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Biological Fouling
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Survey of marine fouling on turbine support structures of the Offshore Windfarm Egmond aan Zee, June 2009

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SUMMARY

This survey report on biological fouling (NZW-MEP task 1.1.2) describes the findings during the 3rd monitoring of marine fouling in the OWEZ windfarm during the third year of operation in 2009. This monitoring has been performed at June 14, 2009.

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 third 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 and second monitoring (2007 and 2008), but the extent of fouling after three years of operation has increased. There is still a clear zonation in fouling communities, which is found at the three monitored monopiles: WTG-07, WTG08 and the MetMast, however, there are clear differences between the 3. The upper zone is dominated by mussel fouling community down to a depth of 15 m, even 24 m (bottom) at the MetMast, which exists in a relative thick layer up to 25 – 30 cm. The mussel fouling in the upper layer as extended (towards lower areas). Below 15 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 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 time clusters of mussels get loose from the surface and

the yellow colour of the coating becomes 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 still might be an influence on corrosion when the coating is damaged due to natural or manual/mechanical removal of fouling species, especially those 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

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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.

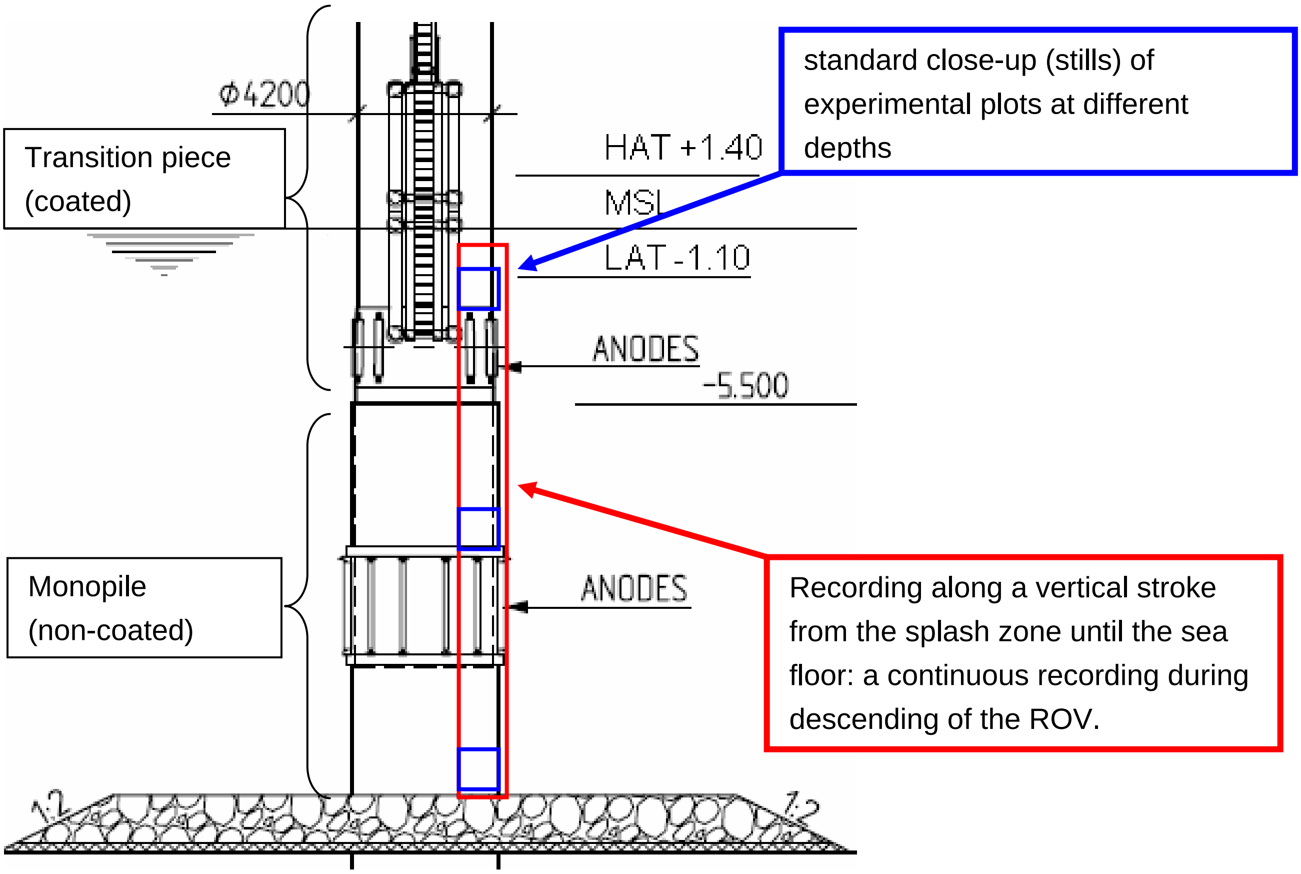


Figure 1 Schematic view on the submerged part of the monopile and OWEZ foundation. The surface to be recorded for the monitoring of biofouling, i.e. a single narrow vertical stroke that is perpendicular to the monopile axis is marked in red. The experimental plot surfaces for making close-ups / stills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

1.1 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 survey boat ‘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 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, 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 where visually observed or other interesting and notable observations where 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 were 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.

