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Ecosystems associated with North Sea oil and gas facilities and the impact of decommissioning options

With attention for local and regional effects

Background report phase 1
Living North Sea Initiative

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Colophon		
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Contents

Executive summary

This report focuses on what is found on and around oil and gas facilities. Due to limited access to marine growth data of oil and gas operators, we have done a comparative study; including platforms, wind turbines and wrecks. The differences between these submerged structures need attention; submerged status, materials, design, age, contamination grade.

	Hard substrate	Exclusion zones
Platforms	3.7 km2	400 km2
Wrecks	30–54 km2	-
Wind parks	0.17 km2	158 km2
Natural reefs	18,000 km2	-
OSPAR MPA	-	41,000 km2

Marine biota associated with artificial hard substrates at the North Sea

Platforms, wind turbines and wrecks form artificial hard substrates in the North Sea area that is dominated by muds and sands. On the structures epifauna and epiflora settles within a few days. Within five to six years a stable ecosystem forms, still allowing small variations in species composition and abundances.

Marine growth on platforms in the southern, central and northern North Sea shows similar species compositions and patterns. Differences in marine growth stem mainly from water depth and passing currents. The latter determines the success of larvae in settling on a structure.

The species that settle on the structures are different from the seabed communities, consequently increasing the biodiversity of the area where the hard substratum is introduced. However, these hotspots of biodiversity are localised and in general do not contain unique assemblages. An exception is the growth of *Lophelia pertusa* at northern North Sea platforms.

From the research on platforms and wind turbines the overall conclusion can be drawn that the colonization of the vertical structures shows the typical zoning, correlated to temperature, light penetration, salinity and others.

Depth	Species composition
0 – 25 m	Mussels, tubeworms, barnacles, algae (red, green, brown), and hydroids in shady parts of structure
25 – 60 m	Hydroids (10 – 15 cm thick covers), anemones (M. senile), soft corals (Alcyonium/Dead Men's Fingers), Tubularia, Tunicates (sea squirt)
Around 60 m and deeper	Hydroids, bryozoa, deepwater barnacles (Balanus hameri), polychaete worm (Filograna implexa), tubeworms, Lophelia pertusa (NNS).

Several research programs about oil and gas platforms and fish have shown a relationship between the two. A record of more than 20 commonly occurring fish near platforms in the North Sea has been identified. Sea mammals that are most observed really close to the structures are harbour porpoises. They frequently visit safety zones around platforms and possibly even approach the platforms.

The effect of the surrounding substrates on the epifauna or epiflora on the structure is very limited. It is the water mass rather than the seabed that defines the species composition on the platform. The distance to shore is important too, because currents from coastal waters influence the larval compositions of the water.

Surrounding substrate

Part of the exclusion zones around platforms is affected by the toxicity from oil-based muds (OBM) present in the drill cutting piles. The toxic effect of the drill cutting piles is very local within a radius of 200 to 400 meters. Research in exclusion zones without OBM drill cutting piles has shown that these areas differ in flora and fauna from the trawled seabeds. The presence of the structure itself does not impact the surrounding seabed much, but the absence of trawling activities leads to higher densities of communities and older generations within the area.

Effects of decommissioning options

Decommissioning oil and gas facilities implies immediate effects of removal and longer-term effects on local and regional scale. Short-term effects are expected smallest for the leave in place option and largest for total removal and total transfer to reef options. Long-term effects offshore will be largest for the leave in place, toppling in place and transfer to reef options. Leave-offshore options are expected to have no significant negative effects. They may even be positively rewarded for diversifying the types of habitat and allowing hard-substrates species to settle. As already indicated, for the sandy southern North Sea this will apply the most.

Short-term effects	Long-term effects
◆ Operational physical disturbances ◆ Sonic disturbances ◆ Destruction of communities ◆ Contaminants from the structures ◆ Toxic effects from drill cutting piles	◆ Availability or absence of artificial hard substrates ◆ Long-term contaminations ◆ Collapse of the structure remnants ◆ Disintegration of the structure ◆ Disappearance of shell mounds

Leave-offshore options

By leaving structures offshore they create an artificial hard substrates or reefs, which can be used for several purposes. Research on artificial reefs shows that they; increase diversity of species; attract or aggregate fish and sea mammals; provide food, shelter and nesting sites; function as stepping-stone.

Opportunities	Threats
◆ Habitat enhancement ◆ Exclusion of trawl fisheries ◆ Avoidance of noise ◆ Enhanced fisheries ◆ Mariculture ◆ Recreation	◆ Unnatural conditions ◆ Source of contamination ◆ Migration barriers for birds and sea mammals ◆ Migration of invasive species ◆ Safety issues ◆ Temporary solutions

Some of the safety zones around platforms have not been fished for over thirty years. This makes them interesting areas for conservation. Research has shown that within a few years the ecosystem of the protected area has grown more complex and dense. Not only

population densities and biomasses have almost more than doubled, but also organism sizes. Moreover, the combination of an MPA and an artificial reef can amplify the conservation, by preventing of (illegal) fisheries. But:
- The 500-m zones are often the same areas that are affected by the cutting piles;
- The exclusion zones are rather small, with a dimension of about 1% of existing MPAs;
- It is not guaranteed that for leave-offshore options the safety zones can be maintained;
- The competition is imbalanced; the unprotected seabeds have immature colonization grades and are more attractive for larval settlement of certain species.

Preliminary conclusions

A. In general platforms have no significant negative effect on the local ecosystem:
- They create areas with higher biodiversity, with probably a limited effect on regional ecosystems.
- The artificial hard substrates change the local habitat, with the largest effect for soft bottom areas, but hard substrates are not foreign to the North Sea. Even in the southern North Sea the section of hard substrates used to be more prominent.
- The majority of the platforms consist for more than 90% of steel, which degrades over time, without significant contamination grades.
- Platforms can fulfil a stepping-stone function, but are not expected to play a large role in the distribution of invasive species.
- Within the safety zone the seabed community is not particularly affected by the platform itself.

B. Platforms create different habitat and increase local biodiversity:
- Platforms lead to higher biodiversity locally. They change the local ecosystem by adding a different habitat. Biomasses on hard substrates are higher than on surrounding soft seabeds.
- The availability of hard substrates has been strongly reduced in the southern North Sea, particularly by oyster fisheries over the last 200 years. Platforms create habitat for hard-substrate species that are inherent to the North Sea ecosystem.
- The safety zones around platforms are no-fished areas, sometimes already during large periods. They can function as small MPAs and inform on the effects of no fishing. It is not guaranteed that the safety zones will remain inaccessible for fisheries.

C. Platforms have probably no significant positive effect on the North Sea ecosystem:
- Platforms are artificial hard substrates and show similar effects as wind parks, wrecks and natural hard substrates. The effective platform surface is low compared to the total availability of hard substrates (~0,02%).
- Platforms create different habitats than natural reefs and cannot offer compensation for the former destruction of the hard substrates of the oyster beds.
- Platforms attract fish and sea mammals. They are used for shelter, breeding and feeding. It is not proven if productivity of e.g. fish is enlarged at platforms.
- The majority of the species that settle on platforms are not unique in the sense that nature conservation would be urgent.
- Platforms may function as a stepping-stone for certain species, but the impact at North Sea scale is small.

D. Decommissioning activities influence the local ecosystem:
- Leave-offshore options are expected to have no significant negative effects. They diversify the existing habitat and allow hard-substrates species to settle. Valuation of the artificial hard substrate is complex. The poor availability of hard substrates in the southern North Sea makes leave-offshore options probably more attractive there than in the northern parts.
- The leave-in-place option is best for local preservation of epifaunal mobile communities. It has also the least impact on drill cutting piles, avoids water column disturbances and does not disturb the seabed locally or at a new offshore site.
- The transfer-to-reef options need towing to new sites. The costs for reefing need to be assessed in combination with the positive effects on biodiversity at local and regional scale. Transfer to reef and toppling is expected only really useful in shallow waters.

E. Leaving (parts of) a platform in situ can be interesting from a management point of view:
- Platforms could be used for research on epifauna and aggregated mobile species and can help to improve knowledge on i.e. production at artificial reefs and stepping-stones.
- Safety zones can be used as research yards and to gather information on the potential of no-take zones. However, the contamination from drilling activities and the small surface areas does not make them the most optimal research areas.
- Platforms can be used for fisheries or maricultures. Fisheries of commercial rockfishes are more efficient when the fish is aggregated around hard substrates such as platforms. Platforms may have a function for mariculture systems with their continuous submerged conditions, lack of sediments in the upper layers and varying surfaces.
- Platforms can be used for second-life opportunities. They can function as stations for i.e. wind, wave or solar energy, recreation, etc.

1. Introduction

In this report we assess whether the process of decommissioning oil and gas platforms can form a positive trend for the North Sea ecosystem by preservation of structures for artificial reefs.

The North Sea area is dynamic and rich in terms of ecosystem services and socio-economic activities. It is typically a shallow basin with flat sandy bottoms. The surrounding economies reflect the proximity of the North Sea with their fisheries, oil and gas winning, shipping, and sand winning. At the same time the intensive use of the North Sea has led to overexploitation of fish, disturbed seabeds, discharges and other influencing events (Halpern *et al.*, 2008).

The Living North Sea Initiative is about creating new and innovative strategies to reverse the current downward trend in ecosystem quality (OSPAR, 2010; IMSAAmsterdam, 2011a;). The initiative explores opportunities for using the upcoming process of decommissioning oil and gas facilities as a catalyst for change.

The North Sea system is altered by the exhaustion of oil and gas reservoirs. It will have its impact in the coming decades and especially the UK, Norway, Denmark and The Netherlands have to get prepared for the socio-economic consequences of losing such an important source of income and source of carbon-based energy. Moreover, the decommissioning activities imply high expenses. It will cost industry and society large sums of money. The Living North Sea Initiative wants to create maximum value with this money: improvement of the North Sea ecosystem and new future perspectives for the communities that depend on the services of this ecosystem.

The Living North Sea Initiative questions whether the current process of total removal of most platforms is the optimal and most sustainable solution for the North Sea area. From an environmental and socio-economic point of view it is worthwhile to consider alternative options too. Hard substrate communities have developed on the underwater parts of the platforms and removal would take these local biodiversity hotspots away. The decommissioning process is energy intensive, leading to emissions and high costs.

There are many different opinions about the North Sea and the acceptability of decommissioning alternatives. With stakeholder dialogues, including all North Sea countries, these alternatives can be made more explicit. It is important to reach consensus about the main issues to make a strategy possible.

Before any stakeholder dialogue is started (phase 2), it is necessary to have a good understanding of the backgrounds of the issues (phase 1). Therefore, IMSA Amsterdam has done an assessment on the North Sea ecosystem issues (IMSA Amsterdam, 2011a) and the decommissioning process (IMSA Amsterdam, 2011b). In this report we discuss what is known about ecosystems at and around oil and gas platforms.

1.1. Problem definition

In the coming decades the North Sea oil and gas production will decline, meaning structures will become redundant. OSPAR (Oslo Paris Convention) issues guidelines to limit the impacts of human activities on the marine ecosystem. OSPAR 98/3, deals with the removal of oil and gas facilities.

Removal of oil and gas facilities affects the local ecosystem that has developed on and around the structures. In this study we intend to define both positive and negative effects of all options and come to best-fit solutions with regard to the local and North Sea ecosystem.

The main research question therefore is:
"How is the North Sea ecosystem affected by the presence and decommissioning of offshore oil and gas facilities?"

1.2. Objectives

- To describe the local ecosystems on and around the oil and gas facilities, including the richness of species, abundances and unique species.
- To analyse the impact of different decommissioning options on both epifauna and epiflora, and on the surrounding benthic and mobile species.
- To elaborate on the knowledge of the functions and effects of hard substrates for local and regional marine developments.
- To discuss the significance of long-term no-fishing safety (exclusion) zones around oil and gas platforms for understanding the potential of the North Sea.
- To evaluate to what extent ecosystem health near oil and gas facilities may contribute to the overall quality of the North Sea system.

1.3. Study approach

This study is part of a preparatory phase and delivers a preliminary inventory of the public data on ecosystems at and around platforms. The report is the end result of a desk study and interviews with experts.

