



50863511-TOS/MEC 10-DRAFT

Biological Fouling
OWEZ_R_112_T1_20100211

**Survey of marine fouling on turbine
support structures of the Offshore
Windfarm Egmond aan Zee, July 2008**

Arnhem, February 11 2010

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

Prepared for Noordzeewind



NoordzeeWind



author : Maarten C.M. Bruijs	06-06-16	reviewed : Henk A. Jenner	06-06-
B 31 pages 1 annex	WSc	approved : M. de Jong	06-06-



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SUMMARY

This survey report on biological fouling (NZW-MEP task 1.1.2) describes the findings during the 2nd monitoring of marine fouling in the NZW windfarm during the second year of operation in 2008. This monitoring has been performed at July 3 and 4, 2008.

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 the second monitoring 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 the fouling is similar to the findings of the first monitoring (2007). There is still a clear zonation in fouling communities, which is found at the three monitored monopiles: WTG-07, WTG08 and the MetMast. The fouling by mussels has increased in thickness of the mussel fouling layer and extension of ~2 metres to deeper areas. The upper zone is dominated by a dense mussel fouling community down to a depth of ~9 m (down to two metres lower than the year before), which exists in a relative thick layer up to 30 cm. Below 9 m to the bottom, the biofouling community mainly exists in soft fouling species, forming a relative thin layer. These findings are similar to the experiences at the Shell/NAM installations, although there are differences, mainly caused by different water 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.* due mortality of mussels and forces by water flows along the surface, clusters of mussels get loose from the surface. This is observed by empty areas

within the fouling layer where yellow coating has become visible. 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 any effect on the drag. The increase in drag coefficient of the hard fouling (*i.e.* mussel fouling) which is only present 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.

There might be an influence on corrosion, if the coating is damaged due to natural or manual/mechanical removal of fouling species that have a strong adhesion to surfaces, like 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 of the Ministry of Economic Affairs under the CO₂ 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 transition piece and the monopile (figure 1) of the wind turbines by means of ROV video recording.

