barnacles, hydroids, tube worms and some oysters
	13			
	16			

Figure 14. Summary marine growth at the WTG-08.

3 COMPARISON OF THE OWEZ FOULING WITH SHELL/NAM AND HORNS REV OFFSHORE CONSTRUCTIONS

3.0 Fouling at the Shell/NAM

The NAM (Nederlandse Aardolie Maatschappij) has had regular monitoring throughout multiple years that is aimed at inspection of the technical integrity and not fouling. During 2002 the NAM has performed a video survey study concerning the fouling on three production platforms in the North Sea, K15, L15 and F3. Platforms K15 and L15 are located at 53 º20' N (L15 closest to the coast). Platform F3 is the most northern platform and is located at about 54º 50' N. The study investigated the geographical distribution and vertical zonation of the fouling species. This study was based on video recordings of the fouling at different installation parts of the platforms. The video recordings concerned a survey of about 6 years after installation of the structures and thus were not part of a monitoring program throughout multiple years.

The mussel *Mytilus edulis* was present on all three platforms, but only at L15 did it reach a depth of 14 m. *Metridium senile* had a good growth on all platforms, showing highest coverage at K15. At L15 it only grew near the bottom. *Obelia* spp was not present at L15, while at K15 no *Tubularia* spp was present. At F3 some growth of *Alcyonium* and *Pomatoceros* were found. The average trend found at all three platforms, was that the layer with hard fouling was followed by layer of soft fouling, mostly anemones that stretches to the bottom.

Furthermore, it was observed that the fouling community at the surfaces was mostly dominated by one species, either mussels, hydroids or anemones. Structures closer to the shoreline were dominated by barnacles. Other observed fouling species were tube worms, barnacles, sponges and sea squirts. At shallow depths, the mussels were the dominant species. The fouling existed in patches on the surfaces, showing dense areas and empty areas. These empty areas could be fouled by bryozoans, but the recordings did not allow to determine this as no close-ups were made.

The fouling communities observed were dense with an estimated thickness between 5 and 20 cm, depending on the dominant species.

A clear vertical zonation was observed. Not all zones found were at similar depths or abundant in similar extent. This could indicate differences in abiotic factors between the locations. The first (upper) zone was fouled with hard fouling, dominated by the mussel *M.*

edulis. The characteristic of this zone was temporary exposure to the air during tides. Mussels are capable of surviving these periods. Also, the wave movement provides a proper supply of nutrients for *M. edulis*. Algae are also found at this zone. At lower zones soft fouling is dominant, existing in anemones and hydroids.

Differences in geographical distribution of species have been observed, however, the quality of the video recordings did not allow analysis at a smaller scale so differences between the NAM-platforms were difficult to make.

3.1 Comparison fouling OWEZ with NAM

In the pre-survey report by KEMA (KEMA, 2006, reference 1), based on the findings at the Shell/NAM offshore structures (Van der Laan, 2003a and b) and other relevant examples, it was concluded that the fouling community that might develop on the offshore structures of the OWEZ windfarm could be as follows: the first colonisers after installation are expected to be hydroids (within several weeks), followed by mussels, barnacles and anemones. Surface coverage of these species will increase during the first growth season (i.e. first year). More species will settle during time: mussels (My*tilus edulis* and *M. galloprovincialis*), anemones *Metridium senile*, *Obelia* spp and *Tubularia* spp. Also a clear vertical zonation of the fouling species is expected. The first (upper) zone was expected to be fouled with hard fouling, probably dominated by a single species, likely by the mussel *M. edulis*. At lower zones soft fouling is dominant, consisting of anemones and hydroids, although growth of soft fouling species might be limited by any sand scour.

It can be concluded from this first field monitoring of the fouling in the OWEZ windfarm, that the development of the fouling community was as expected, i.e. forecasted. A clear zonation has been found. The change in fouling community at a depth most likely determined by abiotic factors, shows a change from a hard fouling community in the upper zone, to the lower zone that is dominated by soft fouling species.