Similar to the observations during 2007 and 2008, the thickness of the biological fouling and size of the specimens 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 very well possible to compare the results of each monopile.

During this monitoring, no samples of living fouling specimens from the monopole were taken. The grab sampler was not mounted on the ROV, since it had been experienced during the previous monitoring sessions (2007 and 2008), it was too difficult to remove fouling specimens from the monopile surface due to movement in the water current and the round shape of the surface.

An overview of the different fouling species is provided as well (Annex A and B). 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). During this monitoring (2009) visibility was very good. 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).

1.2 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 of the 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 2008.

**** the monitoring for 2009 took place in the second week of June 2009

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. The monitoring of 2008 took place at July 3 and 4, the monitoring of 2009 at June 14.

2 MONITORING BY KEMA, JUNE 2009

2.1 Sunday June 14 2009: monitoring WTG-07

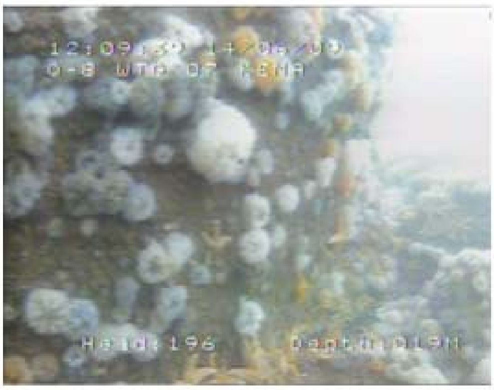
On Sunday July 14th, the ROV monitoring of the turbine monopile WTG-07 took place. At low tide the ROV was lowered into the water.

In the range from the water level to a depth of 15 metres, the surface was covered with a thick, compact layer of mussels for ~100 % (figure 3), no patches of yellow colour of the coating were visible. The mussel species existed in *Mytilus edulis* and likely *Mytilus galloprovincialis* was present as well, however, it was not possible to distinguish between the two mussel species based on the video images as the images did not allow to observe the specific features of each species. The mussels formed a layer up to 30 cm in thickness. Many of the mussels seemed to be relatively small (young), especially on the J-tube small mussels were observed. These had likely settled during the spat fall period during spring 2009. On the mussels a thin layer of mud/soft fouling was observed, possibly *Jassa*, as well as small barnacles, but not below a depth of 6 m. The common starfish (*Asterias rubens*) were foraging on the mussels in very small numbers. Hereafter the ROV was lowered to a depth of 10 m, the upper ridge of the second anode ring. A thick layer of mussels was observed, the anodes were fully overgrown and hardly recognizable, nor any of the other functional structures that are mounted on the monopile.

During descending, at 11 m some soft fouling species were observed on the mussels, among others plumose and other anemones (small clusters and individuals randomly spread over the mussels). At depths below 14 - 15 m, more soft fouling species were observed on the mussels, as well as many starfish. The relatively thin fouling layer existed in anemones, bryozoans, barnacles, hydroids and tube worms. Also the yellow colour of the coating became visible in some areas. In principle, the total surface was covered by this soft fouling community (with the tube worms and hydroids as the main species) only a very limited number of fouling-free surfaces were observed. The thickness was estimated between 1 and 5 cm, depending on the species. Below 16 m no clusters of mussels were found. Large communities of plumose and other anemones dictated this fouling community, covering the monopile surface 100%. The total depth was 20 metres onto the scour protection stones.

Annex A and B show an additional list of species and information 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). The average number of organisms on the monopile of WTG-07 as found by BuWa, was with 3263 individuals per m^2 comparable, but on this monopile mussels were most abundant (average 2042 individuals per m^2 with a total biomass of 505 g afdw per m^2 (ash-free dry weight) followed by anemones (average 828 individuals per m^2) and Jassa spp. (average 353 individuals per m^2).