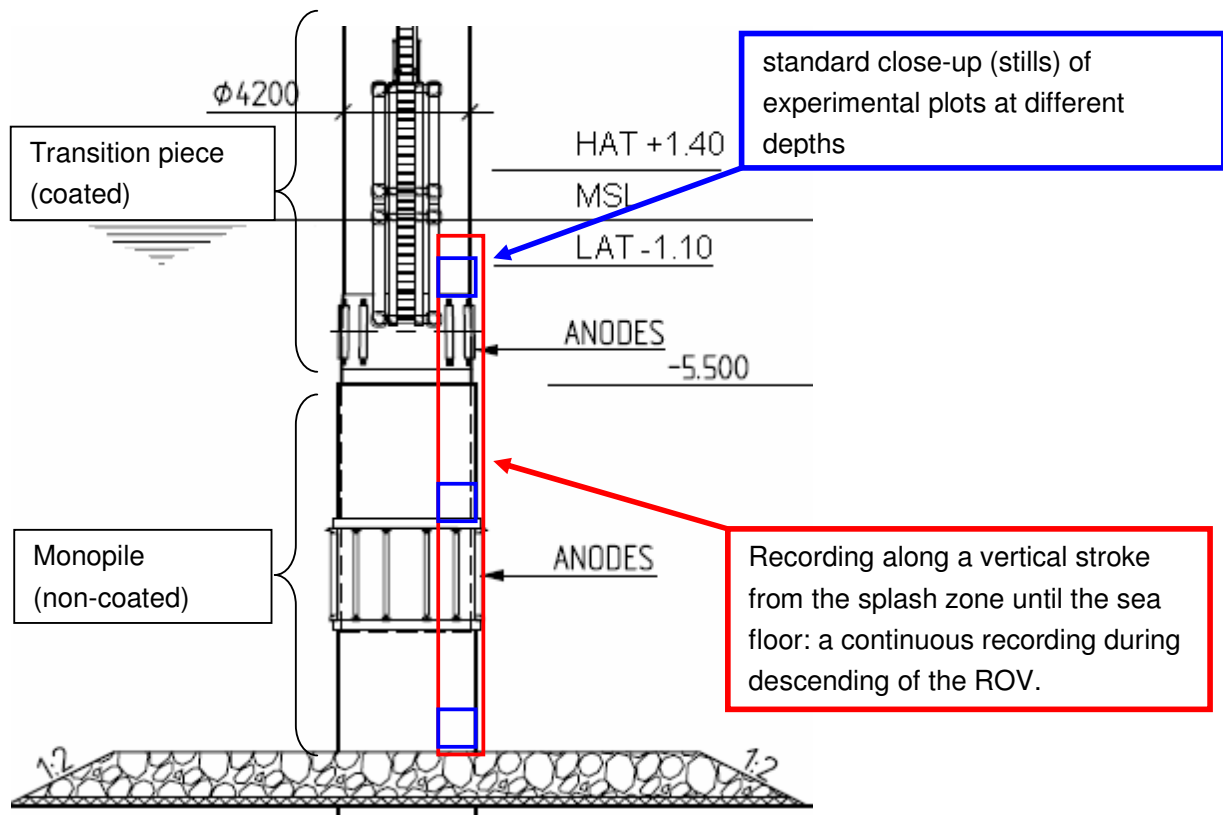


Figure 1. Schematic view on the submerged part of the monopile and OWEZ foundation. The surface to be recorded for the monitoring of biofouling, i.e. a single narrow vertical stroke that is perpendicular to the monopile axis is marked in red. The experimental plot surfaces for making close-ups / stills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

All the tasks for this monitoring have been carried out from the survey boat 'Nautical Server', 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 were carried out Wals Diving & Marine Service based in IJmuiden. The monitoring took place from the survey boat 'Nautical Server' (Annex C). This boat provides a fast transport to and from the OWEZ wind park. In order to keep the support vessel in position at the WTG's, no anchors are needed. The survey boat was tied up to the WTG by means of landing ropes. The survey boat stays stable in the wind/current at the gauge side of the masts.



Figure 2. The 'Nautical Server'.

The deployment of the ROV (Annex D) was done by means of the A-frame at the quarterdeck (figure 2, right picture). When the ROV was in the water, it was disconnected from the frame. The ROV pilot started the inspection sequence and based on his experience he decided which route of inspection will be followed taking current and waves and weather predictions in consideration. After the inspection the ROV was returned to the surface and connected to the A-frame to easily recover the ROV.

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 7° - 58°, camera tilt ± 90°). 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, varies depending on the distance from the object (monopile surface). The images were recorded on the hard disc of a DVD-recorder. At several depths, where significant changes in fouling were 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. After reaching the bottom (scour protection), the ROV was raised again with continuous recording of the images. The depth was recorded as the water column above the ROV.

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 of the different species / species groups that are present and recognised on the video recordings
- *Covering percentage*: From the video it is estimated of the total covering percentage 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 was 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 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.

During this monitoring, no samples of living fouling specimens from the monopile were taken. The grab sampler was mounted on the ROV, but as experienced during the first monitoring in 2007, due to movement in the water current and the round shape of the surface, it was too difficult to remove fouling specimens from the monopile surface. The dimension of the sampled area was therefore difficult to estimate.

An overview of the different fouling species is provided as well (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. This observation was depending on the quality of the images produced by means of the camera, i.e. depending on the general visibility (turbidity in sea water) and video image quality (focus and movement of ROV under water velocity conditions at the time

of recording). 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 during 2007 and 2008 (BuWa, 2008 and 2009).

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			
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 3 and 4, 2008.

The monitoring during the first year of operation (2007) was 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. The monitoring of 2008 took place at July 3 and 4 after the spat season, any new settled species and or specimens will be visible.

2 MONITORING BY KEMA, JULY 2008

2.0 Friday July 3 2008: monitoring WTG-07

On Friday July 3, the ROV monitoring of the turbine monopile WTG-07 took place. At low tide the ROV was lowered into the water to start the monitoring.

The upper layer, splash zone, was clearly covered with algae and barnacles. In the range from the water line to a depth of 5 metres, the surface was estimated to be covered with mussels for ~95 – 100 % (figure 3), some patches of yellow colour of the coating were visible. The mussel species were *Mytilus edulis* and likely *Mytilus galloprovincialis*, however, it was not possible to distinguish between the two mussel species based on the video images as the images do not allow to observe the specific features of each species. The mussels form a layer of a few centimetres up to 25 – 30 cm in thickness, with a roughness of 10 cm. Yellow patches of the coating of the transition piece were visible, probably due to small clusters of mussels that have fallen off the monopile surface. Many of the mussels seemed to be relatively small (young) as observed by their relative length, *i.e.* these likely settled during the second spat fall period during September 2007. On the mussels, common starfish (*Asterias rubens*) were foraging and anemones were observed as well. The ROV was then lowered to a depth of 8 m, the upper ridge of the second anode ring. During ascending, more fouling species were observed, such as plumose and other anemones (small clusters and individuals randomly spread over the surface). At depths below 8 – 9 m, only small numbers of mussels were present. Below 9 m, the relatively thin fouling layer existed in anemones, bryozoans, barnacles, hydroids and tube worms. In principle the total surface was covered by this fouling community (with the tube worms and hydroids as the main species) no fouling-free surfaces were observed. The thickness was estimated between 1 and 5 cm, depending on the species.