The desk study is mostly based on public information and therefore limited. In a follow-up phase it is recommended to work on an open-source database for ecological data concerning platforms. In this phase first steps have been taken for a North Sea ecology network, involving marine institutes from around the North Sea.

The information from platform ecosystems is combined with data available from other underwater structures such as wind turbines and wrecks: a comparative study. Next to this, parallels are drawn with studies in the Gulf of Mexico, where artificial reefing of platforms is common. These experiences are translated into North Sea practices and opportunities. Besides summarizing the existing knowledge in chapter 5 and 6 we discuss the significance of platforms and the decommissioning process with respect to the North Sea. This part needs further elaboration in the next phase. We also define the knowledge gaps and lacking data, which are of importance for decision-making.

1.4. Report outline

We start with a short outline of the geographical setting: the North Sea. Chapter 3 gives an introduction to the available oil and gas facilities and what kinds of platforms are considered in this study. Chapter 4 summarizes information from the case studies of selected structures, presented in annex II. It compares the biodiversity around platforms, wind parks and wrecks. In chapter 5 the positive and negative effects of five decommissioning options are described, on both local and regional scales. Chapter 6 discusses the benefits and threats of leave-offshore options: what are possible functions of the platforms and what preliminary interpretations can be made about ecological benefits. Conclusions are given in chapter 7 together with an overview of recommended research.

2. North Sea

This chapter gives an outline of the North Sea system and ecological characteristics. Further information on these subjects can be found in report 'The North Sea system' (IMSA Amsterdam, 2011a).

The North Sea basin developed into the shallow coastal sea as it is today during the Holocene era, around 6000 years ago. It is interconnected to other seas, with in the southwest the Channel opening to the Atlantic Ocean, in the north the Norwegian Sea and in the east the Baltic Sea.

As defined by OSPAR, the Greater North Sea has a surface area of about 750,000 km^2 and a volume of about 94,000 km^3 (figure 2.1.) The bottom topography is characterised by geomorphological processes of past glacial fluctuations.

Figure 2.1. Maps of the North Sea area (OSPAR, 2000).
For more detail see annex I.

The North Sea area has a high diversity of substrate types (fjords, chalk cliffs, subtidal banks, mud substrates, etc.) with characteristic regional variations in depth, temperature, and water and sediment type. Consequently, the North Sea accommodates many different biotopes and associated species. It is a productive ecosystem, due to the terrestrial and oceanic inputs of nutrients. Especially in the shallow coastal regions and the tidal fronts biodiversity and biomass are high.

Facts North Sea	
North-south dimension	960 km
East-west dimension	580 km
Surface area	750.000 km²
Volume	94.000 km³
Mean depth	95 m
Maximum depth	700 m (Norway)
Annual river outflow	300 km³ directly and 470 km³ via Baltic Sea
Catchment area	850.000 km² (184 miljoen inhabitants)
Mean temperature winter	6°C
Mean temperature summer	17°C
Salinity	34 to 35 g salt per liter water
Tidal differences	0 to 8 m

Figure 2.2. Physical parameters of the North Sea (www.mumm.ac.be).

There is a distinct difference between the northern and the southern North Sea. The northern part is comparatively deep and has a large exchange of water with the Atlantic Ocean. The southern part is less deep and is connected to the Atlantic Ocean via the Channel; it has strong tidal currents, a large amount of land-based inputs and high levels of sediment load. We distinguish three main regions, including an intermediate zone:

- The southern North Sea, up to 50 m of depth, including the Doggerbank;
- The central North Sea, from 50 to 100 m of depth;
- The northern North Sea, from 100 m up to the continental margin. Parts of the northern North Sea are even deeper: the Norwegian trench reaches to 270 m and the Skagerrak to 700 m of depth.

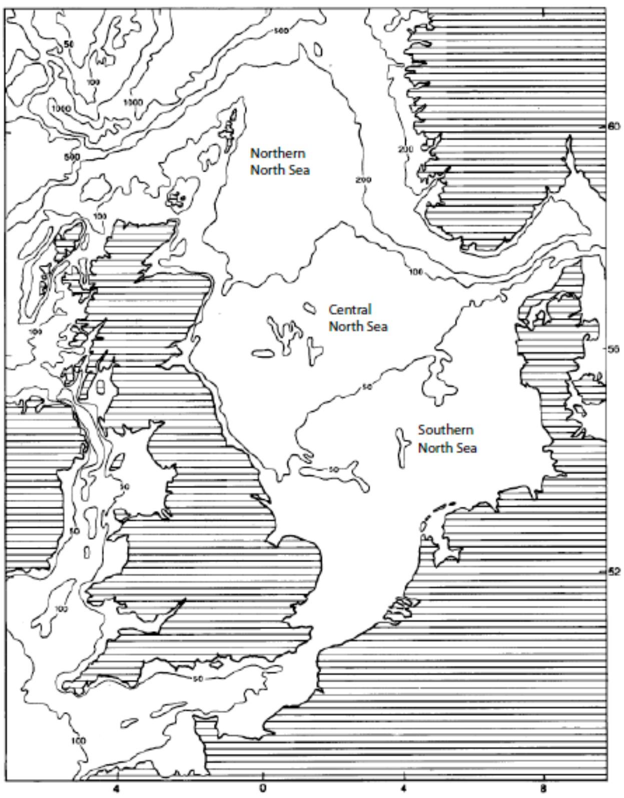

Figure 2.3. Map of the North Sea zoning
(edited from Gerrard *et al.*, 2000).

The Greater North Sea includes the Channel and the Skagerrak. In this report we concentrate on the main basin, where the oil and gas platforms are located. Therefore both Channel and Skagerrak/Kattegat are mentioned separately if included in the analysis.

The seabed varies with depth and currents (for more information see IMSA Amsterdam, 2011a). The southern part typically has coarse-grained sands, while fine sands and clays are more common in the northern part. Hard substrates like gravel and oyster bed used to be more widely available in the past, but with the extensive fisheries at the oyster grounds in the 19th and 20th centuries, most of the biogenic structure has disappeared. Boulder fields occur in the German Bight and off the coasts of Scotland, Orkney and Shetland. And parts of the coasts of Norway and UK are of rocky substrates (figure 2.4.).

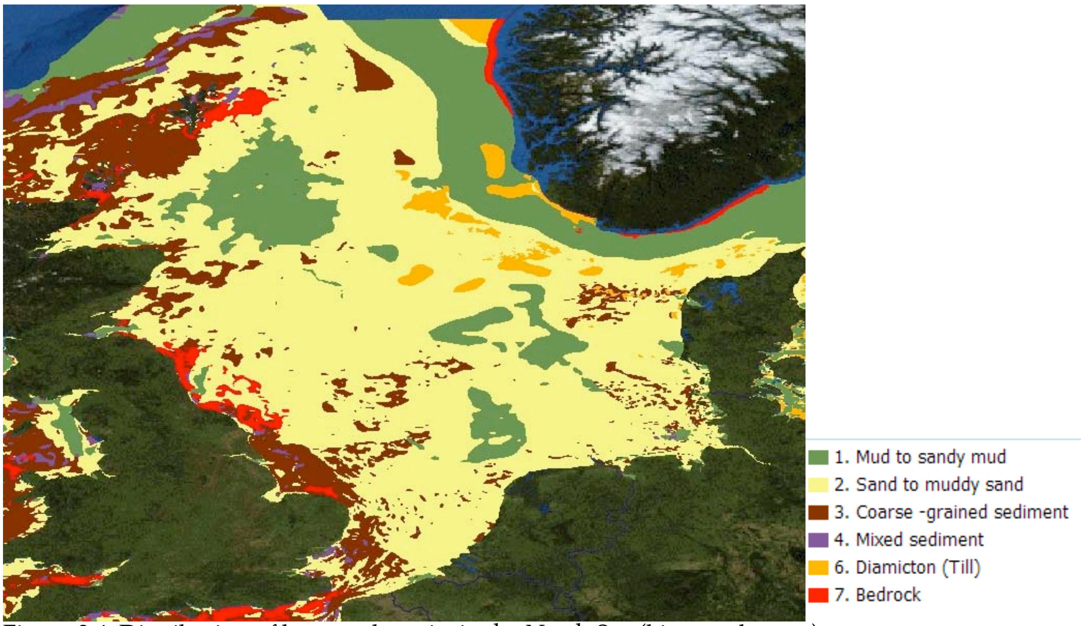

Figure 2.4. Distribution of bottom deposits in the North Sea (bio.emodnet.eu).

For this project we have made a very rough estimation of percentages of hard substrates in the northern and southern North Sea, including the intertidal coastal areas. If we only count bedrock (including boulders) as hard substrate, then in the southern North Sea 0.5% of the seabed surface is hard substrate and in the central and northern North Sea 3.1%; approximately 18,000 km^2 of natural hard substrate for the total North Sea (2.4%). We do not include the diamicton (mixed and coarse-grained substrate), because only part of these sediments will consist of pebbles and cobbles that are large enough to be called 'hard substrate' (IMSA Amsterdam, 2011a).

In winter, the water in most parts of the North Sea is vertically well mixed, or only slightly stratified. From spring to autumn stratifications typically occur in the northern and central North Sea, while the water in the southern part, with the exception of the oyster grounds, remains mixed. The stratified water shows clear differences in temperature between the layers at the surface – getting warmer – and the deeper layers that remain relatively cold (ICES FishMap).

As the North Sea is shallow, there is a strong coupling between benthic and pelagic processes, making the region a productive ecosystem, with average production rates estimated at 150 to 250 gC/m^2 annually. In the coastal areas production is higher and can reach 400 gC/m^2 per year (McGlade, 2002; Aquarone & Adams, 2009).
The diversity of the offshore benthic communities is high, except in areas of direct industrial impact. Crustaceans such as lobsters, crabs, shrimps, and oysters and clams are commonly found throughout the North Sea.

Overall approximately 230 species of fish and shellfish are found in the North Sea; a smaller group (~50) is responsible for 95% of the total biomass of which most are used for commercial purposes. The fish diversity is lower in the shallow southern North Sea, with species such as plaice, sole and dab. In the central and northern North Sea saithe, haddock, cod and whiting are abundant (McGlade, 2002).

The North Sea also accommodates a number of sea mammals, amongst which pinnipeds; the grey and harbour seal are most common in the region (OSPAR, 2005). Sixteen species of cetaceans are regularly observed in the North Sea. The harbour porpoise population is largest (~280,000 individuals), but there are also whales (minke, long-finned pilot), dolphins (common, white sided, white beaked), and killer whales (OSPAR, 2000; OSPAR, 2009b).

Tens of millions of birds make use of the North Sea for breeding, feeding or migratory stopovers every year, which represent 110 different species (McGlade, 2002; Lindén *et al.*, 2009).

At the same time the surrounding countries[1] intensively use the North Sea the last two centuries. Flora and fauna have been impacted by fisheries, dredging activities, shipping, military practices and the offshore energy industry. Eutrophication from land and river runoffs and atmosphere, the influx of alien species by shipping and aquaculture, and overexploitation of fish stocks are examples of human activities that have led to degeneration of the North Sea ecosystem (Aquarone & Adams, 2009).

[1] Norway, Sweden, Denmark, Germany, The Netherlands, Belgium and France (northern and central European mainland) and England, Scotland and Orkney Islands (United Kingdom).

3. Review of North Sea oil and gas facilities

3.1. Geographical setting of North Sea platforms

Over the last four decades the offshore exploration and production of oil and gas has become a large industry for the North Sea countries. The five oldest structures date from 1967 and are all located on the British continental shelf. In total 547 above-water platforms and 534 subsea structures are spread over the British, Norwegian, Dutch, Danish and German continental shelves (IMSA Amsterdam, 2011b). To transport the oil and gas to shore, over 10,000 km of pipelines are placed on or in the seabed.

Of the 547 platforms the majority is fixed steel (89%). There are floating structures (7%) and the minority consists of fixed concrete (4%). Figure 3.1 gives a schematic image of both the above-water and the subsea structures. This last group represents facilities that are directly attached to the well or the seabed.

