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Biological Fouling
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Pre-survey of marine fouling on turbine support structures of the Offshore Windfarm Egmond aan Zee

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By order of Noordzeewind

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SUMMARY

This pre-survey report on biological fouling (NZW-MEP task 1.1.2) covers a description of the methodology, the results of the pre-survey into existing knowledge and approach of monitoring.

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

From literature an oversight is provided on the fouling that can be expected on man-made structures in the North Sea. Important aspects are among others geographical location, species composition, zonation and succession of the fouling community during successive years. The results provide a proper oversight of the fouling that can be expected on the monopiles of the Offshore Windfarm Egmond aan Zee (OWEZ). The type and extent of fouling is location specific. The extent of fouling (biomass) and species composition and succession is determined by influence of both abiotic and biotic parameters, i.e. temperature, turbidity, sand scour, larvae abundance, et cetera. Two studies in the Dutch coastal zone provide information on which an expectation for the fouling at the OWEZ can be based. These studies concern off shore NAM-platforms and artificial reefs.

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 is 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, existing in anemones and hydroids, although growth of soft fouling species might limited by any sand scour.

The yearly monitoring will show the exact fouling composition and succession.

1 INTRODUCTION

Biofouling is the undesirable attachment of organisms to a man-made surface within an aquatic environment. The surfaces immersed in an aquatic environment experience a series of physical, chemical and biological events. The development of biofouling communities follows a pattern of colonisation and succession. Initially, a substrate becomes coated with a film composed of organic matter, proteins, polysaccharides and inorganic substances and ions. The form this 'conditioning' film takes is dependent on the chemical and physical surface properties of the substrate. The film attracts primary and secondary colonisers onto the surface and these form the microfouling community. Microfouling organisms include bacteria, diatoms, algal spores and protozoa. Following this stage, the larvae and spores of tertiary colonisers such as seaweeds, mussels, barnacles and sea squirts begin to settle and as they grow and develop they form the macrofouling community. Adult macrofouling organisms must attach to a substrate to feed, grow and reproduce. Offshore installations make ideal attachment surfaces.

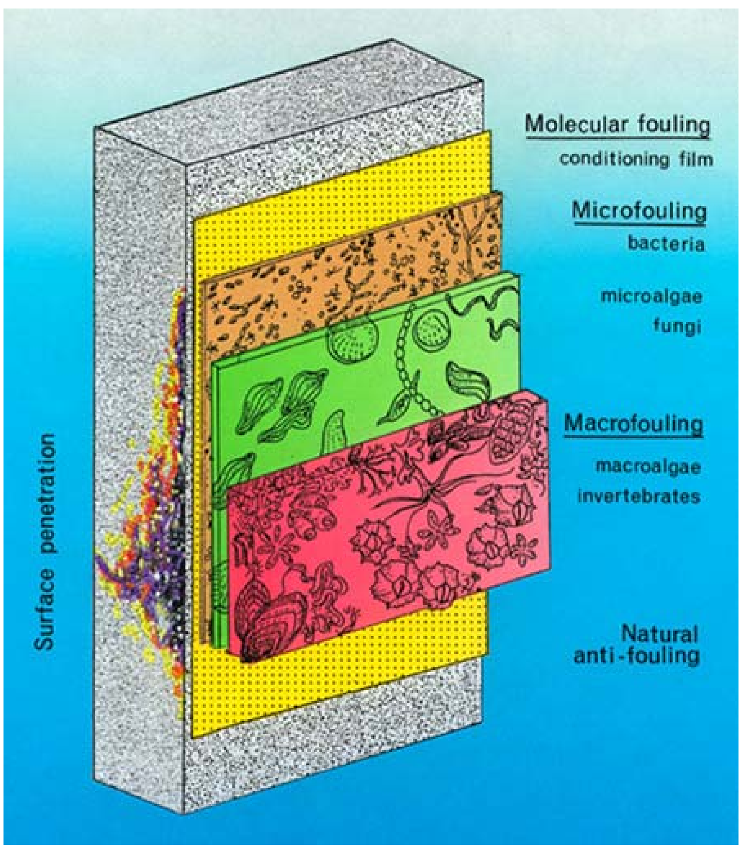


Figure 1 Schematic view on the four main stages of marine biofouling (NERC News 1995)

Thus offshore wind farms provide hard attachment sites for an array of sessile animal species, including barnacles, mussels, scallops, tunicates, bryozoans, and sea anemones. Patterns of colonisation and succession in biofouling communities within temperate regions are highly affected by seasonality. This seasonality is reflected in changes in both the quantity of biofouling and species composition of these communities.

The windfarm is situated offshore Egmond. This is a sandy, high energy coast with occasional hard structures. Nearby artificial hard structures are the jetties of IJmuiden and the northerly sea defence dike (Groet-Petten). Natural hard structures are formed by morene stones and washed out peat layers.