The upper zone consisting of a community dominated by the common mussel (*Mytilus edulis*) and associated species like barnacles (*Balanus crenatus* and *Balanus balanoides*), the common starfish (*Asterias rubens*), several species of worms and crabs and the encrusting sea mat (*Conopeum reticulum*). Covering percentages of mussels within the first few metres from the surface were between 80-100%. Bare patches in between the mussels were colonised by anemones (mainly *Metridium senile* and *Sargartia* spp.) and (tubes of) the small crustacean *Jassa* spp.

The deeper zone was dominated by a community consisting of (tubes of) *Jassa* spp., several species of anemones (mainly *Metridium senile* and *Sargartia* spp.; and less abundant *Diadumene cincta*) and patches of the ringed tubularia *Tubularia larynx*. Green sea urchins (*Psammechinus miliaris*) and common starfish (*Asterias rubens*) were also present in this zone, but occured in low numbers. This community occupied the entire surface of the monopiles (covering percentage 100%) from the zone below the mussels till the sea floor.

The observations made during this first monitoring provide the basis for the monitoring of the marine fouling succession during the coming years. The succession in species composition and coverage percentage will be analysed in time.

3.2 Comparison fouling OWEZ with the Horns Rev offshore wind farm

As also mentioned in the BuWa report (2008), great variations were found in the Horns Rev offshore wind farm between surveys carried out in 2003 and 2004 and in spatial and temporal distribution between species and communities (Leonhard et al., 2005). These findings are an indication for the process of ecological succession. In the splash zone, an almost monoculture population of the giant midge *Telmatogeton japonicus* is present. This population increased significantly between 2003 and 2004. In general the vegetation was very scarce. There was a zonation found in the abundance of algae, brown algae and red algae seemed to be typical for the monopiles till approximately 4 m depth, whereas different species of the green algae Ulva spp. seemed to be typical for the scour-protections. In the sublitoral on the monopiles, just beneath the surface dense aggregations of either spat or larger individuals of the common mussel (*Mytilus edulis*), including associated species like the crenate barnacle (*Balanus crenatus*) and common starfish (*Asterias rubens*). - In the lower zone the plumose anemone *Metridium senile*, *Sargartia* spp. anemones and the crustacean *Jassa marmorata* were very abundant (*Jassa marmorata* was dominant in terms of both numbers and biomass at all turbines sites and on both the monopiles and the scour protection rocks). Less abundant, but common species in the lower zone were the keelworm (*Pomatoceros triqueter*) and the hydroid (*Tubularia indivisa*). During the surveys in 2004 14 new epifaunal species were recorded that were not present in 2003. Notable species included the bristle worm Sabellaria (presumably *Sabellaria spinnulosa*) and the white weed *Sertularia cupressina*, which in the Wadden Sea are regarded as threatened or red list species.

BuWa (2008) mentions that a full comparison between results of surveys carried out in the Horns Rev offshore windfarm and the OWEZ offshore windfarm is not possible at this stage. Surveys in the Horns Rev windfarm have been carried out three times and during two times of the year (end of winter period (March) and end of summer period (September)). In the OWEZ only one survey was carried out in February (end of winter period). However, the preliminary analyses indicated that the growth on the hard structures of the turbines in the OWEZ is comparable with the growth on the hard structures in the Horns Rev offshore wind farm. This is also indicated by the results of the video recordings by KEMA as described in this report.

4 DISCUSSION AND CONCLUSIONS

4.0 Comparison of observed fouling at WTG-07, WTG-08 and the MetMast

The growth at WTG-07 and WTG-08 is found to be very similar. Both monopiles are located relatively close to each other in the wind park, thus it can be expected that the conditions to which both are exposed, as well as the abundance of fouling species (larvae that settle on the structures surfaces) are similar. A clear zonation, i.e. vertical pattern in fouling composition is observed, in general due to particular abiotic conditions. The transition piece and anode ring location show large growth of dominantly mussels and little number of other species. At lower depths the marine growth shows more variety, with abundance of anemones, barnacles, bryozoans and tube worms. The transition piece showed ~90% coverage by marine growth, the monopiles showed nearly 100% coverage.