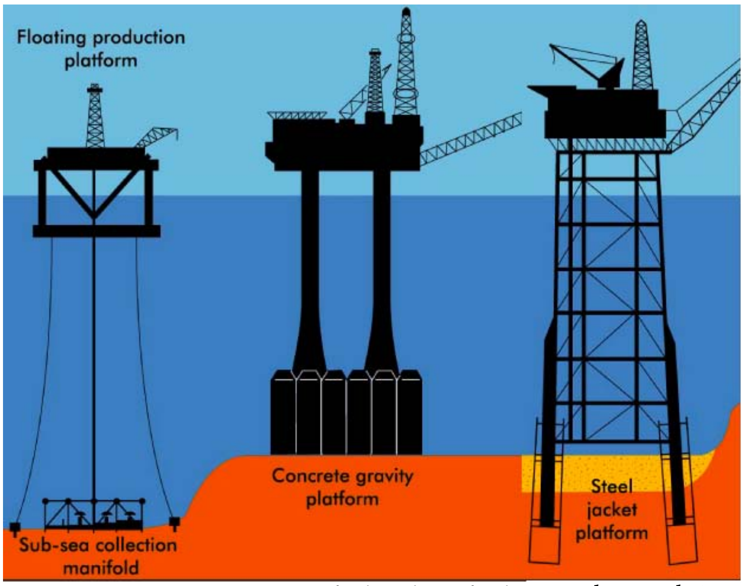

Figure 3.1. Four main groups of oil and gas facilities in the North Sea (modified from BP).

In this report we focus on the fixed structures, consisting of fixed steel, and concrete gravity-based structures (510 platforms). The characteristics and decommissioning of subsea and floating structures are not in the scope of this assessment.

The British continental shelf has the highest share (50%) of fixed structures. For more information see report IMSA Amsterdam (2011b). In the southern North Sea water depths are around 30 to 50 meters. The structures there are smaller than the platforms in the central and northern North Sea, where depths exceed 300 meters. The largest and heaviest structures are found in the northern North Sea, with the largest platform off Norway: the Troll platform of 472 meters of height and 656.000 tons of weight.

As already indicated, the sizes of oil and gas platforms vary from small, unmanned satellite units, up to large platforms with topsides weighing more than 40,000 tons. We classify four groups, based on jacket weight, which are shown schematically in table 3.1. We use indicative values for the hard-substrate area created by the jackets, based on calculations of the external underwater surface area of a steel jacket like Brent Alpha or Brent Delta (personal communication G. Picken).

Table 3.1. Platform categories based on jackets weight (according to OSPAR; IMSA Amsterdam, 2011b).

Platform category	Weight (jacket)	Surface area jacket (in m^2 with platforms heights between brackets)	Number of platforms
Concrete		43,000 - comparable to ultra large steel	21
Ultra large steel	> 10,000 tons	43,000 (140 m)	41
Large steel	2000 – 10,000 tons	10,000 (70 m)	106
Small steel	0 – 2000 tons	2,500 (35 m)	343

Note: The surface areas of the jackets are approximations based on figures of ultra-large structures in the North Sea. These numbers give only rough indications and need to be revised if used for more detailed studies (in consultation with G. Picken).

These platforms currently represent an additional 3.7 km^2 of hard substrates in the North Sea. Around the platforms is a safety zone of 500-meters radius, which are not accessible for other activities than those related to the oil and gas winning. Considering these safety zones around each platform, the 510 fixed platforms together provide 400 km^2 of no-fishing zones. Inclusion of the floating platforms would add another 29 km^2. The subsea structures have no safety zone, because trawling does not harm them.

The fixed platforms occur in all three regions of the North Sea, but most are located in the southern part: 296 platforms, of which 93% is small steel. The northern part has the least but also the largest platforms, with 36 structures of which 14 concrete and 14 ultra-large ones. The central North Sea is most diverse in platforms and accommodates 173 structures mostly of small and large steel. Figure 3.2. schematically shows the platforms per region.

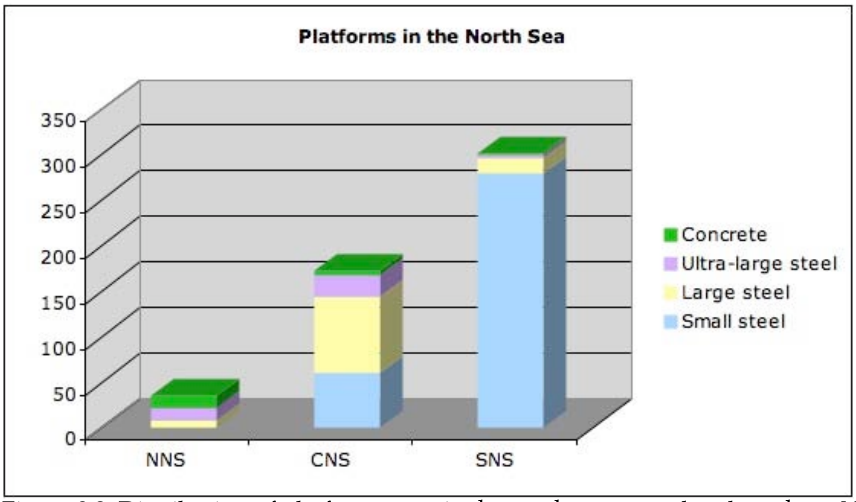

Figure 3.2. Distribution of platform types in the northern, central and southern North Sea.

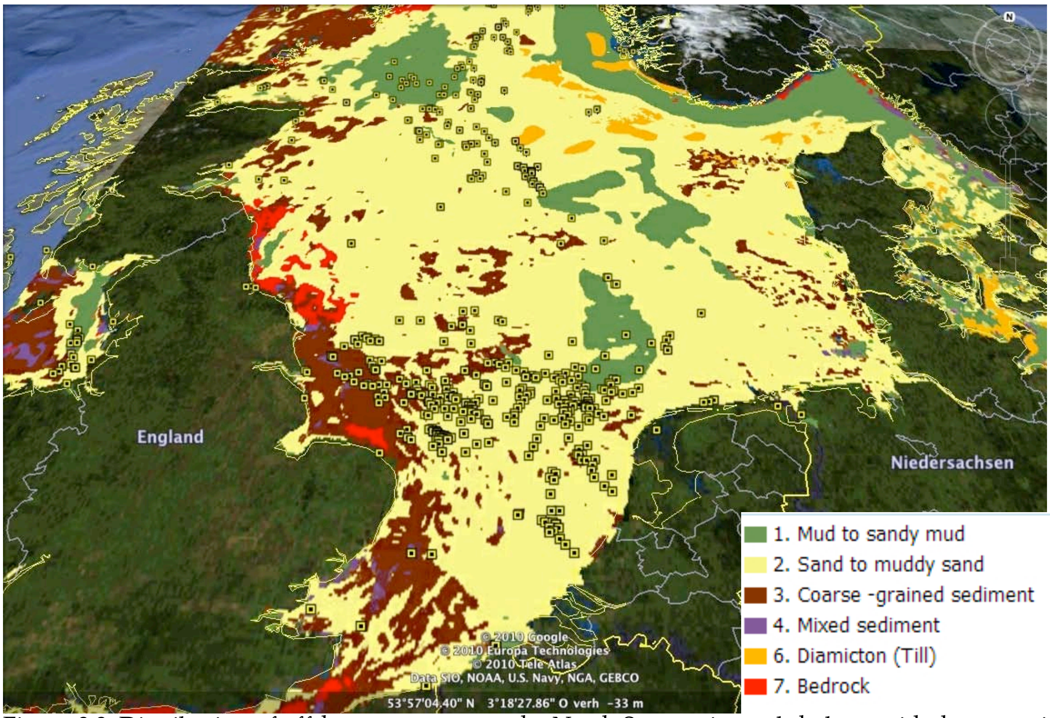

Figure 3.3. Distribution of offshore structures at the North Sea continental shelves, with the exception of the platforms at the Danish continental shelf (due to missing data).

3.2. Physical features of offshore platforms

Offshore fixed production platforms consist of steel jacket or gravity-based substructures. Figure 3.4. shows a typical design of a North Sea steel jacket. Their piles penetrate the seabed several tens of meters, depending on the size of the structure. The jacket rises to above the water surface, carrying the topside. A jacket can be a monopile (1 pile) or can consist of several legs; two to ten legs with frames of steel connections.

The topside varies from small sized (100 tons) to very large elements (40,000 tons) and contains all kinds of instruments and in case of manned platforms also accommodates the personnel. It mainly consists of steel.

The jacket also consists mainly of steel. As already indicated in the former paragraph they differ in size, with the largest structures in the northern North Sea and the smallest ones in the southern part. Subsea parts of jackets will get covered with marine growth after some time. As most jackets are not designed to carry this extra weight, measures have to be taken to prevent and minimise the growth. Such measures include physical removal (by divers) and cleaning with high-pressure water jets. Potential hazardous materials are the coatings, paints and anodes to protect the structures. The sacrificial anodes emit zinc or aluminium to the water. Over the last ten years the use of mixed anodes or aluminium anodes was stimulated, which has led to a decrease in zinc of about 35% (Oranjewoud, 2008). Combined with the figures for the Dutch continental shelf of 2001 (URS) it is estimated that per platform, depending on the amount of anodes needed (related to amounts of steel), per platform 52 to 88 kg zinc is released annually.

Figure 3.4. Example of a steel jacket: the four-legged tubular steel Miller platform (BP, 2008).

Only a very small part of the concrete gravity-based structures are designed in such a way that removal is prepared for. Most of them were meant to store oil at their offshore winning site. They have a large, heavy foot of concrete and moving them to other locations is often very complex (Atkins Process Limited, 2003; OGP, 2003).

Around the platforms often drill cutting piles are found, being the result of well drilling. In the past these rock cuttings and drilling muds were left near the platform on the seabed, often containing oil-based liquids. Since 2000 the North Sea countries managed a phase out of the offshore disposal of these muds, but discharges of water-based muds (WBM) are still occur. The impact of toxicity affects the seabed severe but localised (200 to 400 meters). In most cases benthos in the seabed is reduced and beneath the platform even absent (personal communication NIOZ; OSPAR, 2006). Degradation is slowly, especially when buried and anoxic conditions apply. It can take hundreds of years before the OBM in larger drill cutting piles has degraded.

For more information on the platform design and materials see report 'Analysis of the impacts of decommissioning options of North Sea oil and gas facilities' (IMSA Amsterdam, 2011b).

4. Marine biota associated with North Sea artificial hard substrates

Worldwide research has been done on the biological communities of submerged structures in tropical or temperate seas, but little is known about the effects of structures in cold-temperate areas, amongst which the North Sea.

Settling of organisms strongly depends on the composition of the substrate and the heterogeneity of the structure surface. Most commonly used materials for submerged structures are concrete and steel. The different microscale environments attract different communities, which are probably most influenced by surface heterogeneity. In general research on the distinctive ecological effects of these materials is not abundant (Andersson *et al.*, 2009).

This chapter focuses on what is found on artificial hard substrates (platforms, wind turbines, wrecks) and brings together the similarities and differences of a few cases (annex III). What can we learn from these data sets? Main topics are the diversity and abundance at the hard substrate and the surrounding seabed, where possible including the comparison with a situation without hard substrate (reference in time or space).

4.1. Comparative study: available data

We had limited access to data on ecological developments on and around platforms, therefore we use comparisons with other cases of submerged objects that have been overgrown by all kinds of biota and have become part of the ecosystem habitat.

Wrecks, wind turbines and platforms have similarities, but also distinct differences that should be taken into account:

- Wrecks are totally submerged, are not cleaned and contamination grades depend on the presence and type of cargo. The ages of wrecks differ, but some are already there for long periods.
- Wind turbines are relatively young and have intertidal and subtidal zones. The structures are cleaned on regular basis. The seabed has no contaminations related to the energy winning, but often rocks are laid around the foot of the turbine.
- Platforms have ages varying from recent to 40 years and also have intertidal and subtidal zones. The structures are protected from marine growth and regularly cleaned. The surrounding seabed is often contaminated as a result of drilling activities.