Moreover, the farm is situated in the so-called coastal river, formed by the plume of the river Rhine. As a consequence the water can vary between salt and brackish (30-20 ‰) and even been stratified (with salt at bottom and light brackish at top during periods of high river flow and south western winds). The seawater source is the Channel.

On top, the area is highly variable in nutrients, turbidity (silt) and sand erosion (during storms).

The above will greatly determine the fouling that can be expected on the new structures.

Biofouling may have a negative effect on man-made structures deployed in marine waters, i.e. cooling water systems of offshore power generation or fire fighting systems. Biofouling may also impact on stability of structures. Marine biofouling may become of commercial significance and can have a number of additional effects on offshore installations. The main consequences of marine fouling in general include:

- obscuration of structures, resulting in extended inspection and non-destructive evaluation time
- obscuration of marker signs
- creation of microenvironments that may encourage corrosion
- additions to weight loading
- increased hydrodynamic loading.

Each of these factors has cost implications in relation to the inspection, maintenance and repair of offshore installations.

1.1 Aim of the pre-survey

The goal of the monitoring is to investigate if biological fouling in the OWEZ wind farm has a different pattern, compared to what can be expected based on existing knowledge. The aim is to deliver information on the nature and thickness of the fouling on turbine support constructions, as a function of time (mandatory approach). It holds the framing of an assessment of the (succession of) species composition and the expected biomass through the successive years.

The first phase of construction of the wind farm has started in spring 2006. Before the fouling surveys activities will take place, a baseline description of the fouling on offshore structures will be conducted as a part of the NSW-MEP monitoring programme on biological fouling.

This report covers a description of the methodology, the results of the pre-survey and approach of monitoring.

2 DESCRIPTION OWEZ LOCATION AND EXISTING KNOWLEDGE ON FOULING

2.1 OWEZ location in relation to fouling

The Offshore Windfarm Egmond aan Zee (OWEZ) by NoordzeeWind is located off the coast of Egmond aan Zee at the Dutch coastal zone of the Netherlands Continental Shelf (NCS). In the North Sea there is both a North to South gradient in the abundance of organisms (De Lange & Lummel, 1978) and a gradient East (close to the Dutch coastline) to West. Structures in the northern part of the NCS are influenced by the North Atlantic ocean water, structures in the south of the NCS by water from the Canal.

The East-West gradient is partly caused by the different distribution mechanisms of larvae. Colonisation of structures further away from the coast depends of the movement of the water (flow pattern). Structures close to the coast are in general more easily colonised as the rocky seashore, where the fouling species originate is closer by. Larvae of fouling species that originate for example from river-delta of Zeeland and the IJmuiden pier. These larvae are, as they are in plank tonic phase, passively distributed in the coastal area by the about 15 km wide ‘coastal river’. This part of the North sea transports silt and nutrients from the Dutch rivers and Delta parallel along the Dutch coastal area in northern direction (figure 2). Figure 3 shows the major flow patterns in the North Sea.