In the area below 14 – 15 metres, (lower ridge of the anode ring) the same fouling community as at a depth of 8 – 9 m was observed, covering the monopile surface 90 - 100% as some of the yellow coating was sometimes visible. The total depth was 20 metres onto the scour protection stones.

Annex A and B show an additional list of species and observations by Bureau Waardenburg (BuWa) at WTG-07. These samples were taken during the monitoring and sampling by divers for MEP-NSW (BuWa, 2008 and 2009). Mussels were found to be the most abundant species (average 2042 individuals per m² with a total biomass of 505 g afdw per m² (ash-free

dry weight)) followed by anemones (average 828 individuals per m²) and *Jassa* spp. (average 353 individuals per m²).



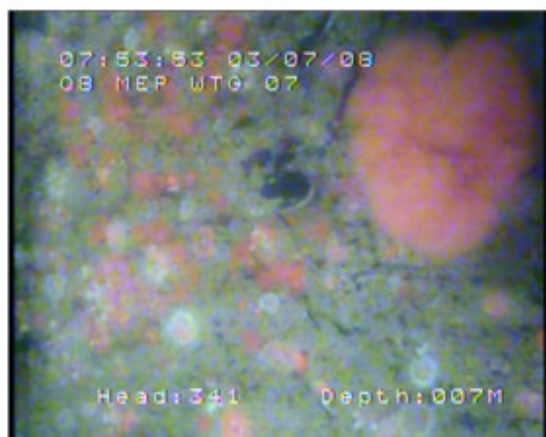
07:43:33

Top anode ring



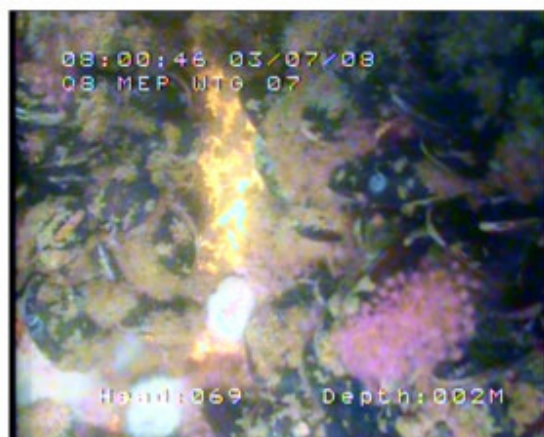
07:59:09

Anode transition piece



07:53:53

Monopile



08:00:46

Transition piece

Figure 3. Pictures of the fouling by means of the ROV recording at WTG-07, July 3 2008.

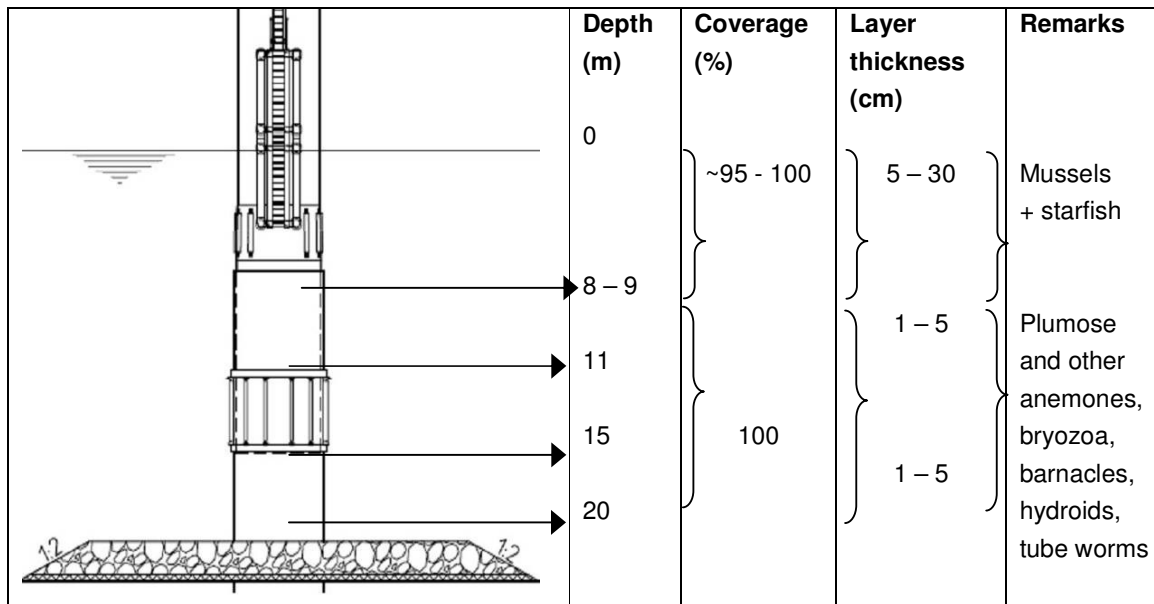
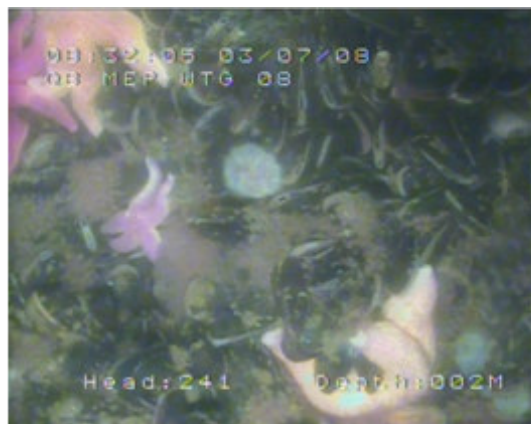


