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Figure 1.
Location and site layout of OWEZ, the first Dutch offshore wind farm (Noordzeewind 2003a)

Key words: hard substrate, benthic reef communities, Dutch offshore wind farm

The development of benthic communities on hard substrates within OWEZ, the first Dutch offshore wind farm

Abstract

This study documents the development of a benthic reef community on the foundations of the first Dutch offshore wind farm in the first years after construction. The wind farm was built in 2006 and has been in operation since January 2007. The turbine monopile foundations and the rocks around the foundations that serve as scour protection, form a new hard substrate habitat in an environment previously dominated by soft sandy substrates.
Five years after commissioning of the wind farm a total of 55 different taxa (including several non-indigenous species) were identified using video footage and samples collected by divers.
The intertidal zone was characterised by a band of green algae, different species of barnacles, oysters and small blue mussels. In the subtidal zone, a patchy but generally thick layer of blue mussels was present to circa 10-12 m depth with associated species such as starfish, crabs and various polychaetes. At greater depth, benthic communities were dominated by small crustaceans, anemones and ringed tubularia. The most dominant species on the scour protection were plumose anemones, small crustaceans and the encrusting sea mat. Total densities of hard substrate species increased over the study period to circa 28,000 individuals per m^2 on the monopiles and circa 2,500 individuals per m^2 on the scour protection layers. Total biomasses varied between circa 450 and 1,400 g AFDW per m^2.
The new hard substrate communities can form a valuable food source for fish and bird species.

This study was commissioned by NoordzeeWind (a joint venture of NUON and Shell Wind Energy).

Introduction

The first Dutch offshore wind farm (Offshore Wind farm Egmond aan Zee, OWEZ) was built in 2006 and has been in operation since January 2007. The wind farm covers a total area of 30 km^2 and consists of 36 turbines located at distances varying from 10 to 18 kilometres off the coast of Egmond aan Zee (figure 1). The turbines are placed on steel monopiles (diameter 4.6 metres) and around the base of the monopiles a scour protection layer was installed, with a diameter of approximately 25 metres, consisting of a filter layer of small sized rock and a top layer of heavier rock grading. The water depth within OWEZ varies between 15 and 20 metres.

Noordzeewind designed an extensive Monitoring and Evaluation Programme (NSW-MEP) to study economical, technical, ecological and social effects of the wind farm. The present study was part of the ecological programme and summarises the development of benthic reef communities on the monopiles and scour protection layers (hard substrates) up to five years after construction of the wind farm. The results of all ecological monitoring programmes (benthos, fish, birds and marine mammals) will be presented to the public at the 5th anniversary Congress of OWEZ held in Amsterdam on the 11th and 12th of October 2012.

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Table 1. Species identified on the monopiles and scour protection of three turbines in OWEZ (*: species identified in 2011 that were not recorded in 2008).

Species	English name	Monopiles	Scour protection
Algae			
*Porphyra spp.**	foliose red algae	x	
Ulva spp.	sea lettuce	x	
Anemones			
Actinia equina	beadlet anemone	x	
*Actinothoe sphyrodeta**	sandalled anemone	x	
Diadumene cincta	orange anemone	x	x
Metridium senile	plumose anemone	x	x
*Urticina felina**	dahlia anemone	x	
Sagartia spp.	-	x	x
Barnacles			
Balanus crenatus	crenate barnacle	x	x
Megabalanus coccopoma	titan acorn barnacle	x	
Semibalanus balanoides	rock barnacle	x	x
*Balanus perforatus**	acorn barnacle	x	
*Elminius modestus**	Australasian barnacle	x	x
Molluscs			
Crepidula fornicata	slipper limpet	x	x
Crassostrea gigas	Pacific oyster	x	x
*Ostrea edulis**	edible oyster	x	
Mytilus edulis	common mussel	x	x
*Nassarius reticulates**	netted dog whelk	x	x
*Tellimya ferruginosa**	-	x	
*Odostomia scalaris**	-	x	
Aeolidia papillosa	grey sea slug	x	
Crustaceans			
Caprella mutica	skeleton shrimp	x	x
*Stenothoe marina**	marine gammarid amphipod	x	
Monocorophium acherusicum	-	x	x
Monocorophium sextonae	-	x	x
Jassa herdmani	-	x	x
Jassa marmorata	-	x	x
Idotea pelagica	aquatic sowbug	x	x
Pilumnus hirtellus	hairy crab	x	
Pisidia longicornis	porcelain crab	x	x
Necora puber	velvet swimming crab	x	x
Cancer pagurus	edible crab	x	x
*Pinnotheres pisum**	pea crab	x	
Insects			
*Telmatogeton japonicus**	marine splash midge	x	
Echinoderms			
Asterias rubens	common starfish	x	x
Ophiotrix fragilis	common brittlestar	x	x
Psammechinus miliaris	green sea urchin	x	x
Sponges			
*Halichondria panicea**	breadcrumb sponge	x	x
Bryozoans			
Conopeum reticulum	sea mat	x	x
Cryptosula pallasiana	orange crust		x
Hydroids			
Tubularia larynx	ringed tubularia	x	x
*Tubularia indivisa**	oaten pipes hydroid	x	x
Obelia spp.	-	x	x
*Obelia dichotoma**	sea threat hydroid	x	
*Halecium halecinum**	herringbone hydroid	x	x
*Opercularella lacerata**	-	x	
Polychaetes			
Lepidonotus clava	scale worm	x	x
*Lepidonotus squamatus**	-	x	x
*Harmothoe impar**	-	x	
Nereis pelagica	-	x	x
*Eunereis longissima**	-	x	
*Eulalia viridis**	greanleaf worm	x	
*Lanice conchilega**	sand mason	x	x
*Spirobranchus triqueter**	keelworm	x	x
Nemertines			
Lineus longissimus	bootlace worm	x	x
Nematodes			
Nematoda	nematodes	x	