Figure 2 The coastal river along the Dutch coastline

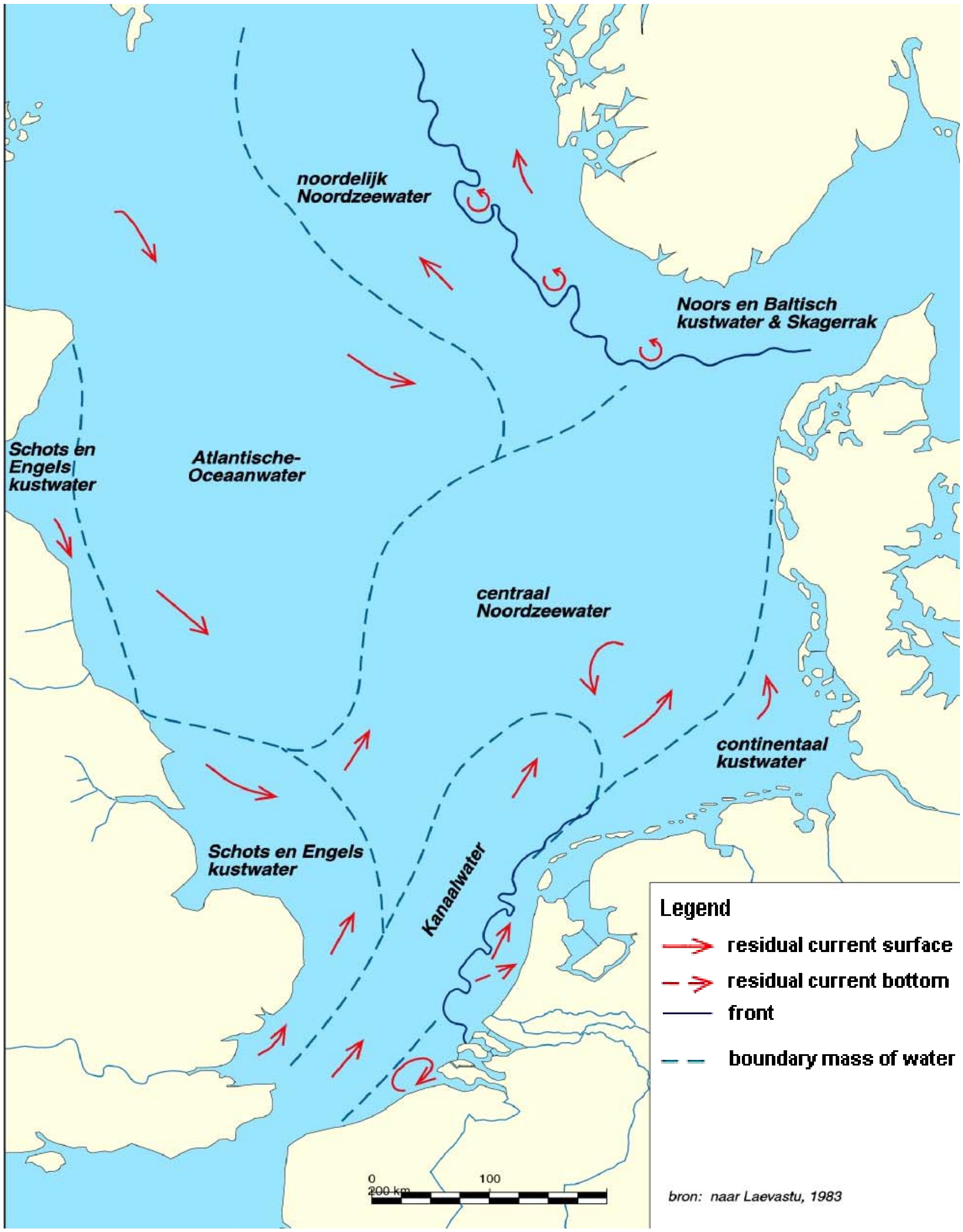


Figure 3 Flow patterns in the North Sea

Several biotic and abiotic factors play an important role in the biology of fouling organisms in the NCS. These are among others nutrients, temperature, water depth, salinity and light. For several locations in the North sea and coast at Noordwijk and IJmuiden, the long term characteristic values for temperature, salinity and sight depth are shown in tables 1 – 3. Values are derived from Donar (RIKZ).

Table 1 Long term temperature values (-1 – -4 m under surface)

Location	Period	Temperature (ºC)		
		Average	Max	Min
Noordwijk beach	1973 - 1996	12.53	22.60	0.00
Noordwijk 1 km off the coast	1975 - 1995	11.71	21.00	0.00
Noordwijk 2 km off the coast	1975 - 2005	11.92	21.84	0.40
Noordwijk 4 km off the coast	1975 - 1995	11.75	21.00	0.90
Noordwijk 10 km off the coast	1975 - 2005	12.82	21.60	1.50
Noordwijk 20 km off the coast	1975 - 2005	11.91	21.00	0.90
IJmuiden 3 km	1983 - 1988	10.83	19.50	0.50
IJmuiden 20 km	1983 - 1988	10.63	18.70	0.40
IJmuiden semafoor beach	1989 - 1996	16.55	22.80	6.90
Wijk aan Zee beach	1973 - 1996	12.79	23.50	-1.00
Zandvoort beach	1973 - 1996	12.59	23.00	0.00

Table 2 Long term salinity values (-1 – -4 m under surface)

Location	Period	Salinity (chloride from conductivity as ‰)		
		Average	Max	Min
Noordwijk beach	1975 - 1995	27.96	35.51	18.69
Noordwijk 1 km off the coast	1975 - 1995	28.45	32.78	18.82
Noordwijk 2 km off the coast	1975 - 2005	28.64	32.85	18.87
Noordwijk 4 km off the coast	1975 - 1995	28.84	32.70	20.35
Noordwijk 10 km off the coast	1975 - 2005	30.45	33.35	22.67
Noordwijk 20 km off the coast	1975 - 2005	31.82	34.16	23.65
IJmuiden 3 km	1983 - 1988	28.65	31.39	24.49
IJmuiden 20 km	1983 - 1988	32.00	34.36	26.42
IJmuiden semafoor beach	1989 - 1996	20.14	28.53	14.99
Wijk aan Zee beach	1982 - 1997	28.77	32.02	22.56
Zandvoort beach	1982 - 1997	28.67	31.34	24.31

Table 3 Long term sight depth values (-1 – -4 m under surface)