Figure 4. Summary marine growth at the WTG-07 (depth is water column above ROV).

2.1 Friday July 3 2008: monitoring WTG-08

On Friday July 3, the ROV monitoring of the turbine mast WTG-08 took place during the same tide as the monitoring of WTG-7. The marine growth at WTG-08 was found to be nearly similar to the marine growth at WTG-07, both in species observed as well as in the growth pattern and zonation. To a depth of 6 - 7 metres the fouling mainly existed in young mussels and foraging starfish. In this range the surface was estimated to be covered with mussels for ~90 – 95%. The mussel species formed a layer of a few centimetres up to 20 – 25 cm. At WTG-8, more yellow surface of the coating of the transition piece was visible in the first 6 metres. On the mussels, common starfish (*Asterias rubens*) were foraging and other species as plumose anemones were present as well. The ROV was then lowered to a depth of 12 m (upper ridge of the anode ring) along the surface of the monopile. Between 6 – 9 metres, many soft fouling species were present, among others plumose and other anemones, bryozoa, barnacles, hydroids, tube worms and also mussels. From 9 - 10 m and below, the abundance of mussels decreased instantly. It was not possible to exactly determine the species. The total surface was covered by this fouling community (100%), no clean surface areas were found. The thickness of the soft fouling was estimated between 1 – 5 cm. In the area below (15 – 20 metres, lower ridge of the anode ring to the bottom) the same fouling community was observed, covering the monopile surface 100%. Some larger clusters of *Metridium* were observed. The total depth onto the scour protection stones was 20 metres.



08:32:05

Transition piece



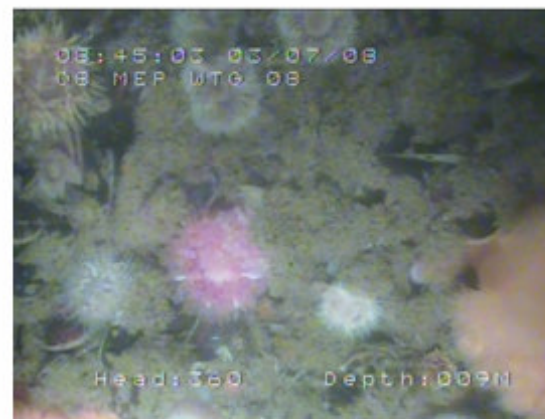
08:38:16

Bottom anode ring



08:33:24

Anode on transition piece



08:45:03

Monopile



08:35:50

Monopile

Figure 5. Pictures of the fouling by means of the ROV recording at WTG-08, July 3 2008.