To get an impression of the availability of industrial materials in the North Sea, information is added on mean surface enlargement and related no-take zones. Where these were not available or accessible, we made estimations by extrapolating the known facts and figures.

Oil and gas platforms

In the '70s and '80s oil and gas operators in the North Sea did research on the ecological status before and after installation of oil and gas platforms. The objectives were a) to understand the effect on the seabed communities and mobile species, b) to measure the marine growth on platform legs for regular cleaning, and c) to determine colonization processes and diversity of species on and around offshore oil and gas facilities. The marine growth received attention, because it affects the integrity and stability of the platform. Marine growth leads to added stress to the structure and enhanced corrosion, and it hinders technical inspection.

In the '90s the research slowed down; the most pressing effects of marine growth on structures had been analysed. The focus of research shifted to the subject of OBM-cuttings and their potential toxic effects on species in the surrounding habitats. The studies on epifauna and epiflora are still performed by operators, but the focus is mainly restricted to measuring the thickness of epifauna communities. Interpretations of species occurrences and effects on the local or larger North Sea ecosystems are mostly lacking. Data may be available in the form of inspection videos or samples, but is in general not analysed to assess biodiversity or ecosystem health.

For this inventory we used the public information of five platforms, located in the central and northern North Sea: Montrose Alpha (with some data of the Forties platforms), Tern Alpha, Eider, Gannet Alpha and Kittiwake Alpha (annex II.B).

Most research on the seabed around platforms was done in areas were OBMs were used. In the 1990s attention was drawn to the negative effects of OBM and SBM attached to the drill cutting piles. Just a few studies focused on the seabed communities in safety zones without toxic drill cutting piles.

It is estimated that platforms provide about 3.7 km^2 of hard-substrate surface and 400 km^2 of safety (or exclusion) zones (see chapter 3).

Wind turbines

Over the last two decades the development of offshore wind energy has grown to a capacity of 2100 MW in the North Sea, delivered by twenty wind parks.

Table 4.1. Wind turbines in the North Sea, excluding Channel and Kattegat (www.4coffshore.com, 2010).

Country	Wind parks	Turbines	Safety zones parks (km2)
United Kingdom	8	266	85
Norway	1	1	0.78
The Netherlands	2	96	41
Denmark	2	171	54
Germany	5	95	65
Belgium	2	61	13
Total	20	690	158

Note: Denmark has an additional 8 parks in the Kattegat, comprising 67 turbines.

The turbines are located at relatively shallow water depths, with the majority ranging from 15 to 25 meters. Here we use a mean surface area enlargement for one turbine of 251 m^2 (4 m diameter; mean depth of 20 m). Different turbine models are used in the North Sea, so these are only rough figures. We exclude the surface enlargement by scour protection or rocks at the foot of the pile. The total hard substrate by wind turbines is then estimated at ~ 0.17 km^2. In a follow-up study these numbers need to be further specified.

The parks and associated exclusion zones create a no-fishing area of 158 km^2. With the ambition of the North Sea countries for offshore wind energy this may expand to 100 GW by 2020 (www.dw-world.de), meaning an addition of about 33,000 turbines (3 MW per turbine) which create ~8 km^2 of hard substrate. Based on the average area per wind farm we estimate an addition of more than 13,000 km^2 of safety zones.

In this inventory we have considered one wind project case in the North Sea: Egmond aan Zee (annex II.C).

Wrecks

Data is available, but not easily accessible. For this inventory we use estimates of the total number of wrecks that are above the sediment in the North Sea.

The surface enlargement by wrecks depends on the type and size of the objects. If we look at a broader North Sea perspective, there are many wrecks, which mainly sunk during the past three centuries and varying from battle ships to lifeboats. No two wrecks are the same, because of differences in the type of ship, the cargo that they carried and the location at which they sunk. To come to a mean surface area estimate we use the number defined by Krone & Schröder (2010) who did an analysis of 64 wrecks in the German Bight. They decided on a mean surface area per wreck of 1200 m^2. For this inventory these figures will be sufficient, but for follow-up studies more detailed information can be obtained from hydrographical services or European registration sites. Since no good public sources are available for the number of objects in Norway and Denmark, we give margins.

Table 4.2. Estimates of wrecks per continental shelf (www.northseawrecks.com).

Country	Surface areas EEZ	Number of objects (~)
United Kingdom	360,000	20,000 (rough estimate: 50% of the 44,000 wrecks around UK and Ireland (www.shipwrecks.uk.com; personal information UK Hydrographical Office).
Norway	150,000	1,000 – 10,000 (www.dykkepedia.com)
The Netherlands	58,000 (including Wadden Sea)	2,600 (Van der Weide, 2008)
Denmark	57,000	1,000 – 10,000
Germany	40,000	1,500 (www.bsh.de)
Belgium	4,000	270 (www.maritieme-archeologie.be)

Note: The surface areas for the exclusive economic zones are calculated from EEZ maps and have a deviation of about 5% (http://en.wikipedia.org/wiki/File:North_sea_eez.PNG).

This brings the estimate of total wrecks in the North Sea at 25,000 to 45,000 units. The total wrecks surface in the North Sea then yields a rough estimate of 30 to 54 km^2 of hard substrates.

Worldwide scientific research is done on wrecks and their biological communities. Also in the North Sea there have been several research programs. In this inventory two studies are used for analyses: wrecks on the Dutch continental shelf (Van Moorsel *et al.*, 1991) and the Belgian part of the North Sea (Zintzen & Massin, 2010). See annex III.

Overview of total man-made hard substrates

Complexity decreases from wrecks, to platforms, to wind turbines with respect to the steel structures. The scour protection and additional rocks at the foot of wind turbines and platforms can increase their complexity and make them more attractive as habitat.

If not removed, the platforms are more beneficial for artificial reefing than wrecks and wind turbines, because their life endurance is expected to be higher than that of the wrecks (heavier structure with thicker materials) and they have a more complex frame than wind turbines, allowing different habitats to develop (personal communication Van Moorsel/Ecosub).

Table 4.3. Hard substrates and exclusion zones at North Sea scale (estimates).

	Surface area	Exclusion zones
Platforms	3.7 km^2	400 km^2
Wrecks	30–54 km^2	-
Wind parks	0.17 km^2	158 km^2
Natural reefs	18,000 km^2	-
OSPAR MPA	-	41,000 km^2

4.2. Ecosystems near submerged artificial structures

The type of material (steel, concrete) will influence the biological communities, due to the roughness of the surface. For example some hydroids are more inclined to settle on concrete, because it is more granular than the relatively flat steel surfaces. Fish assemblages around structures do not show differences among the reef materials; similar communities are observed near rocks, concrete and at steel substrates (Andersson *et al.*, 2009).

4.2.1. Epifauna and epiflora on the structure

When a new hard substrate is introduced settlement of epifauna occurs rather quickly. The artificial reef program near Noordwijk (The Netherlands) showed that within twelve days the first hydroid colonies have already settled (annex II.F).

Three categories of marine growth can be recognized:
- Slimes of bacteria, algae and protozoa (the micro-layer).
- Soft macrofouling, including anemones, sponges, hydroids, bryozoa.
- Hard macrofouling, including mussels, barnacles, tubeworms, and calcareous hydroids and bryozoa.

The slimes do not form significant loading onto the structure, but may influence corrosion processes. Instead, the macrofouling is of high concern to operating parties offshore, due to structure loading. Often it is removed on a regular basis to avoid overloading of the structure.

Species composition

From the research on platforms and wind turbines the overall conclusion can be drawn that the colonization of the vertical structures shows the typical zoning, correlated to temperature, light penetration, salinity and others (Hiscock *et al.,* 2002; annex III). Colonization appears also to change with time. In the first years pioneer communities settle on the structure, such as hydroids and tubeworms: they are often opportunistic species with high growth rates, low sexual maturity ages, high larval dispersal, but short lives. These pioneers are replaced in time by species that are typically slower colonizers, but when settled show high longevity. Most are more competitive and more resistant to predation. Anemones are an example of such species. The overgrowth often goes together with increasing complexity of the ecosystem (Whomersley & Picken, 2003; Kerckhof *et al.,* 2010). Variation in species composition continues, also caused by seasonal changes, but on most offshore submerged structures a climax of marine growth is probably attained five to six years after placement of the structure.

- The upper zones, including the intertidal zone, show high variability in marine growth. This part of the structure creates an opportunity for settlement of shoreline or shallow-water fauna. Therefore the geographical location of the column is a crucial factor; distance to the coast and to other offshore structures and currents determine larvae will reach the structure. In their larval, planktonic stage species can cover large distances, but they have to settle within two to three weeks, when metamorphosis starts. Platforms within the reach of coastal currents often have mussel colonies dominating the upper zone of the structure. *Mytilus edulis* is common in the North Sea. On the platforms that are not influenced by coastal currents mussels are less abundant or even absent. Then other dominant organisms are observed, such as hydroids and algae (e.g. Montrose Alpha, annex II.A). The hydroid *Tubularia* is found throughout the North Sea and has settled at the majority of the platforms. In general the platforms in the northern areas have higher abundances of soft marine growth species at the upper zone, such as kelps, hydroids and bryozoa, while mussels dominate the southern platforms.

- Communities with tubeworms and barnacles are among the pioneers in the intermediate zone of a vertical structure. The secondary cover is a more complex composition of soft epifauna communities of anemones, soft corals, hydroids, sponges and bryozoa (Hardy, 1980; Ralph & Troake, 1980; Southgate & Myers, 1985).

- The deepest part of the vertical column has in general the lowest biodiversity. Hydroids, bryozoa and typically deepwater barnacles and polychaete worms are common. Drill cutting piles at the seabed can affect marine growth at the lower parts of the structure. Studies of platforms with oil-based muds show that epifauna covers those structures to two meters from the piles (annex II).

Table 4.4. Schematic overview of the composition of dominant species within the three indicative zones at vertical columns in the North Sea (personal communication G. Picken; Ralph & Troake, 1980; Whomersley & Picken, 2003; Southgate & Myers, 1985; annex II).

Depth	Species composition
0 – 25 m	Mussels, tubeworms, barnacles, algae (red, green, brown), and hydroids in shady parts of structure
25 – 60 m	Hydroids (10 – 15 cm thick covers), anemones (*M. senile*), soft corals (*Alcyonium*/Dead Men's Fingers), *Tubularia*, *Tunicates* (sea squirt)
Around 60 m and deeper	Hydroids, bryozoa, deepwater barnacles (*Balanus hameri*), polychaete worm (*Filograna implexa*), tubeworms, *Lophelia pertusa* (NNS).

Sampling of mussels growing at platforms in the Gulf of Mexico proved the shells to be free of contamination and fit for consumption (Richards *et al.*, 2008). However, in the North Sea samples of mussels at the Maureen platform were classified as markedly or grossly polluted. The samples showed concentrations of lead, cadmium and PAH (polycyclic aromatic hydrocarbons) that were higher than the guidelines set by the Norwegian Pollution Control Authority (Rogaland Research, 2001).

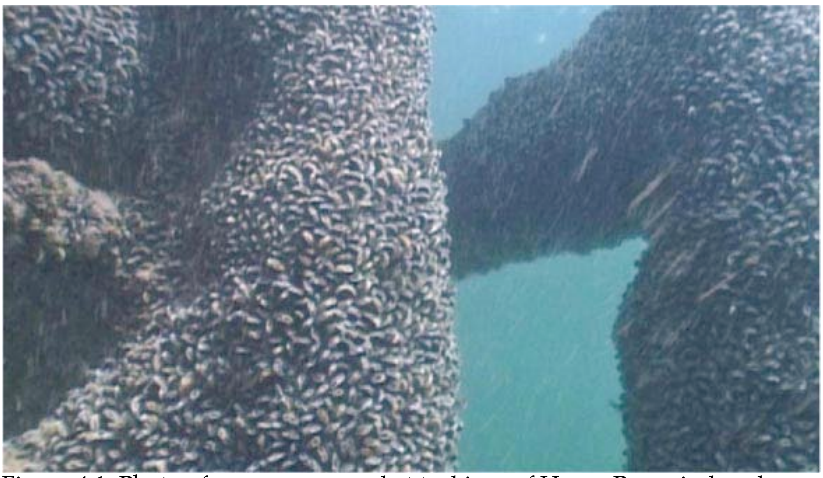

Figure 4.1. Photo of common mussel at turbines of Horns Rev wind park (Jens Christensen, Danish Energy Authority, 2006).