Location	Period	Sight depth (cm)		
		Average	Max	Min
Noordwijk beach	1986 - 1996	71.3	120.0	5.0
Noordwijk 1 km off the coast	1975 - 1978	72.5	160.0	10.0
Noordwijk 2 km off the coast	1975 - 1978	105.7	300.0	30.0
Noordwijk 4 km off the coast	1975 - 1978	139.3	300.0	30.0
Noordwijk 10 km off the coast	1975 - 1978	219.3	300.0	80.0
Noordwijk 20 km off the coast	1975 - 1978	271.0	350.0	130.0
IJmuiden semafoor beach	1989 - 1996	107.9	160.0	50.0
Wijk aan Zee beach	1986 - 1996	83.0	130.0	5.0
Zandvoort beach	1986 - 1996	79.9	120.0	5.0

The seawater in the coastal zone is so-called continental coastal water. In this water mass, that can extent to 40 km out the coast, a clear river component can be recognised due to the river discharge of the rivers Scheldt, Meuse and Rhine. The salinity fluctuates a little bit, dependent on the river discharge into the North Sea. Due to the high nutrient load the coastal water contains relatively much phytoplankton and it is more turbid.

2.2 Fouling of offshore structures

A great deal of work has been undertaken to survey and describe fouling growths on offshore structures. However, for commercial reasons, very little has been published. A clear and concise overview of fouling on offshore structures has been published by Hiscock et al., (2002). His work concerned a high level environmental screening study for offshore wind farm developments. Further published information includes the work of Forteath et al. (1982) for steel platforms in the central and northern North Sea and Picken (1986) on fouling communities in the Moray Firth. Other published work, with similar information, includes Forteath et al (1982) and Terry & Picken (1986). Colonisation on jetty piles, although usually in wave sheltered areas, also provides information on the communities likely to develop on offshore structures. An important long-term observation study by means of video surveys of fouling communities found on offshore installations has been made by Whomersly and Picken (2003). The information is described in the next paragraph.

2.2.1 Fouling species on offshore structures

The descriptions below are taken from Hiscock et al. (2002) and Whomersly and Picken (2003). The first is based on a limited range of observations of jetty piles by one of the report authors (K. Hiscock). Information sources that have been consulted include Hiscock & Cartlidge (1980-1983), observations on the communities that develop on wrecks are also relevant and the MNCR biotopes classification (Connor *et al*. 1997) has been consulted.

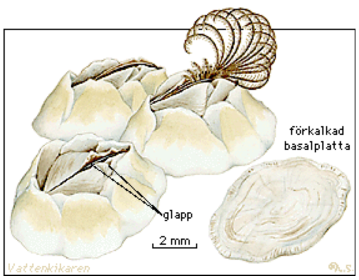
Man-made structures in marine environments provide hard substrate that acts as a habitat for sessile organisms. Such structures are like artificial reefs on which, among others, anemones, hydroids and mussels settle in a way comparable with a rocky seashore. A characteristic of rocky seashores is zonation, i.e. the division of an ecosystem into distinct vertical layers that experience particular abiotic conditions.

The locations where offshore wind farms are planned and expected are in sedimentary wave exposed areas of open sea. Where those locations are in shallow depths (seabed less than about 5 m below chart datum) scour conditions are likely and will most likely prevent the establishment of stable communities. Instead, rapid-settling, fast growing species typical of scoured situations will establish on the structure above the seabed. Any structures that are in areas where sediment scour is unlikely (because of depth to the seabed, stable substratum type or local shelter) or where the structure extends higher in the water column than the area of significant scour, will develop hard substratum communities typical of artificial structures such as jetty piles and wrecks. In Figure 4 an illustration is shown of the types of colonisation species likely to occur in the region of wind turbine towers.

Marine growth on new surfaces typically commences with colonisation by species that produce large numbers of plank tonic larvae for extended periods and are fast growing once settled. Intertidal areas are likely to be dominated initially by green algae and by laver, *Porphyra* spp., later joined by barnacles (*Semibalanus balanoides*) and mussels (*Mytilus edulis*). In subtidal areas, fast growing colonizing species include the keeled tubeworm *Pomatoceros triqueter*, barnacles especially *Balanus crenatus*, encrusting seamats and, in shallow depths, algae such as gutweed *Enteromorpha* sp and sea lettuce *Ulva lactuca*. Where sand is in suspension, the ross worm *Sabellaria spinulosa* may dominate especially near to the seabed. The same species will continue to characterize the communities of areas of the structure subject to frequent sand scour. In the year following establishment overgrowth of initial colonizing species will occur.

Solitary sea squirts, *Ascidiella* spp. are likely to colonize deeper parts of the structure, barnacles (*Balanus crenatus* and *Balanus balanus*) and mussels (*Mytilus edulis*) are likely to become established especially in shallow regions and kelps might grow on the shallowest part of the structure.

Balanus crenatus



Mytilus edulis

Metridium senile

tube worms

bryozoan sp.

Fouling community

Figure 4 Examples of fouling species that can be expected at the offshore wind farm

A more diverse algal community on the upper few metres of the structure and a rich community of ‘soft’ fouling organisms will develop over the three years subsequent to establishment, possibly displacing many initial colonizing species including mussels. The species that will occur include, in shallow depths, a variety of red algae including *Polysiphonia* spp. and *Palmaria palmata*, kelps including *Alaria esculenta* and species of *Laminaria* and some filamentous brown algae especially *Ectocarpus* sp.