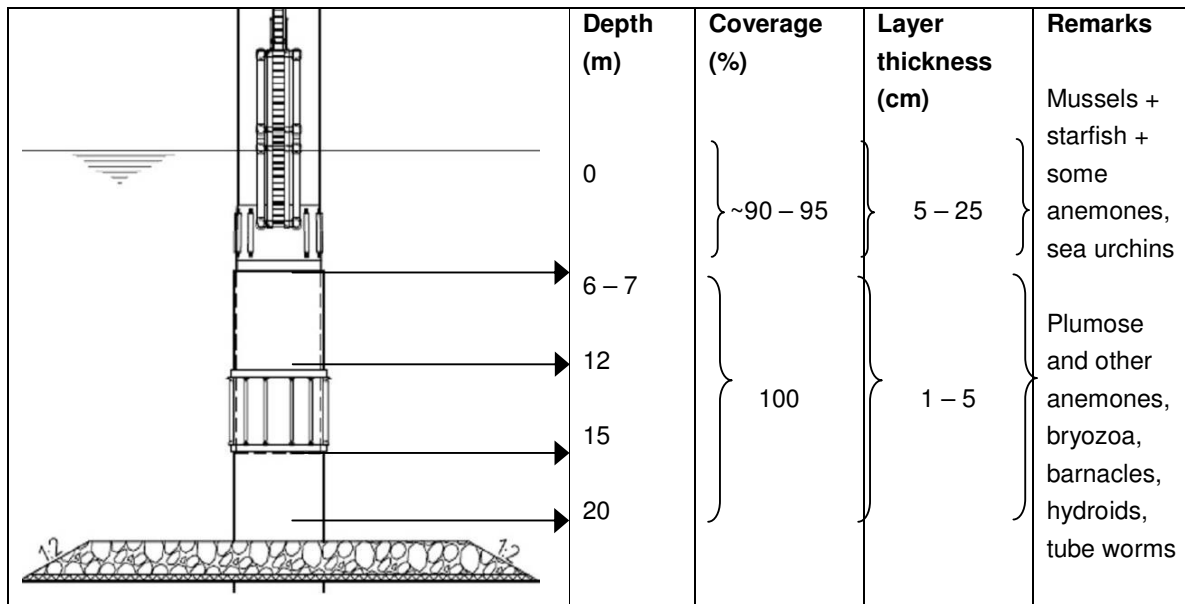


Figure 6. Summary marine growth at the WTG-08.

2.2 Saturday July 4 2008: monitoring MetMast

The ROV monitoring of the MetMast was performed on July 4th. At the transition piece, the fouling mainly existed in young mussels, covering the yellow coated surface for about 70 - 90% at the surface layer and up to 90% in deeper layers (figure 7). The thickness of the mussel fouling was estimated between 5 – 20 cm.

When reaching the ridge between the transition piece and the monopile (depth 4 m), the fouling significantly changed. The fouling existed in mussel clusters and in between the surface of the coated transition piece was visible (70 – 90% coverage of the surface), with some growth of barnacles. At the location of the anodes, mainly anemones, but also mussels, barnacles and sea urchins were observed. The thickness of the mussel fouling was estimated between 5 – 20 cm. At 5 m depth, there was almost no fouling present any more and the bare surface of the monopile was clearly visible. Also soft fouling was not present in high quantity, only a very thin layer is observed.

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 and sea urchins. Similar to the monitoring of 2007, a rather strange pattern of some kind of 'ridges' (figure 7) on the surface was observed as well, on which *Jassia* colonies seem to grow. Also light coloured and dark (black) coloured areas were

observed. On the darker areas more fouling was present, basically a thin layer of *Jassia* colonies and colonies of barnacles. Groups of sea urchins seemed to scavenge solely on these darker areas, as well as on the ridges. Anemones also grew on the darker areas. On the light areas, basically no fouling occurred at all. The thickness of the fouling (very small clusters) was estimated between 1 – 5 cm. In the area below (12 – 18 metres, lower ridge of the anode ring) the same very thin fouling community was observed, covering the monopile surface ~10 – 20%. In the lowest 4 m, the larger numbers of *Metridium* and plumose anemones were observed. The total depth was 25,5 metres onto the scour protection stones.



14:54:18

Transition piece



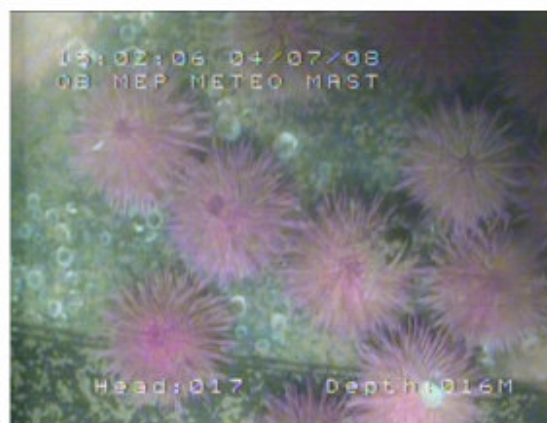
14:59:14

Monopile



14:57:10

Monopile near anode ring



15:02:05

Monopile near anode ring

Figure 7. Pictures of the fouling by means of the ROV recording at different depths.