12:03:27 Transition piece



12:09:39 On the seabed near monopile

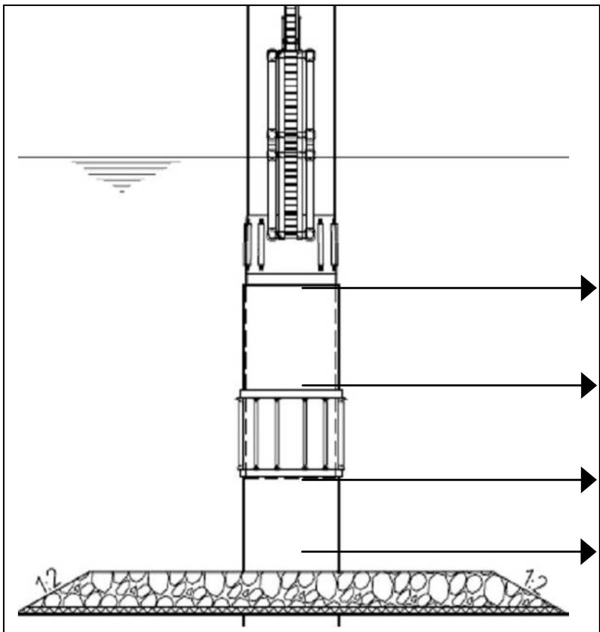
12:07:02 Continuity strip bottom anode ring

12:12:44 Lighting strip over fex joint

12:07:26 Bottom anode ring

12:14:58 J-tube

Figure 3 Pictures of the fouling by means of the ROV recording at WTG-07, June 14 2009.



Depth (m)	Coverage (%)	Layer thickness (cm)	Remarks
0			
	100	5 – 30	Mussels + starfish
5			
		5 – 30	Plumose
11	100		and other anemones,
15			bryozoa,
	~100	1 – 5	barnacles,
20			hydroids, tube worms

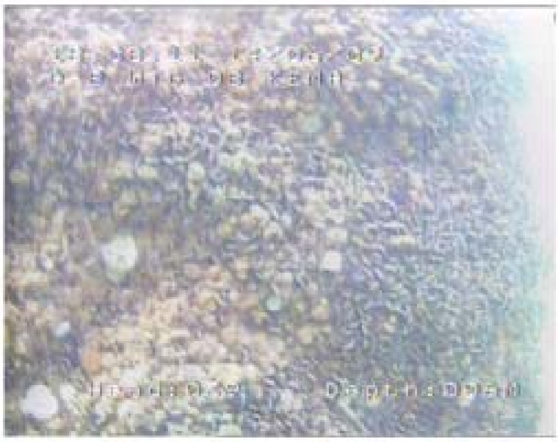
Figure 4 Summary marine growth at the WTG-07 (depth is water column above ROV)

2.2 Sunday June 14 2009: monitoring WTG-08

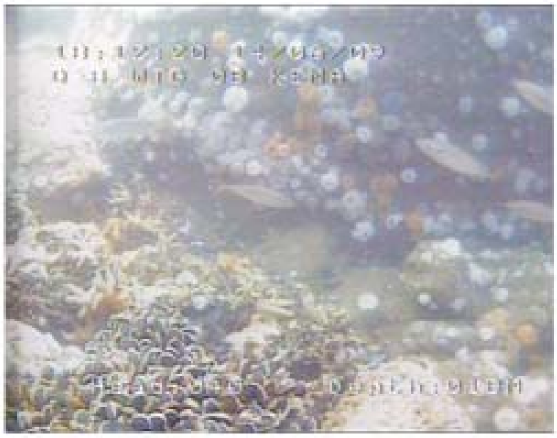
On Sunday June 14th, the ROV monitoring of the turbine mast WTG-08 took place during the same tide as the monitoring of WTG-7. The marine growth at WTG-08 was found to be nearly similar to the marine growth at WTG-07, both in species observed and in the growth pattern/zonation.

To a depth of 6 - 7 metres the fouling existed in a thick layer of mussels. In this range the surface was estimated to be covered with mussels for ~100%. The mussel species form a layer of a few centimetres up to 30 cm. Below 7 m, the layer of mussels became thinner, up to 25 cm. Here, on the mussels, common starfish (*Asterias rubens*) were foraging and other species such as plumose anemones were present as well. At 15 m depth, the soft fouling and starfish number increased, and many empty mussel shells, predated by the starfish, were observed.

In the area below (16 – 18 metres) less mussels were observed and the fouling community was dominated by soft fouling, covering the monopile surface for 100%. Some larger clusters of *Metridium* were observed. The total depth was 18 metres onto the scour protection stones. However, on these stones clusters of mussels were growing as well.