Deeper areas are likely to become dominated by hydroid sea firs such as *Tubularia* spp., *Obelia* spp. and *Kirchenpauria pinnata*, plumose anemones *Metridium senile*, sagartia anemones *Sagartia elegans* and *Actinothoe sphyrodeta*, soft coral *Alcyonium digitatum*, erect bryozoan sea mats such as species of *Bugula*, feather stars, *Antedon bifida*, various solitary or clumped sea squirts such as *Ascidiella* spp., *Ciona intestinalis* and *Clavelina lepadiformis* together with fleshy sea squirts such as the star ascidian *Botryllus schlosseri* and polyclinid sea squirts such as *Morchellium argus*, and sponges such as the orange tassel sponge *Esperiopsis fucorum*.

Shallow areas dominated by algae and sometimes deeper areas, may become covered in the tubes of jassid amphipod crustaceans (*Parajassa pelagica* in very shallow depths, *Jassa falcata* deeper. However, such occurrences were found to be transitory by Hiscock & Cartlidge 1980-1983). Attached fouling growths will attract predators including starfish *Asterias rubens* and various crab species and will be colonized by a wide range of inconspicuous molluscs, worms and crustaceans. Fouling growths were found to be up to about 15 cm thick in the Moray Firth (Picken, 1986). Species that colonize structures will depend mainly on depth to the seabed, degree of scour and geographical location. The description above is for structures to be built closer than ~10 km from the coast; further offshore, larval supply from inshore hard substratum species may be reduced and elements of deep-water communities may occur.

Colonisation on anti-scour structures

Where the base of columns is protected by rock deposited to protect against the winnowing of sediment, the rock will become colonized by marine growth and could also provide a significant habitat for mobile species including commercial species. Because of winter storms and consequent scouring, the community attached to this ‘rock armour’ is likely to be ephemeral and of fast growing species such as barnacles and tubeworms. Solitary sea squirts may also settle, grow rapidly and may survive winters if conditions are not severe. Well-planned scour protection may provide a significant habitat for crustacean shellfish especially lobsters, *Homarus gammarus*, but also brown crabs, *Cancer pagurus*, velvet swimming crabs, *Necora puber*, and various species of squat lobster. Significant work has been undertaken at the University of Southampton to investigate the optimum size of stone that might create additional habitat for shellfish (See Jensen & Collins, 1997 and Halcrow Maritime et al. 2001). Fish, especially wrasse, are also attracted to the fissures and caves created by boulder heaps.

Fouling communities: structure, zonation and succession

This paragraph presents the findings by Whomersly and Picken (2003) who performed an 11-year study on the long-term dynamics of offshore fouling communities on four platforms in the North Sea. These findings likely represent the expected fouling dynamics at the Noordzeewind offshore wind farm.

The results from the study revealed a succession of fouling organisms on the clamps/guides over time leading to a distinct depth zonation (figure 5). Primary fouling organisms were mussels, hydroids and tubeworms. The initial colonisation is by hydroids and tubeworms. Organisms recruiting later in time are mussels and anemones.

Throughout the study a clear depth zonation was found. The shallow depths were dominated by mussels, probably structured by wave action. The middle zones on all platforms were dominated by anemones. The deepest zone was the most diverse and probably structured by physical factors such as scour. The zonation on all platforms was comparable. The study indicated that a wide bathymetric tolerance of fouling organisms exists. The structural complexity and composition of the substratum is probably of influence as well to community structure. Factors influencing colonisation include seasonal availability of larvae and varying degrees of longevity and persistence of the species recruited. Mussels were found on all platforms during the whole monitoring period, probably because the low density of predators and their ability to withstand physical disturbance of wave exposure.

The timing of secondary colonisation differs between the locations, starting after 2 or 4 years. All platforms showed a clear mussel zone in the shallowest depths and until year 4 all platforms exhibited similar fouling assemblages of tubeworms and hydroids. Differences were found though in anemone communities.

Differences between fouling communities at different locations can be explained by physical and biological factors such as temperature, salinity, depth, larval supply and food availability and proximity to fouling communities on coastal and offshore structures.

The study provides comprehensive evidence that succession does occur on artificial substrata. Also, it is proven that video survey and remotely operated vehicles are useful non-invasive biological survey tools that can provide an accurate method to survey fouling communities. Also, this study highlights the need for further long-term studies as fouling communities are continuously changing in time.