There remain dissimilarities between artificial reefs and natural hard bottoms. Even after three years of development the reef types show 25.5 % dissimilarity (Prekel *et al.*, 2008; Carr *et al.*, 2003; Perkol-Finkel *et al.*, 2005). The materials (steel and concrete) and relatively plain surfaces do not offer the same opportunities as natural rocky areas with their rough relief and holes. However, only relatively short-lived artificial reefs have been studied.

Unique species

The species at the structures represent the normal epifauna and epiflora of the North Sea in relation to hard substrates and are not expected to contain unique (new) species to the North Sea system. Below we comment on some of the species that receive attention for settling at platforms.

Lophelia pertusa is a stony coral with a preference for waters of 6 to 8 °C and depths of 200 to 1000 m. Reefs are usually found in the Atlantic waters, but the species is also found in huge colonies at platforms and pipelines in the northern North Sea (north of 62° N); first at the Brent Spar in 1999, and later also at fourteen UK platforms (Bell & Smith, 1999; Highfield, 2006). Remarkable, because the reefs were considered vulnerable and not immune to oil contamination. At the vertical structures they are found at depths below 50 m with a growth rate of 26 (± 5) mm annually. This is high compared to growth rates at natural reef sites of 5 to 10 mm per year. In most cases the contaminated drill cutting piles have no negative effects on the *Lophelia*, except for near to the piles where the colonies show high mortality (Fosså *et al.*, 2002, Gass & Murray Roberts, 2006). The occurrence of this endangered species (CITES list) makes the platforms interesting sites. *Lophelia* reefs create complex habitats with high biodiversity at shelves, slopes and seamounts. They increase biodiversity with a factor ~3 and are expected to play a role in the spreading of fauna (Fosså *et al.*, 2002).

Figure 4.2. Colonies of *Lophelia pertusa* at North Sea platforms (Erling Svensen, www.imr.no).

In the southern North Sea the natural occurrence of the soft coral Dead Men's Fingers is very limited, mainly to the hard substrates at the Cleaver Bank. They are also observed at the legs of platforms, which offer them an alternative hard substrate (annex II). Although Dead Men's Fingers is scarce in the south, in the northern part of the North Sea they are more abundant.

Biomass enlargement

Reef habitat on shipwrecks is associated with biomasses up to 500 g/m^2 (Leewis & Hallie, 2000). Over the whole North Sea the average biomass is 7 g/m^2 AFDW with a decrease northwards. It should be commented that the patterns of biomass distribution are complex and vary with type of sediment, latitude, water depth, wave energy and ecological interactions (McGlade, 2002).

If present, mussels and other bivalves can develop in thick bands at the upper part of the vertical columns, with maximum abundance in the first ten to fifteen meters near the surface. Under offshore conditions mussel growth rates can be higher than in coastal areas. The experiences with off-bottom cultures at mussel farms also show higher growth rates, due to optimal filtering of food by lack of non-digestible particles, the continuously submerged conditions, so they can feed all the time, and the absence of low air temperatures that coastal mussels experience (Joschko *et al.*, 2008; personal communication Van Moorsel/Ecosub & G. Picken). There is strong evidence that the growth rates of mussel *Mytilus edulis* are greater on offshore platforms than in natural intertidal situations.

Invasive species

Research programs on wind parks in the North Sea have shown the settlement of some exotic species on the piles of the offshore turbines. Examples of invasive species in the North Sea that could benefit from additional hard substrates are *Stylea clava*, a tunicate originating from the Northwest Pacific, the Japanese oyster and New Zealand barnacles (Krone *et al.*, 2007; personal communication F. Kerckhof).

Most important factors that promote the settlement of exotic species are the shipping industry (ballast water, marine growth at the submerged parts) and climate change. If the invasive species prefer hard substrate for settlement, the availability of artificial hard substrates can play a role in their spreading. However, it is not expected that platforms are the critical factors in the occurrence of invasive species in the North Sea. The occurrence of invasive species mainly depends on the introduction of the species into the region, in which ballast water has a crucial role (based on personal communication F. Kerckhof, W. Lengkeek - Bureau Waardenburg).

4.2.2. Mobile species on and around the platform

Part of non-attached invertebrates prey on the marine growth communities. Species as the edible crab, sea spider and sea urchin are the species that feed on the structure (Page *et al.*, 2008). The shells that fall down from the structure onto the seabed form feeding grounds for starfish (common starfish, brittle star).

Some of the invertebrates prefer crevices or holes (e.g. lobsters). The wrecks can offer a better habitat for these organisms than the piles of wind turbines or platforms for these organisms. The rocky areas of natural hard substrates are expected to provide the best shelter. Artificial reefs create opportunities for some hard-substrate species. The wrecks in German waters provide shelter for the European lobster that is endangered in this region. It is assumed that wrecks can function as stepping stone structures (Krone & Schröder, 2010).

Platforms show higher densities of crab species (i.e. *Cancer antennarius* and *Cancer anthony*). For some the platforms function as recruitment and residence habitat and for others it is only a refuge for short-term visits (*Cancer productus*, *Loxorhynchus grandis*). For the last group the platform can still play a role in reproduction (Page *et al.*, 1999).

Fish

Within a few days of introduction of a hard substrate, large schools of fish have been observed, even if there is no epifauna settled on the structure yet. This would suggest that fish are attracted by other factors than food at the hard substrate (personal communication G. van Moorsel; Leewis *et al.*, 1997; Reubens *et al.*, 2008; Andersson *et al.*, 2009).

Several research programs about oil and gas platforms and fish have shown the relationship between the two (Stanley & Wilson, 1991; Jensen *et al.*, 2000). Norwegian research at the Ekofisk field, assessments of platforms by the University of Aberdeen and UKOOA surveys all show aggregations of fish around the structures. A record of more than twenty commonly occurring fish near platforms in the North Sea has been identified.

In the northern and central North Sea saithe is most abundant. Haddock, whiting, cod and Norway pout are also well represented. In the southern North Sea demersal species are more abundant: dab, plaice and sole.

Wilhelmsson *et al.* (2006) have done research on the impact of vertical structures on fish assemblages in several areas. They showed that the structure had a positive effect on the local fish densities. For plankton feeders they provide both protection and favourable currents. But also benthic fish gather around the structures. In general fish are present at all depths of the platform. The high-relief objects can have a landmark function, or also increase food availability for these species. However, even when the surrounding seabed is altered by industrial activities (installation, drilling), bottom dwelling fish aggregate around the structure. Flatfish are believed to visit the reef sites for feeding during the night. Most effective for flatfish enhancement are relatively low profiles (of about 3 m) over large areas. During the day the flatfish mainly use the structures for shelter, but they probably stay close to the structure (Fabi *et al.*, 2004; annex II.F).

Fish eating species such as cod, haddock, saithe and mackerel head for the structures to feed. The pelagic fish (e.g. mackerel) stay somewhat at a distance, while the large predators (e.g. cod, saithe) stay close to the structure. The average size of cod and haddock appears to be larger around the platforms. This may also be caused by higher competition at the site, leading to a selection of only the larger individuals (Soldal *et al.*, 2002; Jørgensen *et al.*, 2002; Wilhemsson *et al.*, 2006). They travel over large distances for feeding, spawning etc. Other fish species, such as rays and sharks need hard substrates to lay their eggs on. The hard-substrates then function as nurseries (WWF, 2009).

Experimental results show that the complexity of the structure increases the biodiversity. Charbonnel *et al.* (2002) measured that species densities and biomasses at hard substrates increased more than the actual surface area enlargement. The plankton feeding species decreased; excluding them from the measurements would increase the density with a multiplier of twenty and biomass with a multiplier of ninety (Wilson *et al.*, 2003).
Picken *et al.* (2000) estimated that a large steel platform might hold about 10.000 fish.

Sea mammals

Sea mammals are observed from the platforms: harbour porpoises, minke whales, (white-beaked, white-sided and common) dolphins and killer whales. If not too far from shore harbour and grey seals can also be found. It is likely that most platforms in the North Sea are in the foraging range of the grey seals. The harbour seal has foraging areas closer to shore, but they can be found far enough offshore to reach platforms (personal communication I. Boyd).

The animals that are most observed really close to the structures are harbour porpoises (PremierOil, 2006; Shell UK Limited, 2007). Studies show that harbour porpoises frequently visit the safety zones around platforms and possibly even approach the platforms. It is suggested that they feed around and/or below the platforms at night, comparable to the demersal fishes (Todd *et al.*, 2009; Coghlan, 2009). If these harbour porpoises stay close to the platforms for longer periods, this may even have affected the North Sea survey outcomes according to Todd *et al.* (2009).

Birds around structures

Wind parks are often associated with negative effects on bird migration. During operation the turbines could disturb bird communities, scare them away from their habitat or even lead to mortality by collision. Bird densities decline from the edge to the centre of the wind parks. The avoidance of wind parks by birds has the advantage that there are hardly any collisions recorded (Christensen & Hounisen, 2005).

Platforms do not have the same impact on birds. During operation platforms the light during nighttime is the main hindrance. The platforms create artificial islands offshore. They may be used for resting, feeding or may offer nestling areas. Shellfish or fish eating birds are attracted by the mussel colonies at the upper layers and/or the aggregated fish around the platforms (Russell, 2005; Wilhelmsson *et al.*, 2006).

Goldcrests and brambings have been seen at the structures in the northern North Sea, but also black caps, yellow browed warblers, green finches, siskins, starlings, snipes and curlews have been observed (www.birdforum.net).

4.2.3. Fauna and flora in and on surrounding seabed

Not much research is done at the seabed around platforms where WBM was used or no muds were discharged. As already mentioned most research focused on the safety zones around contaminated sites, to gain understanding on the effects of OBM. Below we discuss shortly the effects of the OBM affected areas and go further into the areas not disturbed by cutting piles containing toxic oil.

Studies have shown the negative effects of the toxic OBM on the surrounding environment. In the southern North Sea the cutting piles are smaller and more spread, due to higher energy levels. Studies from '85–'95 on the Dutch continental shelf showed that six to eight years after drilling ceased concentrations of oil were still in the seabed (Daan *et al*., 1990; 1995; 2006). Typically the sea urchin *Echinocardium cordatum*, occurring over the whole shelf, is very vulnerable to the toxicity of OBM. They are a good indicator, because the density of this species declines with increasing OBMs. Daan *et al.* concluded that long-term biological effects in the southern North Sea are in general found in a zone with a radius of 200 m around the wells. Samples close to the platform (three years after drilling) showed a total absence of fauna.

The degradation of oil was clearly observed, allowing slow ecological recovery, observable at the scale of the ten-year research. Within the hundred-meter radius zone still a number of species was significantly reduced. Additional research twenty years after the well drillings shows that *E. cordatum* is still absent near the wells up to ~200 meters (Daan *et al.*, 2006). The poor conditions form an opportunity as well for species that are favoured by disturbances, i.e. some worm species. In the central and northern North Sea the drill cutting piles are larger and less affected by wave energy. There, toxic effects are expected over a longer time span (UKOOA, 2002).

Duineveld *et al.* (2007) have studied a safety zone where only WBM was used and which is situated in a regularly fished area in the southern North Sea. They did not observe negative effects of the WBM, but note that their samples were restricted to more than fifty meters away from the platform for safety reasons. Near the platform it is possible that WBM creates a smothering effect on the seabed fauna (personal communication NIOZ).

Their data shows a clear difference between the fauna in the safety zone near the platform and the fauna in the regularly trawled surroundings. In the safety zone large, fragile bivalves that are vulnerable to beam trawling were more abundant and greater in size. They did not find younger stages of these bivalves, but only older animals, which had possibly already settled before installation of the platform. Unexpectedly, mud shrimps were also more abundant near the platform than in the trawled areas. As they live permanently in tunnels in the seabed, down to 50 cm deep, trawling (reaching to about 8 cm) would not be expected to harm them severely. Greater densities of *Amphiura filiformis* (brittle star) were observed as well.