Material & Methods

Video footage, pictures and samples collected by professional divers were used to describe benthic reef communities (both qualitative and quantitative) on hard substrates of three selected turbines. The first assessments were carried out in February and September 2008 and the results were reported in Bouma & Lengkeek (2009). In 2011 these assessments were repeated in the same months, selecting the same turbines and using the same methods (reported in Bouma & Lengkeek, 2012).

Video footage was collected from the entire depth range of the monopiles and from the rocks of the scour protection using a video camera in a handheld underwater housing. Images were linked to depths by using a depth gauge connected to the underwater housing.

Samples of organisms on the monopiles were collected at five different depths (intertidal zone, 2, 5, 10 and 15 metres of seawater) and at both the northern and southern side of the monopile. At each sample point all organisms within an area of approximately 28 centimetres by 20 centimetres were scraped of the monopile using a putty-knife and collected in a fine-mesh net (mesh size circa 0.25 mm). Samples of organisms on the scour protection layers were taken by collecting several small rocks.

In the laboratory the collected organisms were sorted and species identified and counted. Subsequently, biomasses (as ash-free dry weights, AFDW) were determined for the most abundant taxa (dried at 60° for 60 hours and combusted at 520° for two hours).

Results

A total of 55 taxa were identified on the monopiles and 35 species on the rocks of the scour protection layers (table 1).

Monopiles

The intertidal zone of the monopiles was generally characterised by the presence of a band of green algae (*Ulva spp.*), different species of barnacles (table 1), oysters (both the Pacific oyster (*Crassostrea gigas*) and the edible oyster (*Ostrea edulis*)) and a band of small mussels (*Mytilus edulis*)(figure 2). In 2011, several larvae of the marine splash midge (*Telmatogeton japonicus*) were also found in this zone. This species was not identified in 2008. Mussels in the intertidal zone were more abundant in September than in February, possibly because of

Figure 2. Growth in the intertidal zone of a monopile in OWEZ.

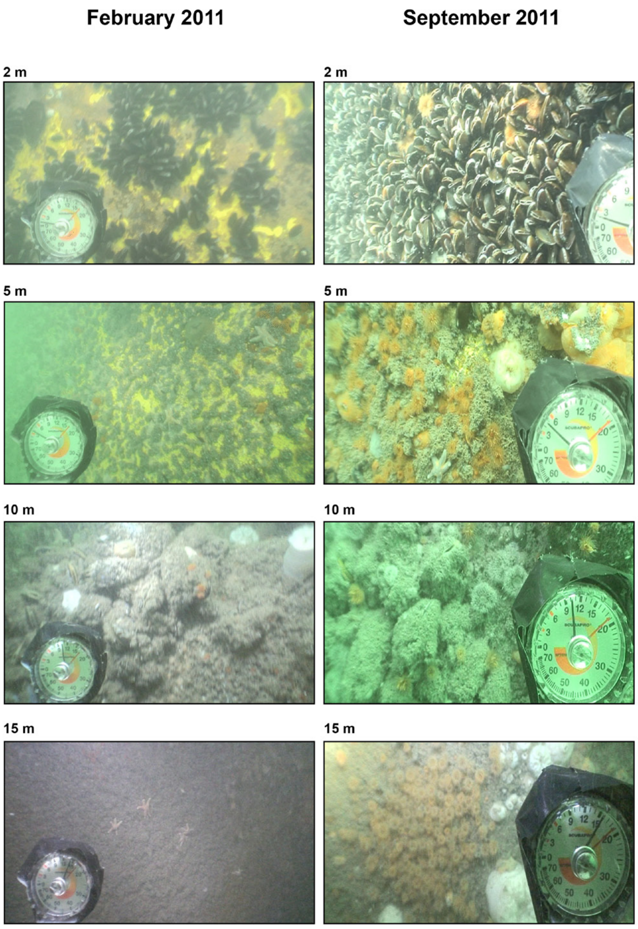

Figure 3. Growth in the subtidal zone of a monopile in OWEZ.

Figure 4. Video still of rocks of the scour protection layer of a turbine in OWEZ.

loss of mussels during winter storms and recolonisation during the summer months.