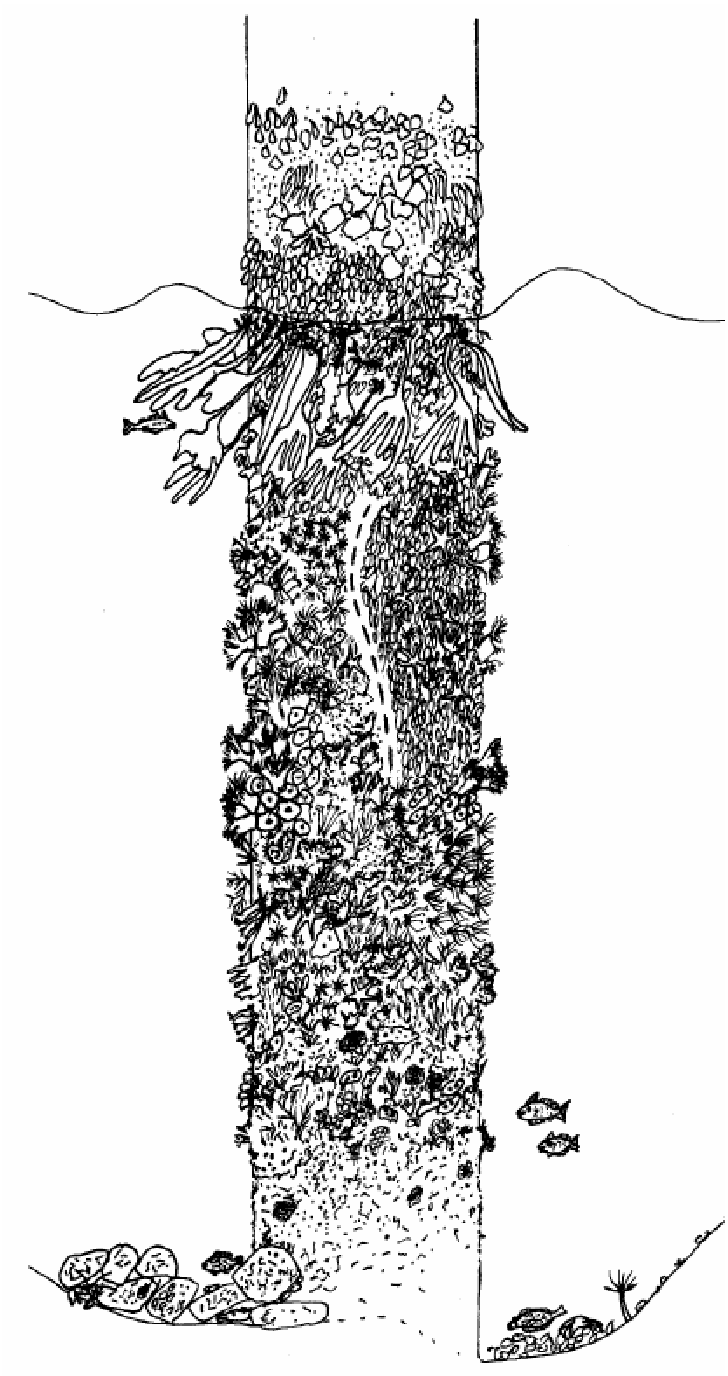


Figure 5 Zonation of fouing (Hiscock *et al*., 2002)

Intertidal zone: Predominantly barnacles and ephemeral algae including: the barnacles *Semibalanus balanoides* and *Elminius modestus*, sea lettuce *Ulva lactuca*, gut weed *Enteromorpha intestinalis*, and laver, *Porphyra* spp.

Kelp zone c+.1 – 2 m: Kelps, foliose red seaweeds, barnacles, encrusting sea mats. Mussels sometimes dominant below kelps. Foliose algae (including *Palmaria palmata* and *Polysiphonia* spp. especially) may extend deeper

Shallow subtidal c+. 2 – 6 m: Two alternative are illustrated:

1 (Left-side of illustration.) Plumose and other anemones, sponges, possibly hydroids. Large individuals of the plumose anemone *Metridium senile*, with groups of sagartia anemones *Sagartia elegans* and patches of hydroids, *Tubularia larynx* and sponges, *Halichondria panicea*. Occasional red seaweeds especially filamentous species.
2 (Right-side of illustration.) Dominated by mussels, *Mytilus edulis* with scattered elements of the above and starfish (*Asterias rubens*) predators.

Main column to scoured area: Likely to be dominated by plumose anemones *Metridium senile*, sagartia anemones *Sagartia elegans*, soft corals *Alcyonium digitatum*, hydroid sea firs including *Obelia* spp., *Kirchenpauria pinnata*, *Tubularia indivisa*, sponges such as *Amphilectus fucorum* and solitary sea squirts *Ascidiella* spp. Patches of feather stars (*Antedon bifida*) may be present as well as areas of the colonial sea squirt *Diplosoma listerianum* and the sponge *Polycarpa* spp.