18:08:11 Transition to monopile crossing



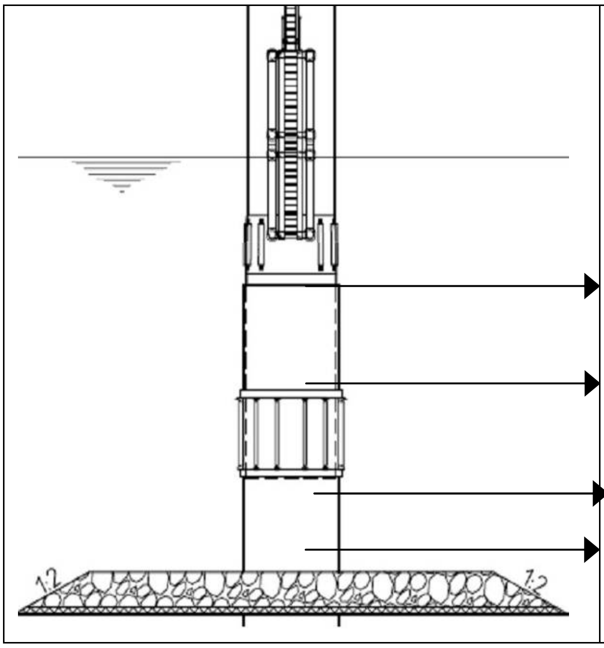
18:12:19 On the scour protection

18:08:57 Top side anode ring

18:13:08 J-tube

18:11:03 Monopile

Figure 5 Pictures of the fouling by means of the ROV recording at different depths



Depth (m)	Coverage (%)	Layer thickness (cm)	Remarks
0			Mussels + starfish + some anemones, sea urchins
	100	10 – 30	
6			
12	100	10 – 25	Plumose and other anemones, bryozoa, barnacles, hydroids, tube worms
16			
	100	1 – 5	
18			

Figure 6 Summary marine growth at the WTG-08

2.3 **Sunday June 14 2009: monitoring MetMast**

At the transition piece, the fouling mainly existed in young mussels, covering the yellow coated surface for almost 100% at the water level and up to 90% in deeper layers (figure 7) to about 3 m depth. On the mussels soft fouling, probably *Jassia* were present The thickness of the mussel fouling is estimated between 10 – 30 cm.

When reaching the ridge between the transition piece and the monopile (down to 5 m), the fouling significantly changed. The fouling existed in mussel clusters. On the anodes, mainly mussels and some anemones and the common starfish are observed. The thickness of the mussel fouling was estimated between 5 – 20 cm. At 5 m depth and below, there was almost no fouling present and the surface of the monopile was clearly visible. Also soft fouling was not present in high quantity, only a very thin layer. However, on the J-tube and some areas (most probably the darker areas on the surface of the monopile as observed during the survey of July 2008), the anodes and any other structure attached to the monopile were covered with fouling. The J-tube is mainly covered with very young mussels and a layer of soft fouling. The mussel fouling and soft fouling (mainly small clusters of anemones) was observed down to the bottom, mainly on the J-tube and other small structures where it was able to grow, following the particular pattern on the surface (figure 7).. The total depth was 24 metres onto the scour protection stones.

18:56:47 J-tube first anode ring

19:00:14 Aditional J-tube/bell mouth

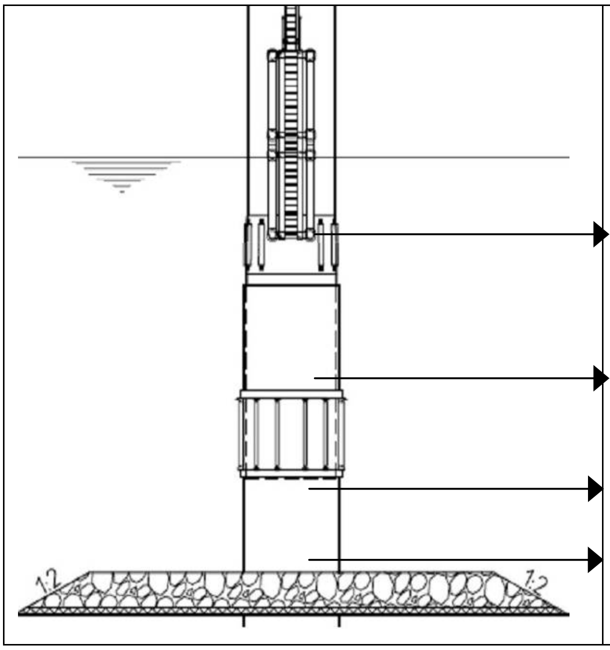
18:57:03 Anodes first anode ring

19:01:33 3rd anode ring

18:59:07 Monipile

19:06:47 Surface monopile

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



Depth (m)	Coverage (%)	Layer thickness (cm)	Remarks
0	100	10 – 30	Mussels + starfish + anemones
4	60 – 80	10 – 30	
14	10 – 20	5 – 20 *	Some mussels, plumose and other anemones, barnacles and hydroids*
21	10 – 20	5 – 20 *	
24			

Figure 8 Summary marine growth at the MetMast. On the J-tube and other structures, high numbers of fouling are observed. The surface of the monopile itself is mostly free from fouling. * only growth at structures where the fouling was able to grow, not no the surface of the monopile