The marine growth on the MetMast differs from WTG-07 and WTG-08. Because of J tube maintenance requiring cleaning, the MetMast had partially been cleaned and the mussels are smaller (younger specimens). Probably these are the result of a second spat-fall during September 2007, possible because of higher water temperatures at the end of the summer. At lower depths, on the monopile, it was observed that the metal surface was largely ‘clean’, free from extensive marine growth and the bare material of the monopile was visible. The images do not indicate that this could be caused by physical stress on the fouling community by for example sandblasts during ‘sand storms’ during storms at sea. Such sandblast may remove specimens from the surface of the lower parts of the monopiles. However, the visual impact of such effects should be visible at the other monopiles as well. As the MetMast was installed during 2003, and therefore has a longer fouling history, it was expected that the marine growth would be more extensive than at WTG-07 and WTG-08. It was mentioned by Nuon (personal communication Martin Dekker, 2008) that during construction it was found more difficult to weld the material of the MetMast, which is an indication that there can be significant differences in surface characteristics or the material. As some growth is present and a specific pattern has formed (presumably unaffected by sand scour), it is hypothesised that the difference in fouling can be explained by potential differences between the monopiles with respect to the material used, or different treatment of the raw material of which the monopile is made.

The fouling community found during the OWEZ monitoring shows a similar distribution (zonation), as observed at installations of the NAM and the Horns Rev wind park. During future monitoring the succession of the fouling community will become more clear, i.e. if other species will develop within the OWEZ wind park and species currently found will decrease in number.

4.1 Fouling development and it's effects on corrosion

Fouling starts with the development of a biofilm. After the biofilm has set, it becomes possible for macrofouling species to settle. This macrofouling forms a thick layer, depending on the species size and characteristics of growth and attachment. In general, at the surface side of a fouling layer, underneath the biofilm, an anaerobic environment develops because of the absence of oxygen. The oxygen is used up by the organisms on the upper side of the biofilm. Within the anaerobic environment, organisms like sulphate reducing bacteria (SRB's) may enhance the development of MIC (Microbial Influenced Corrosion). In order to protect the transition piece, the surface is coated.

The main macrofouling (hard fouling) community observed are mussels. With respect to the structural integrity of the transition piece and the monopile, it can be noted that there is an strong indication that the marine growth regulates itself. Within the mussel community, the mussels at the lower side, i.e. the specimens that attach to the surface, will have less fresh water to filter for oxygen and nutrients that the mussels on the outer side of the layer which are exposed to the aquatic environment. The mussels that provide the attachment of the layer to the coated surface are thereby expected to have a higher mortality rate. As soon as mussels die, the shells open and the inner body tissue goes out of the shells quickly. The byssus threads by which they attach are lost as well, leaving no connection. Therefore, when the mussels die the connection to the surface is lost and hence it becomes easier to remove this layer by means of the water velocity. Foremost the mussels are able to form thick layers of fouling, at this moment, as assessed from the video images, up to 15 cm in thickness. The other, soft fouling species do not form thick layers as these do not cluster. When the clusters of mussels are > 15 cm thick, due to currents during the tides (up to 3 m/s) and mortality of the specimens attached to the surface (underneath), patches and clusters of mussels are expected to come loose from the surface, leaving open spaces where new marine growth can develop It was indeed observed that patches of mussel fouling had fallen off, whereby no indication of coating damage has been observed. It was also observed that small, young mussels have settled in these 'empty' areas. Based on the observed surfaces, no signs of material degradation of the transition pieces due to fouling have been observed during this monitoring session.

Several species like the Japanese oyster and barnacles cement themselves to a surface. These species are difficult to remove due to a very tight adhesion. When being removed (only manually), the chance exists that the coating becomes damaged. However, only very small numbers of these species have been observed so far.

4.2 Effect of accumulation of biomass on the drag coefficient of the monopile cylinder

With respect to the roughness and thickness of the biofouling layer and its effect on drag forces on the monopile, the most important area is the upper 7 metres below water level. Here the hard fouling community, dominated by mussels, formed a relatively thick layer (up to 20 cm). This layer has a specific roughness, *i.e.* the thickness of the mussel fouling varies locally (thick and thin areas are recognised). This roughness has an effect on the drag forces. The layer of other fouling species below 7 m and deeper, form rather thin layers and no significant effect on surface roughness and increased drag would be expected.