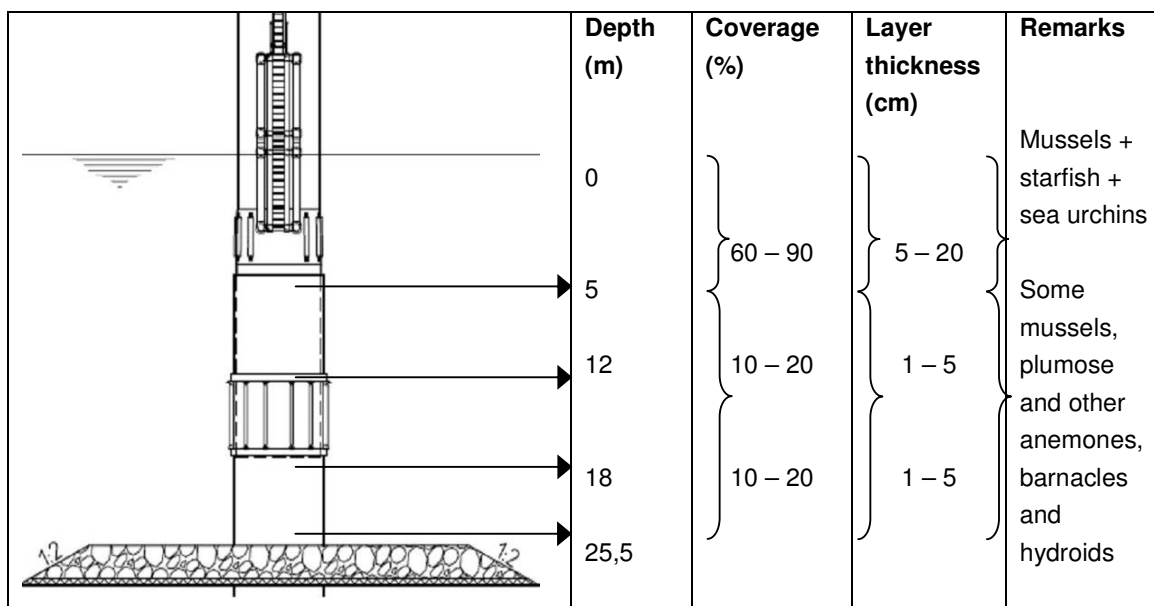


Figure 8. Summary marine growth at the MetMast.

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 °20' N (L15 closest to the coast). Platform F3 is the most northern platform and is located at about 54° 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 (*Mytilus 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.

Similar to the monitoring of 2007, it can be concluded from this second 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 is consisting in 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 occurred 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 second monitoring campaign do not differ much from the previous monitoring. The fouling has increased to some extent, *i.e.* a thicker layer of mussels due to growth and a further distribution of ~2 metres along the monopile surface to deeper areas.

3.2 Comparison fouling OWEZ with the Horns Rev offshore wind farm

As also mentioned in the BuWa reports (2008 and 2009), 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 sublittoral 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 and 2009) mention 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 has been carried out in February (end of winter period). However, the preliminary analyses indicate 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 the monopiles of WTG-07 and WTG-08 is found to be very similar, although the layer of mussel fouling extended a few meters deeper. 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. As during the first surveys, a clear zonation, i.e. vertical pattern in fouling composition is observed, in general due to particular abiotic conditions. The transition piece and upper anode ring location show large growth of dominantly mussels and little number of other species. During the second year of operation, the mussel fouling was found at lower levels than the first year. At lower depths (< 9 m) 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.

Similar to 2007, the marine growth on the MetMast still clearly differs from WTG-07 and WTG-08. A similar pattern of growth has been observed compared to the year before. The upper part showed an increase in mussel growth compared to 2007. However, below 4 m, the monopile was still largely 'clean', free from extensive marine growth and the bare material of the monopile was visible. The images do not indicate that physical stress (e.g. sandblasts during 'sand storms' during storms at sea) could explain this. There is still a strong indication that significant differences in surface characteristics or the material used cause the differences between the MetMast and WTG-07 and WTG-08.

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 a 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 than 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 30 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 could come loose from the surface, leaving open spaces where new marine growth can develop. It was indeed observed that patches of mussel fouling fell off the surface, 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 a limited number of these species have been observed so far and only at the MetMast manual cleaning has been performed.