2.4 Fouling development in the OWEZ from 2007 – 2009

The fouling development on WTG-07, WTG-08 and the MetMast in the OWEZ windfarm in the period 2007 – 2008 is summarized in figures 9 - 11. It is clear for monopiles WTG-07 and WTG-08 that the hard fouling, mainly by mussels, has extended to deeper areas, from only the first few meters below the surface in 2007 to over half the water depth in 2009. Also, the thickness has increased, which can be explained both by growth of specimens as well as colonisation of specimens after the spawning season on top of the existing mussel population. Only the MetMast shows a rather consistent fouling of mussels, as on this monopile the mussel population does not extend to deeper areas in time. This is likely explained by the surface characteristics which are suspected to play an important role, *i.e.* the surface of the MetMasts' monopile shows a typical pattern and hardly any fouling is present. For all three monopiles, the soft fouling community has not changed in thickness, which was expected because these species live next to each other and are not able to settle on top of each other. The lower part of the monopile of the MetMast has shown little change, *i.e.* after 3 years the surface is still relatively clean compared to the other monopiles and the same patched pattern is still visible.

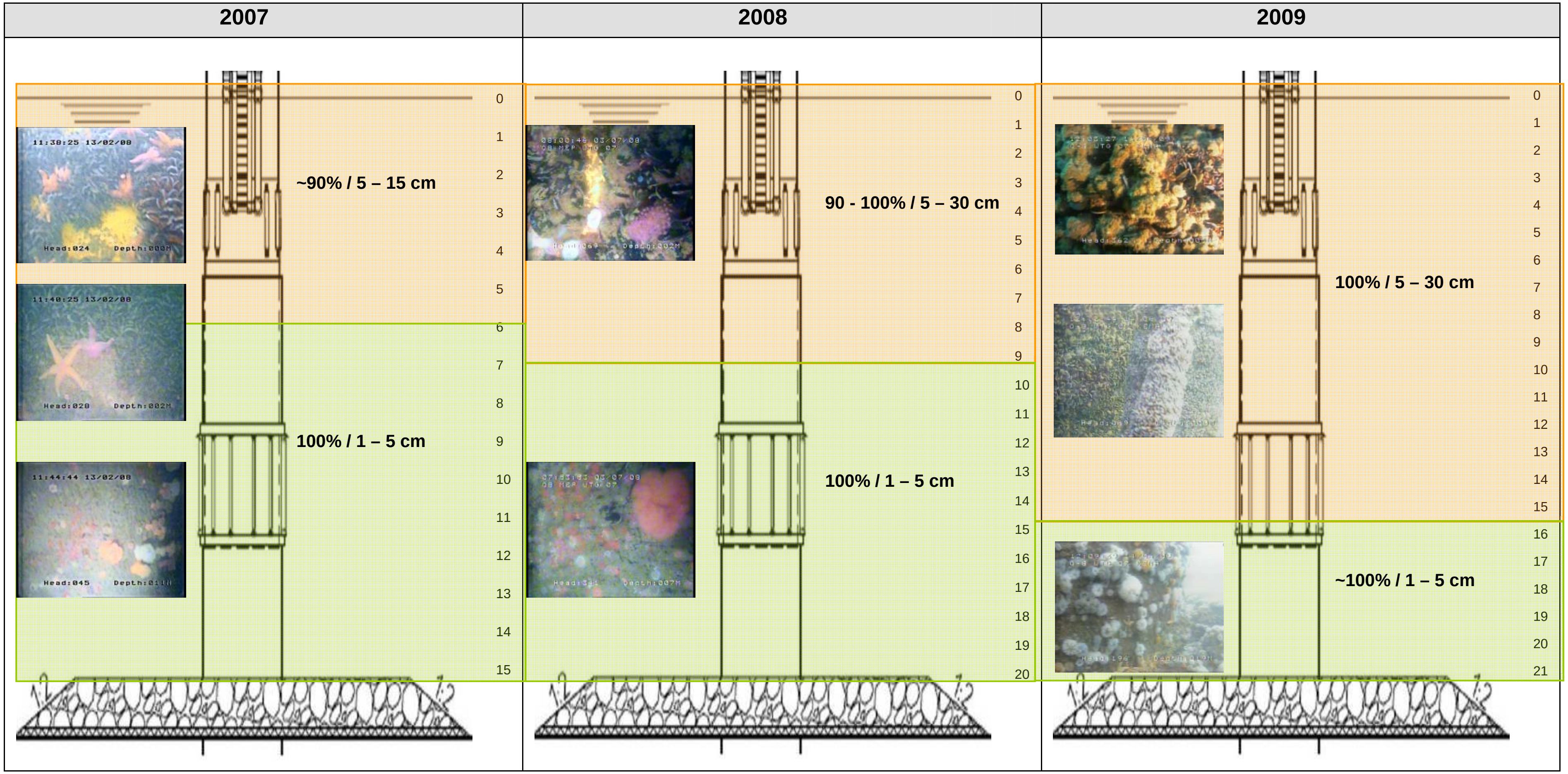


Figure 9 Fouling development during 2007, 2008 and 2009 at monopile WTG-07

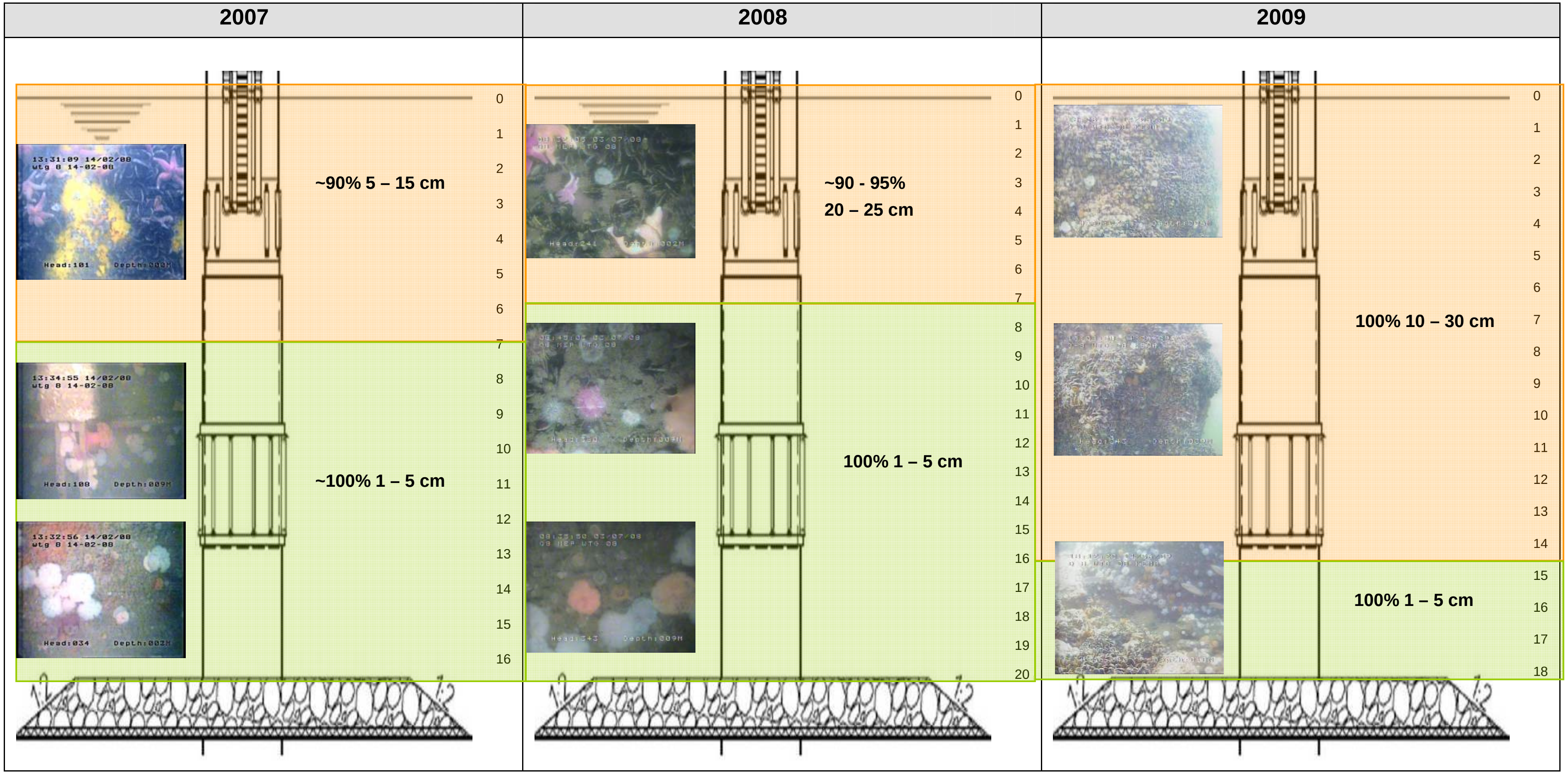


Figure 10 Fouling development during 2007, 2008 and 2009 at monopile WTG-08

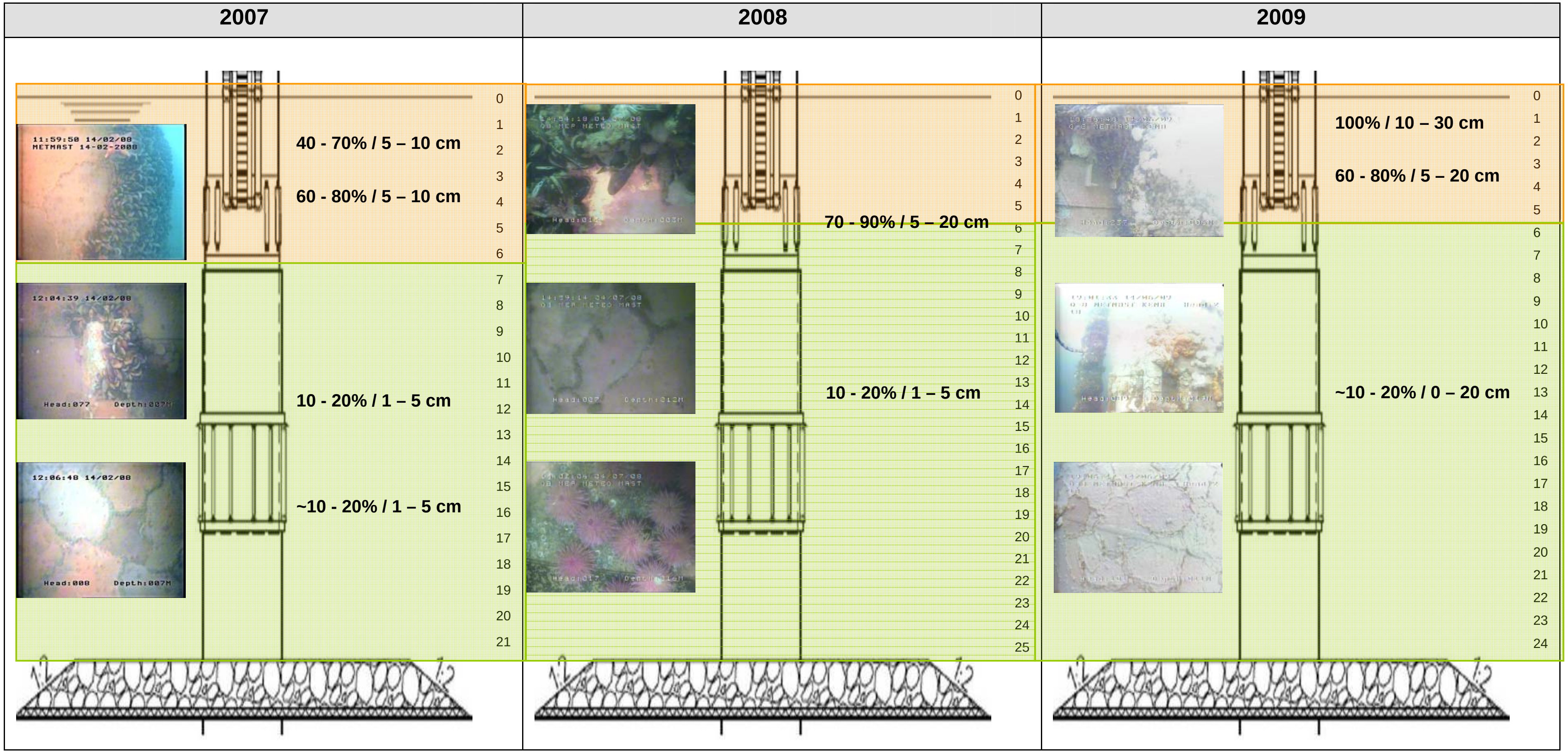


Figure 11 Fouling development during 2007, 2008 and 2009 at the MetMast

The abundance of different species (species community) has not changed during the successive years, although differences in composition (community structure, combination of species and relative abundance) shows some differences although not very clear. This could be a seasonal effect.

The extension of hard fouling to deeper layers as well as the increase of roughness of the surface due to the thicker layer varying from almost no fouling up to 30 cm, will have an increasing effect on the drag on the monopiles. However, it was calculated that the total effect of this roughness is not very high. Also, the mussel fouling seems to regulate itself as there is a strong indication that clumps of mussels get loose from the surface. There is also regulation of the mussel fouling by predation by starfish. It is not expected that the total layer thickness will increase much during the coming years. However, species composition may change. In the event more fouling by the Japanes oyster (*Crassostrea gigas*) develops, this may have a large impact since these species cement themselves to surfaces and are hard to remove and do not get loose from the surface such as mussels do. Also, adult specimens of the Japanese oyster are large (~30 cm) and are able to form reef-like structures. It is therefore recommended to follow the potential development of fouling during the coming years and if necessary, clean the surfaces.

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

3.1 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.

3.2 **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.