For the calculation of drag it is important to mention that it only concerns an increase of the drag on the upper layer of the masts (until the fouling layer changes from mussel fouling to soft body fouling species which form a relatively thin layer).

The hydrodynamic drag force *D* on a cylinder in steady flow is given by:

$$D = \tfrac{1}{2}\rho V^2 C_D D L$$

Where ρ is the density of the medium (1000 kg/m^3), V is the flow velocity C_D is the drag coefficient, D is the diameter of the cylinder and L its length. $L >> D$ will be assumed. For unsteady flow, like wave induced flow, this is still an important part of the force, but there is an additional frequency dependent part.

The drag coefficient in general depends on the Reynolds number Re = VD/ν and the surface roughness k/D. ν is the kinematic viscosity, approximately equal to 10^{-6} m^2/s in water. In the case of the monopile for the V90 turbines (diameter approximately 4.5 m) the Reynolds number exceeds 10^6 for flow velocities higher than a few decimeters a second. For this range of Reynolds numbers (Re > 5 10^5) the flow is ‘supercritical’ and the drag coefficient depends only on the surface roughness (Sarpkaya and Isaacson, 1981).

With an estimated average surface roughness of 10 cm, k/D is approximately equal to 1/50, which corresponds to a C_D value of approximately 1.9. For the smooth cylinder the C_D value would be approximately 0.8. Hence the increase in drag coefficient is a factor of 2.4, between smooth and rough.

The increase of effective diameter has only a small effect compared to the roughness effect. If the effective diameter increases by 45 cm, this would correspond to an increase of only 10% in the drag force.

4.3 Conclusions

A clear zonation has been observed by the presence of different fouling communities at different depths. The existing fouling community has settled formed on the coated surface. During the visual observations of the recordings, it iswas observed that the thickest fouling layers are formed by mussels, forming a relatively thick layer. The mussels are presentwhich extend to a depth of 4 – 7 metres. At lower depths far less mussels are present. It was observed that clumps of mussels had fallen off, leaving a surface free for new settlement. At this stage, there is no indication found of coating damage or corrosion. The thickness of the fouling layer varies between 1 and 15 cm. With an average surface roughness of 10 cm, the increase in drag coefficient is a factor of 2.4, between smooth and rough, as calculated by ECN. The observed roughness has aan relative small effect on the drag. The effect of the thickness itself is small.

REFERENCES

1: KEMA, 2006. Biological Fouling. Pre-survey of marine fouling on turbine support structures of the Offshore Windfarm Egmond aan Zee. OWEZ_R_112_July 19 2006. 50562062-TOS/MEC 06-9409.

2: BUWA, 2008. Development of underwater flora- and fauna communities on hard substrates of the offshore wind farm Egmond aan Zee (OWEZ). 24 April 2008. BuWa Report nr 08-079.

3. VAN DER LAAN B.B.P.A., 2003a. Biological Issues regarding Production Activities on the Dutch Continental Shelf of the North Sea. Containing A Preliminary Study on Biofouling. Student report RUG, Department of Marine Biology.

4. VAN DER LAAN B.B.P.A., 2003b. De Geografische Verspreiding van Biologische Aangroei op Productieplatformen en in Koelwatersystemen. Studentverslag RUG, Afdeling Mariene Biologie.

5. LEONHARD S.B. & PEDERSEN J., 2005. Hard bottom substrate monitoring Horns Rev offshore windfarm. Annual status report 2004. Elsam Engineering, May 2005.

6. WHOMERSLEY P. & PICKEN G.B. 2003. Long-term dynamics of fouling communities found on offshore installations in the North Sea. J. Mar. Biol. Ass. U.K. 83, 4288/1 – 5.

7. SARPKAYA, T AND ISAACSON, I. 1981. Mechanics of Wave Forces on Offshore Structures. Van Nostrand Reinhold Company Inc.