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 9 metres below water level at WTG-07 and WTG-08 and the upper 4 metres at the MetMast. Here the hard fouling community, dominated by mussels, formed a relatively thick layer (up to 30 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 9 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:

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

Where ρ is the density of the medium (1000 kg/m³), V is the flow velocity C_D is the drag coefficient, D is the diameter of the cylinder and L its length. $L \gg D$ 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 $Re = VD/\nu$ and the surface roughness k/D . ν is the kinematic viscosity, approximately equal to 10⁻⁶ m²/s in water. In the case of the monopile for the V90 turbines (diameter approximately 4.5 m) the Reynolds number exceeds 10⁶ for flow velocities higher than a few decimeters a second. For this range of Reynolds numbers ($Re > 5 \cdot 10^5$) 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**

Compared to the first monitoring in 2007, a clear zonation is still present as observed by the presence of different fouling communities at different depths. The fouling has increased in terms of layer thickness of the mussel fouling (only upper part of the monopile) and some extension (~2 metres) to deeper areas of the mussel fouling. The existing fouling community has settled formed on the coated surface of WTG-07 and WTG-08. The uncoated monopile of the MetMast is only slightly fouled. During the visual observations of the recordings, it was observed that the thickest fouling layers are formed by mussels, forming a relatively thick layer up to 30 cm. The mussels are present which extend to a depth of 4 metres (MetMast) to 9 metres (WTG-07 and WTG-08). 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 30 cm. With an average surface roughness of 10 cm, the increase in drag coefficient is a factor of 2.4, between smooth and rough. The observed roughness has a relative small effect on the drag. The effect of the thickness itself is small.

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ANNEX A SPECIES OBSERVED BY BUREAU WAARDENBURG

By Bureau Waardenburg (BuWa, 2008 and BuWa, 2009), 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 is reported separately.

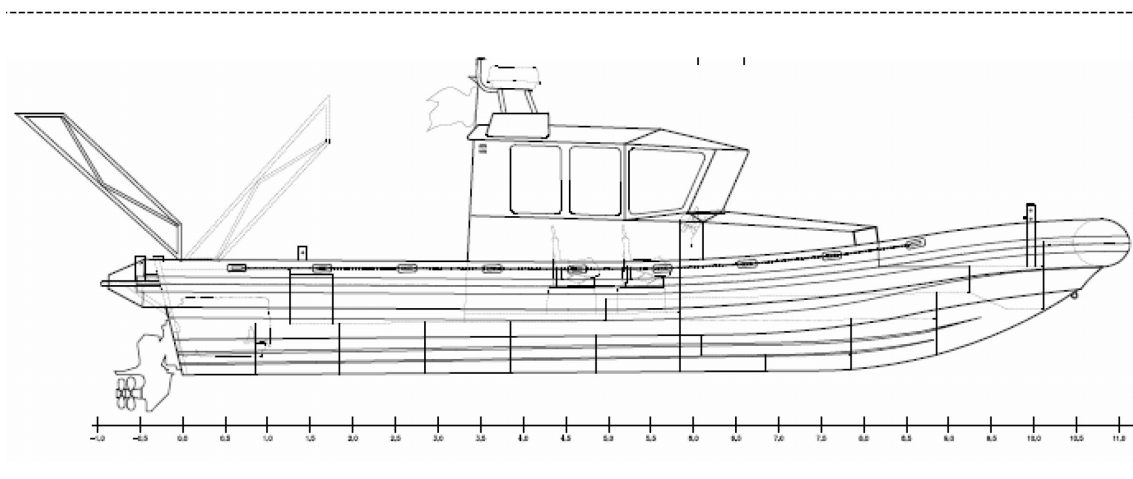
Species observed at WTG-07	English name	2007 (BuWa, 2008)	2008 (BuWa, 2009)
Green algae			x
Anemones (Cnidaria)			
<i>Diadumene cincta</i>	orange anemone	x	x
<i>Metridium senile</i>	plumose anemone	x	x
<i>Sargatia</i> spp.		x	x
Barnacles (Crustacea)			
<i>Balanus crenatus</i>	crenate barnacle	x	x
<i>Semibalanus balanoides</i>	rock barnacle	x	x
Molluscs			
<i>Crassostrea gigas</i>	Japanese oyster	x1 (1 adult)	x
<i>Mytilus edulis</i>	common mussel	x	x
<i>Aeolidiella glauca</i>	(marine nudibranch)		x
Crustacea			
<i>Caprella linearis</i>	skeleton shrimp	x (1 individual)	x
<i>Corophium volutator</i>	mud shrimp	x	x
<i>Idotea balthica</i>	Aquatic sowbug		x
<i>Jassa</i> spp.		x	x
<i>Pilumnus hirtellus</i>	hairy crab	x (1 individual)	x
<i>Pisidia longicornis</i>	Porcelain crab		x
<i>Cancer pagurus</i>	Northsea crab		x
Echinodermata			
<i>Asterias rubens</i>	common starfish	x	x
<i>Psammechinus miliaris</i>	Green sea urchin		x
Bryozoa			
<i>Conopeum reticulum</i>	sea mat	x	x
Hydroids			
<i>Tubularia larynx</i>	ringed tubularia	x	x
<i>Obelia</i> spp.		x	x
Worms			
<i>Lepidonotus clava</i>	scale worm	x	x
<i>Annelida</i> (multiple species)		x	x
<i>Nereis</i> spp			x