The presence of structures does not impact the surrounding seabed much; at distances of more than twenty meters no changes in faunal composition are observed (Leewis & Hallie, 2000). The decaying organic material from the structure, such as mussel shells, can lead to oxygen deficiency and affect the benthic fauna of the seabed. Especially when the load of organic material is high and water renewal is relatively low, oxygen depletion is possible. This has a smothering effect on flora and fauna. If the surrounding seabed is of soft bottom, the formation of shell mounds will also lead to a local habitat change; specific communities settle on the shell mounds, attracting other species such as fish, sea stars and sea urchins (Wolfson *et al.*, 1979; Rogaland Research, 2001; Goddard, 2008).

The aggregation of large fish schools around the structures can have its impacts on the seabed community. Near artificial reefs it has been observed that densities of gobies and shrimp communities in the first hundred meters decreased, caused by feeding of pout schools near the platform (Van Moorsel, 1994).

4.3. Overall conclusions

Below we give a summary of the findings with first rough interpretations. Chapter 6 goes further into the value and meaning of these themes.

Hard substrate

- Wrecks, platforms and wind parks are the main components of artificial hard substrates in the North Sea. Together they provide about 34–58 km^2 of hard substrate surface below the water surface. In the southern North Sea, where about 900 km^2 of natural hard substrates is available (5% of total area), this is more significant than in the central and northern North Sea, which contain about 17,100 km^2 of hard sediments (95% of total).

- Piles of platforms and wind turbines, and wrecks form artificial hard substrates in an area that is dominated by muds and sands. On the structures epifauna and epiflora settles within a few days and these communities are dominated by pioneering species such as hydroids and barnacles. Within five to six years a stable ecosystem is formed, that still shows small variations in species composition and abundances. Along the vertical column of both platforms and wind turbines a clear zonation can be recognized.

- The species that settle on the structures are different from the seabed communities, consequently increasing the biodiversity of this area when a hard substratum is introduced (Leewis & Hallie, 2000). This enlarges biodiversity. However, these hotspots of biodiversity are localised and in general do not contain unique assemblages. An exception is the growth of *Lophelia pertusa* at northern North Sea platforms.

- Marine growth on platforms in the southern, central and northern North Sea shows similar species compositions and patterns. Differences in marine growth stem mainly from water depth and passing current. The latter determines the success of larvae in settling on a structure.

- The effect of the surrounding substrates on the epifauna or epiflora on the structure is very limited. It is the water mass (planktonic composition) rather than the seabed that defines the species composition on the platform. The distance to the shore is important too, because currents from coastal waters also influence the larval compositions of the water (personal communication G. Picken).

- However, in soft bottom areas an artificial reef will increase biodiversity more, by adding other habitat, than in areas with natural hard substrate.

- There remain dissimilarities between artificial hard substrates and natural hard seabed. In general complexity decreases from wrecks, to platforms, to wind turbines. If not removed, the platforms are expected more beneficial for artificial reefing than wrecks and wind turbines, due to their life endurance and the level of complexity of their frames.

Surrounding substrate

- The fixed platforms provide a total no-fishing area of 400 km^2. In the North Sea more no-take zones are created by wind parks (158 km^2), but of more significance for the future are the OSPAR Marine Protect Areas (MPA), that represent a total area of ~41.000 km^2 (OSPAR, 2010) and the Natura 2000 areas. Paragraph 6.2 will go further into MPAs.

- Part of the safety zones around platforms is affected by the toxicity from OBM present in the drill cutting piles. In the unaffected parts of the safety zones the ecosystem is more diverse, with more and often larger individuals.

- During research programs near platforms the seabed could only be studied as close as 50 meters from the platform. In the area directly beneath or next to platforms (smothering) effects of organic material from the structure can occur (personal communication NIOZ). The toxic effect of drill cutting piles is very local within a radius of 200 to 400 meters.

5. Effects of decommissioning options

5.1. Decommissioning options

Under OSPAR 98/3 total removal of oil and gas platforms is prescribed. It only allows derogations for a few types of platforms of which decommissioning is proven to be technically highly complex or to have negative effects on environment or safety. Heavy steel jackets weighing more than 10,000 tons and gravity-based concrete installations are taken into consideration, with additional attention for certain floating concrete and concrete anchor-base installations.

Chapter 4 described the occurrence of dense epifauna and flora at the structure. In this chapter we consider different options for decommissioning platforms, to show the effects on the ecosystem when the structures are not, partially or totally removed. We also discuss the options that are not permitted under OSPAR 98/3.

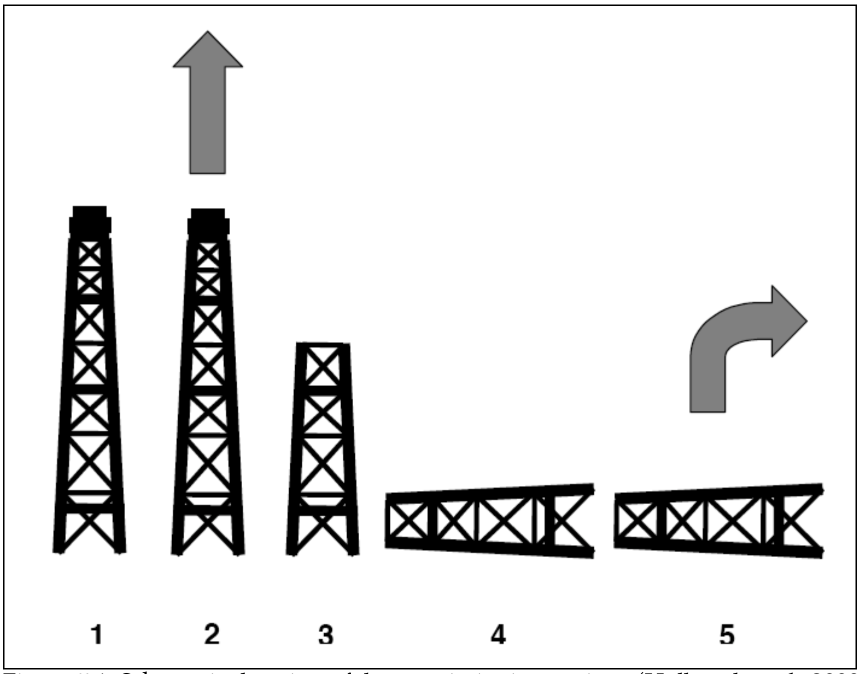

Figure 5.1. Schematic drawing of decommissioning options (Holbrook *et al.*, 2000).

For all options all platform elements will be cleaned from environmentally unfriendly materials and fluids (i.e. heavy metals, residual hydrocarbons, radioactive substances). These will be reused, recycled or treated.

The topsides are often large elements that will degrade and deteriorate rapidly without regular maintenance. Maintenance is costly, in the order of € 0.5 to 1 million annually. This will only be interesting if the second-life use of the platform is valuable. Additionally, the degradation of the topside increases risks. From a safety point of view it might be best to remove the topside anyway, immediately or in a later stage (IMSA Amsterdam, 2011b). We only shortly consider the leave behind of the topside for the decommissioning option of leaving the structure in place in upright position.

Table 5.1. Overview of decommissioning options.

Decommissioning option	Description
Leave in place	When leaving the structure in place, we refer to the jacket and footings. There are two subgroups: leaving the topside or removing it to shore. For this option the integrity of the structure is an important issue. Disintegration of the structure at the shorter (steel) or longer term (concrete) is inevitable. The presence of anodes can increase the lifetime, but not prevent collapse.
Toppling in place	Toppling the structure means removing the topside, after which the jacket is knocked over, by cutting the piles or by using explosives. Fall down of the structure is done under controlled conditions, after which it is left on the seabed. With this option the structure is no longer an obstacle the upper layers of the water column.
Partial removal	Partial removal considers a smaller or larger part of the structure. After removal of the topside, the jacket is cut at a certain height above the seabed, probably in agreement with the IMO agreement of a -55 m clear water column from the water surface. The removed part is brought to shore or to an offshore location (see last two options).
Total removal	This option involves removal of the topside, removal of the jacket and conductors, and removal of the footings from the sediment. OSPAR 98/3 does not prescribe removal of the eventual drill cutting piles on the seabed. All elements will be dismantled at a demolition yard, after which they are reused, recycled or disposed onshore. The removed part is brought to shore or to an offshore location (see last two options).
Transfer to reef area	The case of transfer to reef areas describes an option of placing structures at an approved location for artificial reefing. Part or the whole jacket can be towed to the reef location. In this study we exclude the topside for reefing, based on the potential hazardous materials that can be present. The structure will be put at its side, to prevent it from moving. Several structures can be grouped together to enhance reef formation.
Transfer to deep sea	This option is only shortly considered, to include the effects of disposal offshore when not for reefing specifically. For this transfer too, we consider the jacket and footings for disposal and not the topside. Deep-sea locations are those with depths over 55 meters, to avoid interaction with the shipping industry.

In case of leave-in-place options (total or partial) the sacrificial anodes shall be removed to avoid their potential negative effects. The degradation rate of the steel will consequently increase and reduce the lifetime of the structure.

5.2. Impacts of decommissioning on the surrounding ecosystem

Below we discuss the potential effects of decommissioning, including both the immediate effects of removal and the longer-term effects on local and regional scale. In most cases it is not possible to make an exact prediction. Taking into account the uncertainties, we describe the possible consequences of each decommissioning option. We do not discuss economic nor social effect, but only focus on the ecological aspects.

Short-term effects

The short-term effects are those occurring during or directly following the decommissioning activities, which include the arrival and anchoring of lifting vessels and removing or moving platform elements.

- Operational physical disturbances: it depends on the complexity of the project which activities will be needed and how long they will take. Anchoring of support vessels and barges can disturb the surrounding seabed. Cutting of the piles and lifting the structure most probably also affects the seabed and water column. In case explosives are used, mortality of animals surrounding the platform is probable (Holbrook *et al.*, 2000). In the North Sea the use of explosives is not likely to be used.

- Sonic disturbances: industrial activities in the North Sea have already increased the noise levels significantly (OSPAR, 2009a). Marine animals use sounds for orientation, feeding, locating predators and preys, and for communication. They show behavioural responses to continuous noise levels of about 120 dB. The levels produced by (i.e. barge, tanker, support) vessels are in the order of 140 to 180 dB (Shell UK Limited, 2007). It is not yet evident what the exact effects of offshore industrial activities are, but concern is growing (personal communication I. Boyd; Weilgart, 2005; International Ocean Noise Coalition). Decommissioning activities will cause additional noise locally. During the years of decommissioning at North Sea level a noise increase can be expected from the removal of about 600 platforms.

- Destruction of communities: only in the leave-in-place option communities will be preserved. The upper part of the community will in general not survive the options of toppling, partial removal and total removal, unless the structure is relocated in very shallow water, which is not probable. The community on the middle part of the structure can survive if (part of) it is relocated to an area with similar depths. If toppled in its new location, survival of these species is uncertain. Preservation of the lower zone species is expected in the toppling, partial and reefing options.

- Contaminants from the structures: during decommissioning the risk of release of contaminants will be increased (these include paints, coatings, zinc and aluminium from anodes, etc.) The offshore service industry is well developed and regulations are strict, so we do not expect risks from major incidental releases.

- Toxic effects from drill cutting piles: the removal of structures may affect the piles, which can lead to temporary spreading and disappearance of local seabed communities. The expected affected area per platform is estimated at a radius of 500 to 1000 meters during a period of about one year (Daan *et al.*, 2006).

Long-term effects

The effects that slowly evolve over time as a result of decommissioning events are more difficult to foresee. Some processes take years to decades to become tangible. Especially the regional effects are neither easily pinpointed nor quantified (Holbrook *et al.*, 2000). We summarize the impacts as suggested by literature and those that we would expect to occur.

- Availability or absence of artificial hard substrates: platforms have local and potential regional effects. They create habitat and possible stepping-stones for hard-substrate species. At macroscale it can be questioned what the impact will be if all platforms are removed. No clear conclusions can be drawn yet. For recommendations about follow-up research, see paragraph 7.3.