ANNEX A SPECIES OBSERVED BY BUREAU WAARDENBURG

By Bureau Waardenburg (BuWa, 2008), monitoring has been performed on the fouling community of several wind masts, among others WTG-07. This monitoring has been performed by divers who collected specimens for further identification in the laboratory. Below a list of species observed, which confirms the species as observed by means of the ROV recording. The work of Bureau Waardenburg will be reported separately.

Species	English name	Monopile Turbine 7
Anemones (Cnidaria)		
Diadumene cincta	orange anemone	x
Metridium senile	plumose anemone	x
Sargatia spp.		x
Barnacles (Crustacea)		
Balanus crenatus	crenate barnacle	x
Semibalanus balanoides	rock barnacle	x
Molluscs		
Crepidula fornicata	slipper limpet	
Crassostrea gigas	Japanese oyster	x1 (1 adult)
Mytilus edulis	common mussel	x
Crustacea		
Caprella linearis	skeleton shrimp	x (1 individual)
Corophium volutator	mud shrimp	x
Jassa spp.		x
Pilumnus hirtellus	hairy crab	x (1 individual)
Echinodermata		
Asterias rubens	common starfish	x
Bryozoa		
Conopeum reticulum	sea mat (encrusting bryozoan)	x
Hydroids		
Tubularia larynx	ringed tubularia	x
Obelia spp.		x
Worms		
Lepidonotus clava	scale worm	x
Annelida (multiple species)		x
Platyhelminthes?		x1 (1 individual)
Pomatoceros triqueter	keelworm	
	Total number of species	**18**

ANNEX B OBSERVATIONS BY WALS DIVING DURING THE YEARLY CONSTRUCTION MONITORING WTG-07, WTG-08 AND THE METMAST, MAY / JUNE 2007

During May and June 2007, inspections of the wind turbine support structures, among others the turbines WTG-07, WTG-08 and the MetMast, took place. These monitorings were carried out by means of ROV and were intended to observe any abnormalities of the submerged support structures. During these inspections, also some observations and remarks were made by Wals Diving and Marine in their report with respect to marine fouling. The remarks described in the monitoring reports are listed below. Although these observations are rough indications, they are the first estimates of fouling made in the wind farm. These observations are no part of the monitoring program, but still are interesting to mention.

Remarks during inspection WTG-07 at May 23, 2007
Marine growth on transition from main sea level till Grout annulus has a thickness of approximately 2 cm and a coverage of 80% on the structure, the gradation of the marine growth is 30% hard marine growth 1,4 gr/cm² and 70% soft marine growth 1,2 gr/cm². The marine growth on the monopile has a thickness of approximately 3 cm and a coverage of 80% the gradation is soft marine growth.

Remarks during inspection WTG-08 at May 23, 2007
Marine growth on transition from main sea level till Grout annulus has a thickness of approximately 2 cm and a coverage of 80% on the structure, the gradation of the marine growth is 30% hard marine growth 1,4 gr/cm² and 70% soft marine growth 1,2 gr/cm². The marine growth on the monopile has a thickness of approximately 3 cm and a coverage of 80% the gradation is soft marine growth.

Remarks during inspection MetMast at June 7, 2007
The marine growth on the MetMast varies from all the WTG foundations. There is less marine growth on the MetMast, which is strange due to the fact that this structure is in the field since 2003. The marine growth on the transition piece from the main sea level till monopile has a coverage of 90%, existing in 20% hard marine growth and 80% soft marine growth. The marine growth on the monopile has a coverage of 40% what has mainly concentrated on the north of the structure. The gradation is soft marine growth.