Organisms in the subtidal zone showed a 'patchy' distribution with strongly varying covering percentages, but generally a thick layer of adult mussels was present from the shallow subtidal zone to circa 10-12 m depth (figure 3).
In 2011 these mussels were more overgrown by other species (mainly by small crustaceans and the orange anemone (*Diadume cincta*) than in 2008.

Common species associated with these mussels included common starfish (*Asterias rubens*), several species of crabs and various polychaetes (table 1). Edible crabs (*Cancer pagurus*) were often found in open 'patches' between the mussels, especially during the September 2011 survey.

From circa 12 m to the seafloor at circa 15 m depth, the monopiles were fully covered by small crustaceans, anemones (mainly plumose anemones (*Metridium senile*), but also the orange anemone *Diadumene cincta* and *Sargartia spp.* anemones) and 'patches' of the ringed tubularia (*Tubularia larynx*).

In 2011 total densities of hard substrate species on the monopiles reached values up to circa 28,000 individuals per m^2. Most numerous were small crustaceans (circa 22,000 per m^2) anemones (circa 1,000 per m^2), polychaetes (circa 500 per m^2) and common starfish (circa 130 per m^2).
A clear increase in total densities occurred over the study period between February 2008 and September 2011.

The total biomass of hard substrate species on the monopiles varied between circa 450 (February 2008) and 1,400 g AFDW per m^2 (September 2008). Mussels and anemones contributed most to this biomass (on average circa 83% and 7%).

Scour protection layers

The most dominant species on the rocks of the scour protection layers were plumose anemones (figure 4), small crustaceans and the encrusting sea mat (*Conopeum reticulum*). Common starfish were also abundant. Less abundant species include other anemone species, various crabs, polychaetes and hydroids (table 1). In 2011, eight new species were identified that were not recorded in 2008 including the breadcrumb sponge (*Halichondria panicea*) and eggs of the mollusc *Nassarius reticulus*.

The density of marine life on the rocks of the scour protection layers was high. Densities of anemones were circa 2,500 individuals per m^2 and densities of common starfish circa 180 individuals per m^2.
The covering percentages of the sea mat and small crustaceans varied between 60-100% and 30-50% respectively.

Discussion & Conclusions

Benthic communities as a food source for fish and/ or birds

Small crustaceans, mussels and polychaete worms can form a valuable food source for fish and bird species. A simplified extrapolation showed an availability of circa 7,400 kg AFDW mussels and circa 100 kg AFDW small crustaceans and polychaete worms.

Identifying causal relationships between the presence of these hard substrate species and fish and or birds was beyond the scope of the study. However, a study focusing on the residence time and behaviour of sole (*Solea solea*) and cod (*Gadus morhua*) in OWEZ showed that juvenile cod stay in the wind farm for prolonged periods of time. 55% of tagged individuals stayed in OWEZ for several weeks or months and 15% during the entire study period of 8-9 months (Winter *et al*., 2010). Inventories of demersal fish species showed that several demersal fish species, including sole, whiting (*Merlangius merlangus*) and striped mullet (*Mugil cevalus*), have significantly increased in the wind farm and not in reference sites outside the wind farm (Hille Ris Lambers & Hofstede, 2009; Lindeboom *et al*., 2011). Studies on flight patterns and on distribution of local birds (Krijgsveld *et al*., 2011 and Leopold *et al*., 2011) showed that cormorants (*Phalacrocorax carbo*) are attracted to the wind farm, mostly because the turbines provide the resting place that these birds require to dry their feathers. Cormorants foraged for fish on a regular basis in the wind farm, especially during the summer months. Also various species of gulls were shown to forage within the wind farm. The most abundant gull species occurring in the area and within the wind farm were lesser black-backed gull (*Larus fuscus*), herring gull (*Larus argentatus*) and common gull (*Larus canus*), but also the larger great black-backed gull (*Larus marinus*) in winter, and the smaller black-headed gulls (*Larus ridibundus*) and kittiwakes (*Rissa tridactyla*). Gulls feed on a variety of food, including smaller fish and crustaceans, which were encountered in high densities in the wind farm. Sea ducks, such as scoters (*Melanitta nigra*) that could potentially benefit from the high biomass of the mussels, were seen flying through the wind farm only occasionally (Krijgsveld *et al*., 2011, Leopold *et al*., 2011).

Non-indigenous species

Several non-indigenous species were identified including the titan acorn barnacle (*Megabalanus coccopoma*), the acorn barnacle (*Balanus perforatus*), the Australasian barnacle (*Elminius modestus*), the slipper limpet (*Crepidula fornicata*), the Pacific oyster (*Crassostrea gigas*), the skeleton shrimp (*Caprella mutica*), the small crustacean (*Jassa marmorata)*, the hairy crab (*Pilumnus hirtellus*) and the marine splash midge (*Telmatogeton japonicus*). The presence of these species indicates that newly introduced hard substrates provide a habitat for both indigenous and non-indigenous species.

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