- Long-term contaminations: paints and coatings slowly erode and spread in the water column. They are not expected to have large impacts. The same counts for the greases used at jackets, which will also slowly dilute into the water. Especially with machinery and pipelines, radioactivity and mercury contaminations should be taken into account. Mercury can penetrate steel and other materials, and only be removed during recycling processes. These materials will be brought onshore. Cleaning of pipelines can remove most contaminants and is already regulated.

- Collapse of the structure remnants: expected within fifty to a hundred years. Zonation and related communities to the upper water layers will vanish, but new habitat develops at the site where the structure falls down. The lower communities can survive the collapse. Where the structure falls down the infauna of the seabed will be replaced by hard-substrate species.

- Disintegration of the structure: the steel slowly crumbles away and corrosion finally leads to full disappearance of the platform. Many of the wrecks in the North Sea have largely degraded over the last fifty years. The heavier platform materials are expected to endure longer. We estimate the process to take 150 to 200 years and, for the concrete parts, to take twice as much time. For concrete the issues are even smaller, as it concerns materials that are similar to rocky seabed. It should be commented that research is needed to understand the aging of structures and degradation rates if anodes are removed (personal communication SodM).

- Disappearance of shell mounds: removal of the upper zone will lead to an absence of mussels and barnacles at the structure. Consequently the shell mounds at the feet of the structures will not be replenished and the feeding grounds for e.g. star fish will disappear (Holbrook *et al.*, 2000).

- Long-term whirling up of drill cutting piles: removal of the structures will allow trawling fisheries in the former safety zones. Even for the leave in place option it is not guaranteed that the safety zone will be maintained. It may lead to continuous whirling up of the muds. The toxic effects of this process are known, but the extent and seriousness are not (i.e. consequences for the health of commercial fish). With the emerging SumWing instruments, with no chains touching the seabed, and if used as a substitute for beam trawls, the drill cutting piles will possibly be less disturbed.

Overview impacts per decommissioning option

For safety and environmental reasons we suggest topsides are removed in all cases. This implies that lifting vessels are needed in all decommissioning options and disturbances by e.g. anchoring are not avoidable. The anodes can be removed relatively easily and recycled zinc is economically beneficial (personal communication SodM).

We assume that for the options of transfer to shallow and deep sea the platforms will be toppled once in their new place. For these cases we only discuss the impacts at the new location. For the effects at their original locations the options of partial and total removal apply.

Table 5.2. Overview of impacts of different decommissioning option, considering steel jackets.

Decommissioning option	**Short term effects**	**Longer term effects**
Leave in place	• Removal of the topside will provoke physical and sonic disturbance of the upper water column • No additional impacts on ecology from decommissioning	• Preservation of all attached and mobile communities • Within 50 to 100 years the structure is expected to collapse • Disintegration of the structure • Erosion of paints and coatings, but no expected significant effects
Toppling in place	• Cutting and laying the structure at its side will provoke physical and sonic disturbance of the whole water column, also extending in horizontal direction (about 20 to 100 meters, depending on the platform size and the cutting techniques) • Removal of upper epibenthic communities • Disturbance of the seabed and whirling up of drill cutting piles • Destruction of seabed communities at location of toppling	• Preservation of all lower hard-substrate habitat and associated communities • Addition of hard substrate at the seabed • Overall biodiversity at location is expected to decline, due to cut off of the highly productive upper layers • Disintegration of the structure • Settlement of shallower epibenthic communities locally is disabled • Erosion of paints and coatings, but no expected significant effects
Partial removal	• Removal will provoke physical and sonic disturbance of part of the water column, proportional with the removed top part • Removal of the upper epibenthic communities	• Preservation of all lower hard-substrate habitat and associated communities • Biodiversity at location will decline, due to cut off of the highly productive upper layers. • Disintegration of the structure • Settlement of shallower epibenthic communities locally is disabled • Erosion of about 40 to 70% of paints and coatings, without significant effects
Total removal	• Physical and sonic disturbance of the whole water column. In case of large structures (> 100 m) additional cutting is needed for safety reasons • Removal of all epibenthic communities • Disturbance of the seabed and whirling up of drill cutting piles	• Destruction of hard substrates locally, disabling the settlement of epibenthic communities • Possible long-term toxic effects of drill cutting sediment in the water column, by continuous trawling activities
Transfer to shallow reef area (total or partial) <u>Attention</u>: impacts at new location	• Physical and sonic disturbance of the whole water column • Destruction of the habitat at new site	• Possibly survival of the hard-substrate communities that correlate with the reef location conditions; upper and middle zone communities • Creating a new habitat elsewhere, with again high diversity and biomass at its former location. Local biodiversity is expected to increase, especially when surrounding substrates are soft bottoms
Transfer to deep sea (total or partial) <u>Attention</u>: impacts at new location	• Physical and sonic disturbance of the whole water column. • Destruction of the habitat at new site	• Possibly survival of the hard-substrate communities that correlate with the reef location conditions; middle and lower zone communities • Creating a new habitat elsewhere, with probably lower diversity and biomass than at its former location or at shallow reef sides in high productive surface waters. The biodiversity can be increased somewhat, due to diversification of habitat types

Highest biodiversity on the long term is expected for the leave-in-place option with its vertical gradient covering the whole water column. Toppling options in situ or at reef sites will probably show highest biodiversity at shallow reef, followed by in situ options and last by deep sea. The effect of partial decommissioning on biodiversity strongly depend on the part of the structure left in situ or at reef site. Total decommissioning will remove the whole hard substrate and in the long term the seabed will restore to its natural conditions.

The above impacts are assumed to be localised, creating a temporary hard substrate, which adds habitat and attracts species in an area of some hundreds of meters.

In summary, the effects of leave-offshore options are expected to have no significant negative effects. They may even be positively rewarded for diversifying the types of habitat and allowing hard-substrates species to settle. As already indicated, for the sandy southern North Sea this will apply the most.

6. Discussion on the presence of oil and gas facilities

The development of the offshore oil and gas industry has created a need for inspection of the marine growth at the platform legs, affecting the material and structure strength of platforms. On a regular basis the marine growth at the submarine structure is measured and, if becoming too thick, quenched with fresh water. After external cleaning the recovery of the epifauna communities takes place very quickly. The surface is ideal for new pioneering, due to the survival of a thin biofilm of algal spores and other microspecies.

The hard substrate itself and the marine growth species provide habitat that attracts other species such as fish, shrimps and mammals that feed, breed and rest near the structure. The precise effects of the hard-substrate habitat on the larger ecosystem need more study. In this chapter we give an overview of the facts, the uncertainties and the ongoing debate concerning the impacts of hard substrates and no-take zones; both enabled by platforms.

6.1. Offshore structures create hard-substrate habitat

Chapters 2 and 4 have already discussed the natural ecosystem. The North Sea has a natural combination of soft and hard sediments, in which the soft seabeds dominate (> 90%). In the past there used to be more hard substrates formed by oyster beds, gravel and boulders. Addition of artificial hard substrates is in principle unnatural. Though, with respect to the dynamics of the system and the removal of hard substrates by human activities, it is worthwhile to consider its effects.

The impact of addition of hard substrates locally depends on the naturally occurring sediments. In case of a soft seabed, such as muds or fine sands, the artificial reef will strongly change the natural habitat. In case of rocky sediments and boulders, the supplement of hard materials will primarily increase the surface area.

Global programs on hard substrates for artificial reefs

The presence of man-made constructions offshore (bridges, wrecks, oil and gas installations, pontoons, wind turbines, etc.) has proven to influence surrounding marine life. This concept is also purposely used, to enhance or restore aquatic ecological conditions. If well designed, artificial reefs create habitat for a variety of marine flora and fauna, enlarging the biodiversity of the area and providing food and shelter for fish (Andersson *et al.*, 2009; Baine, 2002).

An artificial reef is a structure, which is submerged to the seabed to create a local substrate for reef and eco-forming (according to EARRN). The construction of artificial reefs has become a popular management tool, used by governments and private parties. Reefs are associated with high catch rates of economically important fish species (Grossman *et al.*, 1997). Both sport and commercial angler fishers intensively use wrecks. In the Gulf of

Mexico oil and gas facilities received attention from fishermen and are maintained by reef programs to allow fisheries (see annex IV).

Artificial reefs have several uses. They can:
- function as sea defences to reduce wave energy and flood impact (Maldives);
- function as shelter areas for human activities such as shipping and recreation;
- provide habitat for crustacean fisheries (i.e. lobsters) and for enlarging stocks (UK deliberate sinking by fishermen);
- provide habitat for algae and molluscs for aquaculture (Japan, Monaco, Finland, Israel);
- be used as habitat protection constructions to avoid trawling activities (Hong Kong);
- function as areas for fish aggregation for recreational activities such as sport angling and diving (Gulf of Mexico);
- be used for habitat restoration after degradation of the seabed (Ecoreef program Indonesia), with the remark that this practice is still under debate referring to the necessity of hard substrate in places of sedimentary seabeds;
- compensate habitat loss within the system by creating new habitats that suit the system (Ouse reef East Aglia);
- enhance marine richness and abundance by providing bodies with relief and extra hard surfaces for shelter, habitat, food. We make the remark that the production function versus the aggregation function is still debated by researchers, though probably artificial reefs have both functions (Pickering & Whitmarsh, 1996).
- create a barrier structure to improve near-shore recreation (surfing) and to avoid shore erosion by reducing wave energy and littoral drifts (Australia Gold Coast);
- be a alternative waste purpose to land disposal and random dumping at sea.

The implementation of artificial reefs can of course also be used for a mix of the above objectives (Nautilus Consultants, 2003).

Especially in the USA, Japan and Italy artificial reefs are frequently used for fisheries and mariculture. Japan is leading in artificial reef research on efficiency and design. Italy is most progressive for European standards (Baine, 2001). See annex IV for more information on reef programs in the USA. The effects of artificial reefs are not yet fully understood. Main lessons learned about the artificial reef ecosystems from research and artificial reef programs are the following:

a) Local diversity and abundance is not a concrete measure for ecological impact. The effective regional impact depends on a) interconnectivity of populations, b) the total platform reef area compared to total reef areas and c) the effect on specific key species that favour the conditions of platforms (Holbrook *et al.*, 2000).
b) The diversity of species and their possible production rate is assumed to increase with reef complexity. The importance of design complexity, configuration of the reef, size and volume are noted by many researchers (Baine, 2001).
c) It is unlikely that the presence of an artificial reef will cause widespread ecological damage (Grossman *et al.*, 1997).
d) Artificial reefs attract and aggregate fish. Increases of fish catches around artificial reefs of 5% to 4000% have been documented (Santos *et al.*, 1996). From a fish experiment at the Ekofisk platform the researchers concluded that platforms can enhance fishing

operations, because aggregations of large fishes such as cod and saithe are significant (Soldal *et al.*, 2002).

e) Artificial reefs provide food, shelter and nesting sites for fish. As a result stock sizes may increase, although evidence on this is still scarce (Ralph & Troake, 1980; Cripps & Aabel, 2002). Some studies show the increase in volume per individual. It is suggested that these fat fishes may have higher reproduction rates. Again evidence is scarce.

f) Artificial reefs may function as stepping stones for both sessile and mobile species (Langhamer, 2007). They provide the necessary habitat for hard-substrate species that would otherwise be absent. A study of Belgian wrecks shows the wrecks can be an opportunity for hard-substrate species in the southern North Sea (see annex II.E).

6.2. Safety zones around offshore structures

Some of the safety zones around platforms have not been fished for over thirty years. This makes them interesting areas for conservation (Marine Protected Area, MPA) and for research.

There is no universally accepted definition of the term MPA, but most widely used is the one by IUCN (1988): "Any area of intertidal or subtidal terrain, together with its overlying water and associated flora, fauna, historical and cultural features, which has been reserved by law or other effective means to protect part or all of the enclosed environment".

Not all MPAs are protected from fisheries. They all have the overall purpose to enhance nature conservation, but can have different targets, i.e. protection of specific (groups of) species, protection of juveniles, managing natural age compositions among fish communities, protection of habitat types, or dedicated areas for scientific research and monitoring (Lindeboom & Bäck, 2005).