ANNEX B OBSERVATIONS BY BUWA DURING THE MONITORING OF 2008 (BUWA, 2009)

In February 2008 the hard substrate community dominated by mussels and associated species occurred to approximately 6 m depth. Covering percentages of mussels in the zone from the surface to approximately 6 m depth varied between 80-100% and only a few bare patches colonized by (tubes of) *Jassa* spp. and anemones were present. At 6-7 m depth mussels became scarcer and the second hard substrate community dominated by (tubes of) *Jassa* spp., anemones and patches of the orange anemone *Diadumene cincta* and the ringed tubularia *Tubularia larynx* takes over. Tubes of *Jassa* spp. Were most dominant (covering percentages between 40-80%) followed by the plumose anemone *Metridium senile* (covering percentages between 5-30%) and *Sargartia* spp. anemones (covering percentages between 5-25%). The orange anemone *Diadumene cincta* and the ringed tubularia *Tubularia larynx* were also common, but occurred in patches (covering percentages less than 5%). Other less common species identified on the monopile of turbine 7 included the Japanese oyster (*Crassostrea gigas*), the skeleton shrimp (*Caprella linearis*) and the hairy crab *Pilumnus hortellus*.

In September 2008 the intertidal area to approximately 0,5 m depth was colonised by green algae (*Ulva* spp. and/or *Enteromorpha* spp.). Below 0,5 m depth the hard substrate community dominated by mussels and associated species has expanded to approximately 10 m depth. Growth of mussels has become more dense and the bare patches in between the mussels present in February 2008 are now colonized by mussels (covering percentage 100% to 10 m depth). In between the mussels plumose anemones, *Sargartia* spp. anemones and patches of the orange anemone *Diadumene cincta* are common and some starfish are present. At 10-14 m depth mussels become scarcer and the community dominated by plumose anemones (covering percentages between 30-40%), *Jassa* spp. (covering percentages between 40% and 60%) and patches of the orange anemone *Diadumene cincta* (covering percentages between 5- 10%) is recognised. This community is dominant from approximately 12-13 m depth to the seafloor (circa 17 m depth), but patches of mussels still occur to depths of 15 m. Six new species were identified on the monopile of turbine 7: green algae, the aquatic sowbug (*Idotea balthica*), the porcelain crab (*Pisidia longicornis*), the velvet swimming crab (*Necora puber*) (common at all depths), the Northsea crab (*Cancer pagurus*) (one individual seen on video at 15 m depth) and the green sea urchin (*Psammechinus miliaris*).

ANNEX C SURVEY BOAT 'NAUTICAL SERVER'



„NAUTICAL SERVER“

GENERAL

Type of Vessel	Techno Marine TM-1226 Cabin twin inboard
Basic functions	Survey/Supply/Crew boat
Building year	2008
Classification	MCA Cat.2

DIMENSIONS

Length o.a.	11,95 m
Beam o.a.	3,96 m
Designed draft	0,70 m
Displacement	8,00 metric tons
Boat weight	5,00 Ton

TANK CAPACITIES

Fuel oil	1680 Ltrs
Fresh water	150 Ltrs

PERFORMANCES

Maximum speed	40,00 Knots
Cruising speed	32,00 Knots

SAFETY EQUIPMENT

Life raft	12 persons
Crew finder	6 persons
Solas B box	Raymarine
SAR equipment	

PROPULSION SYSTEM

Main engines	2 Volvo D6 370hp each
Propulsion	2 Volvo stern drive duo props

AUXILIARY ENGINE

Generator	220V 8 KVA
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ACCOMMODATION

Wheelhouse including space for survey equipment.
Accommodation for 6 persons, toilet

NAUTICAL EQUIPMENT

Radar	Raymarine
GPS chart plotter	Raymarine
Echo sounder	Raymarine
VHF	

ANNEX D ROV TECHNICAL INFORMATION**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, $\pm 90^\circ$ 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 $\pm 90^\circ$
 Built-in video switch for 2nd Camera
 1,000 m (3,300 ft) rated, recessed and hardened port

Instrumentation

Fluid-gimbaled fluxgate compass. Accuracy: $\pm 3^\circ$
 Electronic depth gauge. Accuracy: $\pm 1\%$ 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