Scoured area: Dominated by keeled tubeworms, *Pomatoceros triqueter*, and barnacles *Balanus crenatus*, with encrusting bryozoan sea mats near the top of the zone. May be dominated by ross worm *Sabellaria spinulosa*. Large amounts of bare substratum likely to be present. Base of structure Two alternatives are illustrated:

1 (Left-side of illustration.) No or few mussels on structure above and antiscour in the form of small boulders installed. Boulders colonised by same species as scoured structure although sheltered intertices may attract solitary sea squirts and other species. Reef species such as wrasse, *Labrus bergylta*, wreck fish *Trisopterus luscus*, lobster *Homarus gammarus*, crab *Cancer pagurus*, and *Conger conger* attracted.
2 (Right-side of illustration.) Mussels dominant on structure above and no anti-scour. Live and dead mussels accumulate at base. Possibly peacock worms *Sabella pavonina* present. Scavengers such as crabs and flat fish attracted.

2.2.2 Fouling at off shore structures in Dutch coastal waters

In the Netherlands a few studies describe the potential fouling that will develop on the monopiles. However, these studies best describe the potential fouling at the OWEZ monopiles. The first study is conducted by RIKZ (1997) and describes the fouling at artificial reefs in the North Sea. This artificial reef had been constructed at 8.5 km of the coast at Noordwijk, in the area of the Meetpost Noordwijk at 18 m depth. The area exists in a flat, sandy bottom and no other obstacles like ship wrecks are present in the direct area. The fouling succession on 4 artificial reef islands had been monitored from 1992 – 1995 and represents the potential fouling that may develop at the OWEZ -monopiles. Table 4 presents the species found during these monitorings of the artificial reef near Noordwijk (Van Moorsel, 1993; RIKZ, 1997).

Table 4 List of fouling species found on the artificial reef near Noordwijk

Phylum	**Scientific name**	**Dutch name (species / group)**
Amphipoda	*Jassa sp*	Kokerbouwende vlokreeft
Annelida	*Lanice conchilega*	Schelpkokerworm
Annelida	*Pomatoceros triqueter*	Driekantige kokerworm
Annelida	*Sabellaria spinulosa*	Kokerworm
Arthropoda	*Elminius modestus*	Nieuw-Zeelandse zeepok
Arthropoda	*Semibalanus balanoides*	Gewone zeepok
Cnidaria	*Aurelia aurita (benthisch)*	Oorkwal
Cnidaria	*Bougainvillea ramose*	Haarpijpje
Cnidaria	*Campanulariidae*	Hydroid poliepen
Cnidaria	*Clytia hemisphaerica*	Getand zeemos
Cnidaria	*Coryne sp.*	Hydroid poliep
Cnidaria	*Diadumene cincta*	Golfbrekeranemoon
Cnidaria	*Hydractinia echinata*	Ruwe zeerasp
Cnidaria	*Metridium senile*	Zeeanjelier
Cnidaria	*Obelia bidentata*	Hydroid poliep
Cnidaria	*Obelia geniculata*	Geknoopt zeedraad
Cnidaria	*Opercularella lacerata*	Hydroid poliep
Cnidaria	*Sagartia troglodytes*	Slibanemoon
Cnidaria	*Sagartiogeton undatus*	Weduweroos
Cnidaria	*Tubularia indivisia*	Hydroid poliep
Cnidaria	*Tubularia larynx*	Hydroid poliep
Ectoprocta	*Alcyonidium digitatum*	Dodemandsduim (mosdiertje)
Ectoprocta	*Alcyonidium parasiticum*	Mosdiertje

Table 4 Continued: List of fouling species found on the artificial reef near Noordwijk

Ectoprocta	*Bowerbankia sp*	Mosdiertje
Ectoprocta	*Conopeum reticulum*	Zeevitrage (mosdiertje)
Ectoprocta	*Electra pilosa*	Harige vliescelpoliep (mosdiertje)
Mollusca	*Crepidula fornicata*	Muiltje
Mollusca	*Mytilus edulis*	Mossel
Porifera	*Halichondria bowerbanki*	Sliertige broodspons
Porifera	*Halichondria panacea*	Broodspons

The first colonisers were present 12 days after installation: hydroids, followed by barnacles and anemones. Within 10 weeks surface coverage was 20 – 80%. After a longer period maximum coverage reached 95%. In the first year, 1992, 11 species were found, in 1993 17 species and in 1995 22 species. The biomass increased during these years, but it never reached values that are found at other hard substrates such as shipwrecks.

The second study has been performed by the NAM in 2002. This study concerned 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 videos 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 programme throughout multiple years.

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

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

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

From the results a clear vertical zonation is found. Not all zones observed are 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 *M. edulis*. The characteristic of this zone is temporary exposure to the air during tides. Mussels are capable to survive 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 to analyse at a smaller scale by which differences between the platforms are difficult to make.

3 NSW-MEP MONITORING PROGRAMME MARINE FOULING

3.1 Approach of monitoring

Windfarm structures and any scour protection are subject to the settlement and growth of biofouling communities by species present in the area. At new projects in the maritime climate, the initial settlement starts within weeks after installation, after the surface of the structure is conditioned. However, it is shown by KEMA-experience that the main growth of macro-organisms occurs from the second year after installation.