Similar to the monitorings of 2007 and 2008, it can be concluded from this third 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 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 third monitoring campaign in the OWEZ windfarm do not differ much from the previous monitorings (2007 and 2008). The fouling by mussels has increased however, *i.e.* a thicker layer of mussels due to growth and a further distribution of about 5 metres along the monopile surface to deeper areas.

3.3 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 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.

In BuWa (2008 and 2009) it is mentioned 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

4.1 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 heavily grown with fouling, down to a depth of 15 m. 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 extensive growth of fouling by dominantly mussels and a small 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 ~100% coverage by marine growth, the monopiles showed nearly 100% coverage.

The marine growth on the MetMast differs from WTG-07 and WTG-08, as was also observed during previous monitoring sessions during 2007 and 2008. At lower depths, on the monopile, it was observed that the metal surface was largely ‘clean’, only small patches of extensive marine growth was present and the bare material of the monopile was visible. It was observed that any fouling mainly occurs on what was observed during the monitoring of July 2008 at darker areas, as well as on structures mounted on the monopile, like the J-tube and anodes. On the lighter areas, still no fouling was found. As the MetMast is placed already during 2003, and has therefore a longer fouling history, it was expected that the marine growth would be more extensive than at WTG-07 and WTG-08. It is not clear why these differences exist.

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.

4.2 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 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 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.

4.3 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). As this layer has increased down to 15 m, the effect on the drag will have increased as well.

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.

4.4 Conclusions

Similar to the monitoring sessions in 2007 and 2008, a clear zonation is present as observed by the presence of different fouling communities at different depths. In 2009, the fouling has clearly increased in terms of layer thickness of the mussel fouling and extension to deeper areas of the mussel fouling (down to 15 meters). It is clear that the new settlement of young mussels during spring 2009 has been intensive.

The existing fouling community has settled formed on the coated surface of WTG-07 and WTG-08. The uncoated monopile of the MetMast is still only slightly fouled, mainly on the structures mounted on the monopile such as the J-tube and anodes. 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 5 metres (MetMast) to 15 metres (WTG-07 and WTG-08). At lower depths far less mussels are present. It was again 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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APPENDIX I SPECIES OBSERVED BY BUREAU WAARDENBURG

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

APPENDIX II OBSERVATIONS BY BUWA DURING THE MONITORING OF 2008 (BUWA, 2009)

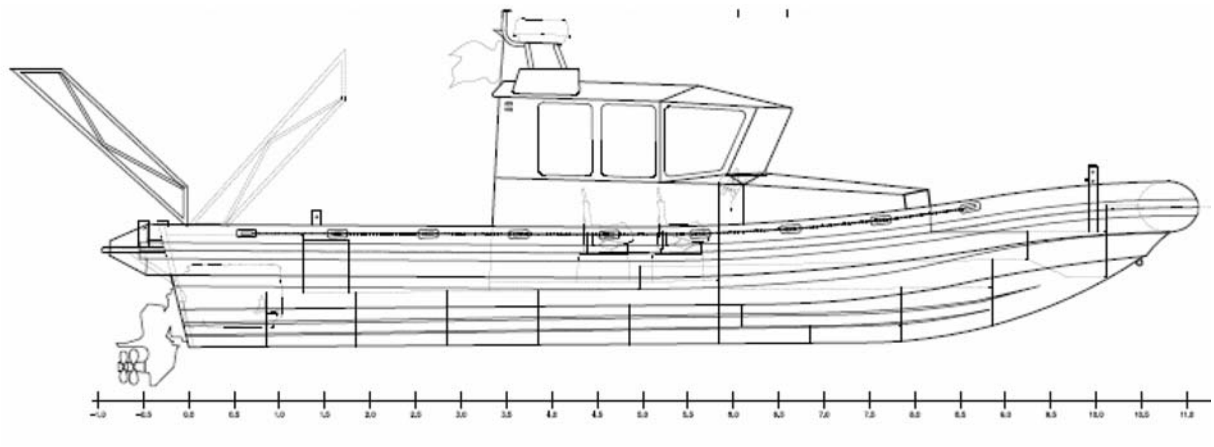
No monitoring by BuWa took place during 2009, therefore the observations made during 2008 are mentioned here.

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 colonised 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 laryn*x 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 *Pilimnus 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 denser and the bare patches in between the mussels present in February 2008 are now colonised 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*).

APPENDIX III SURVEY BOAT 'NAUTICAL SERVER'

WALS
diving & marine-service



„ 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	Raymarine
Solas B box	
SAR equipment	

PROPULSION SYSTEM

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

AUXILARY ENGINE

Generator	220V 8 KVA

ACCOMMODATION

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

NAUTICAL EQUIPMENT

Radar	Raymarine
GPS chart plotter	Raymarine
Echo sounder	Raymarine
VHF	

APPENDIX IV 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.

Appendix IV page 2

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

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