ANNEX C ROV TECHNICAL INFORMATION

DEEP OCEAN ENGINEERING

Phantom® HD2+2

Strong Current Capability Workhorse

Phantom® HD2+2

- Dependable ROV for offshore inspection and light work tasks
- For use in moderate to strong currents to depths of 300m (1,000 ft.)
- Accommodates cameras, sonar, tracking, manipulators and custom tooling

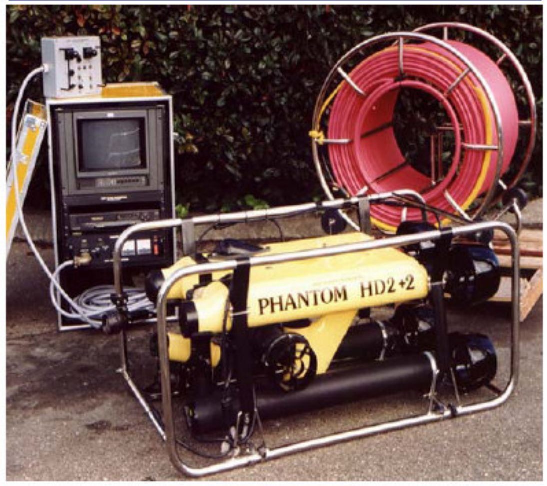
The Deep Ocean Advantage

- Well established company with over 20 years of experience & supply to the ROV industry.
- Over 460 ROV systems delivered.
- Broad international customer base, with clients in over 30 countries.
- Diverse industry applications:
  Military, customs & police
  Search & recovery
  Survey & inspection
  Nuclear & hydroelectric
  Offshore oil & gas
  Scientific research
  Underwater filming
- World class engineering and R&D
- Solutions oriented customer service support
- Rugged reliable products, easy to use & maintain
- Ability to integrate tooling & sensor packages

Phantom® HD2+2 Applications

- Outfall/Intake inspections.
- Jack-up and template inspections.
- NDT inspections.
- Mooring and anchor chain monitoring.
- Telecommunication cable inspection.
- Mine countermeasures.
- Body and evidence recovery.
- Oceanographic survey.
- Fisheries research.
- Environmental surveys.
- Marine archeology.

Phantom® HD2+2



Features

- Superb video quality, ± 90° camera tilt
- Hardwired Phantom control system — easy to troubleshoot and add accessories
- Shock-mounted full perimeter stainless steel crash frame for rugged protection and durability
- Interchangeable components with DOE Phantom Spectrum vehicles
- Enhanced vehicle stability with low center of gravity and torque-balanced horizontal thrusters.

Specifications

Weight:	120kg	265 lb
Operating depth:	305m	1,000ft
Overall length:	1400mm	55"
Overall width:	686mm	27"
Maximum height:	673mm	26.5"

Performance - forward thrust:

Normal:	68kg	150 lb
Full:	91kg	200 lb
Lateral thrust:	7kg	15 lb
Vertical thrust:	7kg	15 lb
Payload (with lateral thruster fitted)	4kg	10 lb

Power requirements

Input Voltage:	100-250vac
Frequency:	50/60Hz
Power Rating:	6kva
User Power Available	
– Instrumentation:	24vdc @6A
– Auxiliary Power:	80vdc @ 0.6A

Lights: Tungsten-halogen 2 X 250 Watt. 3 settings

Camera

DOE 18:1 optical zoom high-resolution color camera
PAL/NTSC >470 Lines— 1/3" CCD
Sensitivity 1 Lux @ f1.4
Auto-iris, wide angle lens, viewing angle 7°-58°
Auto/Remote focus select
External motorized camera tilt ±90°
Built-in video switch for 2nd Camera
1,000 m (3,300 ft) rated, recessed and hardened port

Instrumentation

Fluid-gimbaled fluxgate compass. Accuracy: ± 3°
Electronic depth gauge. Accuracy: ± 1% fsd.
Auto heading and auto depth
Audio feedback of ROV condition
Leak detector
Onscreen graphic video display

Standard Umbilical Tether

Lengths: 168m (550'); 335m (1,100'); 670m (2,200')
Diameter: 20mm (0.8")
Weight in fresh water: Neutral

Options

- Cable reels and slip-ring units available.
- Sonar
- Navigation and tracking systems
- Additional cameras & lights.
- Set additional buoyancy. +3kg/6.6lb Payload.
- Customized versions available.
- DOE single function manipulator.
- Sensor packages.
- Additional components on request

DEEP OCEAN ENGINEERING
1431 Doolittle Drive, San Leandro, CA 94577 USA
Tel: 510-562-9300
FAX: 510-430-8249
E-mail: info@deepocean.com
www.deepocean.com