As explained above, the development of fouling occurs in phases, after at first instance bacterial fouling (microfouling) forms a biofilm, colonisation of the substrate by macro-organisms (macrofouling) takes place. This is however a rather slow process which depends on environmental parameters such as temperature and abundance of larvae of fouling species. During the first year of operation the amount of fouling will be limited, however, there is need to visually inspect prior to the start of the second operational year. In order to obtain proper information on the (succession of) biological fouling it is necessary to start in the first year to have a ‘zero-measurement’.

Biological fouling will occur on the submerged surface of the monopiles, from the splash zone to the bottom. Macrofouling at both zones will be monitored by means of video surveys. Biological fouling processes are rather slowly, thus an inspection frequency of once a year is sufficient to observe the variations and increase in macrofouling in detail.

After year 1, 2 and 3 video-surveys of the fouling succession will be made by means of video at the measuring mast (installed in 2003) and two additional masts. The results shall be compared with the existing knowledge and video-survey recordings of existing offshore constructions of the NAM.

The required inspections with respect to corrosion and biological fouling for the NZW-MEP program will be performed as much as possible according to the existing reporting sheets and procedures as used in the O&M program. Part of the inspections are carried out under water. The below water inspections of the monopiles and foundations (figure 6) of the wind turbines will be carried out either by ROV or by divers. The items to be inspected are the Monopile, Access Arrangement, J-tubes and cable exits, Anodes and the Seabed.

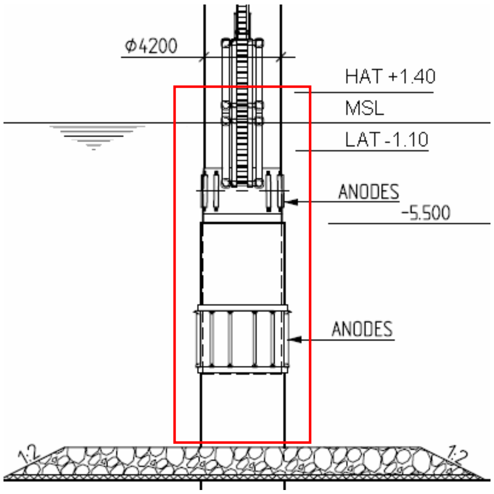


Figure 6 Schematic view on the submerged part of the monopole and OWEZ foundation. Monopile surface is to be monitored from the intertidal zone to the foundation, as indicated by the red line

3.2 Measuring variables of the biological fouling

In order to characterise the biological fouling, the next variables will be assessed from the video-survey recordings and be used for the comparison with recordings of existing offshore constructions:

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

4 DISCUSSION AND CONCLUSIONS

4.1 Conclusions pre-survey

Fouling on offshore installations shows a clear succession, i.e. different species at different times during colonisation. The colonisation start as soon as a structure is installed. Clear differences in fouling between depths (zonation) are also found. The extent of fouling (covering percentage and biomass) increases in time until a maximum has been reached, then the biomass may vary between years and season, depending on the supply of larvae of fouling species and other factors like temperature and nutrients.

The Offshore Windfarm Egmond aan Zee is largely influenced by the coastal river, supplying larvae and nutrients from the southern region (Delta and rivers Rhine and Meuse). There is a wide variety of species that may settle on the masts, among others mussels, oysters, bryozoans, anemones, hydroids, sponges, barnacles, tube worms, et cetera. In order to be able to distinguish the different species and to estimate biomass, not only video recordings (i.e. close ups), but also samples must be available.

4.2 Expected fouling for the OWEZ Windfarm

The type and extent of fouling is location specific. The extent of fouling (biomass) and species composition and succession is determined by influence of both abiotic and biotic parameters, i.e. temperature, turbidity, larvae abundance, et cetera.

Two studies in the Dutch coastal zone provide information on which an expectation for the fouling at the OWEZ can be based. These studies concern off shore NAM-platforms and artificial reefs.

Only the succession of the fouling in terms of species composition in time can carefully be predicted. However, species composition, settlement and growth may vary with season, (larvae abundance, nutrient availability, marine conditions, et cetera). As mentioned before, this is strongly location specific. 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.

A clear vertical zonation of the fouling species is expected. The first (upper) zone is expected to be fouled with hard fouling, probable dominated by a single species, likely by the mussel *M. edulis*. The characteristic of this zone is temporary exposure to the air during tides. Mussels are capable to survive 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, although growth of soft fouling species might limited by any sand scour. Other fouling species that are expected are tube worms, barnacles, sponges and sea squirts. Depending on the dominant species, the fouling layer may be dense with an estimated thickness between 5 and 20 cm.

The yearly monitoring will show the exact fouling composition and succession.

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