Research by Halpern and Warner (2002) showed that within a few years the ecosystem of the protected area has grown more complex and dense. Not only population densities and biomasses have almost more than doubled, but also organism sizes (plus 20 to 30%) are larger inside the MPA. They conclude that the size of the MPA is not a restriction and even small areas, such as exclusion zones around platforms, can show similar figures.

Moreover, the combination of an MPA and an artificial reef can amplify the conservation. The presence of hard structures, especially near the borders of an MPA can help prevent illegal activities such as trawling fisheries (Claudet & Pelletier, 2004).

The OSPAR list of North Sea Marine Protected Areas has extended to approximately 41,000 km^2 (revised from OSPAR, 2010). Especially Germany has a large share of MPAs, accounting for about 30% of the total offshore marine area. To compare: UK has about 2 or 3 % of MPA (www.ukmpas.org). However, in most areas actual management measures are still to be established and implemented.

As already mentioned the exclusion zones could possibly also be used as research yards. The longevity of their existence makes them competitive with the OSPAR MPAs that have extended fast during the last years. But:

a) The 500-m zones are often the same areas that are affected by the cutting piles; they are not natural, unperturbed areas; even when no OBM or SBM was discharged, the seabed around the platform can have received contaminants from the platform;
b) The exclusion zones are rather small, with a dimension of about 1% of the existing MPAs; moreover it is not guaranteed that in case of leave-offshore options the safety zones can be maintained; fisheries will plead for accessibility to these zones.
c) Due to intense trawling in the surrounding areas, these unprotected seabeds have immature colonization grades and are more attractive for larval settlement of certain species; the competition is imbalanced.

6.3. Opportunities of maintaining structures offshore

For all of the below opportunities counts: the construction of artificial reefs is costly. In the case of the North Sea platforms the structures are already offshore and consequently expenses will be limited. Towing the structure to a designated area is not a must: the network of platforms is interesting for the stepping stone function for epifauna at the structures.

Secondly, for all of the below opportunities counts that if the platforms are left intact and the topsides are not removed, they can also be utilized for second-life uses, such as wind energy, solar and recreational projects (IMSA Amsterdam, 2011b). The additional impacts of these activities must be looked at separately.

Habitat enhancement

Oil and gas facilities can serve as habitat for fish and invertebrate assemblages. In the EU Marine Strategy Framework Directive habitat enhancement is approved as compensation for habitat loss elsewhere. However, the total effect of the hard substrates by platforms is probably for most species negligible at regional scale. On the other hand, for some vulnerable or overexploited species, the protected areas can provide shelter and a favourable habitat. An example is the growth of *Lophelia pertusa* at platforms in the northern North Sea. Further enhancement can be created by reduction of the distances between reefs (increase of interconnectivity) or accumulation of structures leading to larger protected reef areas. Provided that the topsides are left behind, the platforms can also function as nestling places offshore for birds.

Exclusion of trawl fisheries

The safety zones around the platforms function as no-take zones. Maintenance of structures in place or development of reef areas provides restricted areas where trawling is not allowed or possible. It is not guaranteed that the safety zones will be maintained. But, if maintained, the network of platforms or artificial reef sites forms a North Sea with patches of undisturbed benthic communities and with potential spill-over effects to adjacent areas (Wilhelmsson *et al.*, 2006). The exclusion of trawl fisheries is not only a tool for nature conservation, but e.g. also for fisheries enhancement at small scale. In Norway fishermen have expressed their concern on the effects of trawling on the occurrence of *Lophelia pertusa* colonies. *Lophelia* reefs provide excellent line fisheries sites and are assumed to be nursery areas for fish. It is estimated that 30 to 50% of the reefs have been harmed or destroyed by trawling fisheries in the last decades (Fosså *et al.*, 2002).

Avoidance of noise

The decommissioning of oil and gas facilities will inevitably generate noise. Cutting, , lifting and shipping of topsides, jackets and footings will add to the current industrial noises in the North Sea. From this point of view the option of leaving the structure in place is most attractive. The noise impacts will only be temporary, but considering the total decommissioning process of the North Sea the effects can become significant. More research on this topic is needed for further conclusions.

Enhanced fisheries

Especially the aggregation of commercial fish species in the central and northern parts of the North Sea can be beneficial for commercial line fisheries. It is preferential to leave the entire structure, to stimulate the attraction of both demersal and pelagic fish. Wilson *et al.* (2003) observed higher fish biomass and density around platforms compared to other artificial reefs and natural reefs in the Gulf of Mexico. This suggests that the vertical column attracts more fish than when toppled or partially removed. To avoid stock overexploitation at the platforms, regulations are needed to define the catches per area and the allowed size/age per fish species (Cripps & Aabel, 2002). Only the platforms that are at reasonable distances from the coast come into consideration for fisheries.

Mariculture

Worldwide the marine aquaculture is growing, including offshore developments. Japan has invested in culturing fisheries. In the Gulf of Mexico some platforms are accessible for mussel cultivation (Kolian & Sammarco, 2005). The company ECOMAR has intensively tested the mussel quality and proved them to be safe to market for human consumption. They started mariculture business at some of the platforms and their program is economically sound with a profit per platform of approximately $50,000 to $75,000 from shellfish harvesting (Richards *et al.*, 2008). Still it remains a vulnerable sector, due to the concerns of stakeholders on health and safety issues if shellfish is cultivated at oil and gas platforms. Next to this also crab and lobster species can be cultivated at the structures. Some commercial crab species have been studied on their behaviour near platforms. They use them for shelter, recruitment or temporary visits (Page *et al.*, 1999). Especially larger crabs that find their residence in the structure or on the seabed beneath it, can be an opportunity for commercial use.

Recreation

In the Gulf of Mexico the platforms are intensively used for scuba diving, the so-called rig diving, and platforms for diving are also supported by the Bureau of Ocean Energy Management, Regulation and Enforcement (www.gomr.boemre.gov). Wreck diving is popular also among North Sea divers. Sports fishers often use wreck sites for their line fisheries. The platforms can offer alternative fish sites. The disadvantage is that it can lead to ghost nets and other left-behind fishing gear (www.duikdenoordzeeschoon.nl).
For all activities the platforms close to the coasts are most preferential. The large offshore platforms in the central and northern North Sea will probably not be used.

6.4. Threats of leaving structures offshore

Unnatural conditions

It can be questioned if platforms in areas with no natural hard substrates are beneficial to the ecological developments. Their extension throughout the water column allows different species to settle, which could not settle without the platform. The platform can also affect the seabed by provoking changes in physical environment, i.e. currents and grain-size distribution. The smothering effect of shell mounds and other death organic material coming from the structure can negatively affect the surrounding seabed (Cripps & Aabel, 2002).

Source of contamination

Greases, paints and coatings are not expected to provoke significant impacts, but it is important to avoid leaving materials that are contaminated with mercury and radioactive materials.

Migration barriers for birds and sea mammals

The presence of platforms may form an obstacle to birds, but different from that of wind farms. Main issues with wind turbines are the turning wings and sounds. In the case of platforms it should only be taken into account that navigational lights can distract birds (Degraer *et al.*, 2010). We expect the negative effect to be very small. Instead platforms can offer resting, feeding and nesting areas for birds during migration. For sea mammals the single platforms are probably not a significant hinder. They may use the structure for feeding and resting locations. The positive or negative impacts of larger reefs by bringing platforms together are uncertain (Coghlan, 2009).

Migration of invasive species

The impact of platforms on invasive species is not yet well understood. Platforms are not expected to play a major role in the spreading of new species, but with the increase of wind turbines offshore, this may change in the future.

Safety risks

The integrity of the structures is in principle estimated at twenty to thirty years. The life endurance of many structures appears to be longer. Though, when structures are (partially) left behind, without regular maintenance, the structure will degrade. If anodes are also removed, the degradation rate will even speed up. Monitoring of the structures offshore is required, but the moment of collapse can probably not be foreseen. If fisheries, diving and other recreational and commercial activities are allowed safety, issues arise. Entanglement of nets and other fishing gear, or even collision of ships and platform may lead to risky situations (Cripps & Aabel, 2002). Licensing, management and monitoring are needed, which bring additional costs with them.

Temporary solutions

The maintenance of oil and gas structures has, similar to wrecks, a temporary effect. Degradation of the steel jacket will lead to collapse of the vertical column within about 50 to 100 years. The further degradation of the steel will take about 150 to 200 years. Concrete bases will last longer, with a lifespan of about 300 to 400 years (rough estimates). This means that eventually the structures do not provide permanent habitat.

7. Conclusions and research topics

7.1. Main conclusions

Below we present preliminary conclusions on the effects of platforms and decommissioning activities on the local and regional North Sea ecosystem.

In general platforms have no significant negative effect on the local ecosystem

a) They create small-scale areas with higher biodiversity, with probably a limited effect on the regional ecosystem.
b) The artificial hard substrates change the local habitat, with the largest effect for soft bottom areas, but hard substrates are not foreign to the North Sea. Even in the southern North Sea the section of hard substrates used to be more prominent.
c) The majority of the platforms consist for more than 90% of steel, which degrades over time, without significant contamination grades.
d) Platforms can fulfil a stepping-stone function, but are not expected to play a large role in the distribution of invasive species.
e) Within the safety zone the seabed community is not particularly affected by the presence of the platform structure.

Platforms create different habitat and increase local biodiversity

a) Platforms lead to higher biodiversity locally. They change the local ecosystem by adding a different habitat. Biomasses on hard substrates are higher than on surrounding soft seabeds.
b) The availability of hard substrates has been strongly reduced in the southern North Sea, particularly by oyster fisheries over the last 200 years. Platforms create habitat for hard-substrate species that are inherent to the North Sea ecosystem.
c) The safety zones around platforms are no-fished areas, sometimes already during large periods. They can function as small MPAs and inform on the effects of no fishing. It is not guaranteed that the safety zones will remain inaccessible for fisheries.

Platforms have probably no significant positive effect on the North Sea ecosystem

a) Platforms are artificial hard substrates and show similar effects as wind parks, wrecks and natural hard substrates. The effective platform surface is low compared to the total availability of hard substrates (~0,02%).
b) Platforms create different habitats than natural reefs and cannot offer compensation for the former destruction of the hard substrates of the oyster beds.
c) Platforms attract fish and sea mammals. They are used for shelter, breeding and feeding. It is not proven if productivity of e.g. fish is enlarged at platforms.

d) The majority of the species that settle on platforms are not unique in the sense that nature conservation would be urgent.
e) Platforms may function as a stepping-stone for certain species, but the impact at North Sea scale is small.

Table 7.1. Estimations of hard substrates and exclusion zones at North Sea scale.

	Surface area	**Exclusion zones**
Platforms	3.7 km^2	400 km^2
Wrecks	30–54 km^2	-
Wind parks	0.17 km^2	158 km^2
Natural reefs	18,000 km^2	-
OSPAR MPA	-	41,000 km^2

Decommissioning activities influence the local ecosystem

a) Leave-offshore options (toppling, partial, transfer to reef) are expected to have no significant negative effects. They diversify the existing habitat and allow hard-substrates species to settle. Valuation of the artificial hard substrate is complex. The poor availability of hard substrates in the southern North Sea makes leave-offshore options probably more attractive there than in the northern parts.
b) The leave-in-place option is best for local preservation of epifaunal mobile communities. It has also the least impact on drill cutting piles, avoids water column disturbances and does not disturb the seabed locally or at a new offshore site.
c) The transfer-to-reef options need towing to new sites. The costs for reefing need to be assessed in combination with the positive effects on biodiversity at local and regional scale. Transfer to reef and toppling is expected only really useful in shallow waters.

Leaving (parts of) a platform in situ can be interesting from a management point of view

a) Platforms could be used for research on epifauna and aggregated mobile species and can help to improve knowledge on i.e. production at artificial reefs and stepping-stones.
b) Safety zones can be used as research yards and to gather information on the potential of no-take zones. However, the contamination from drilling activities and the small surface areas (0.05% of the North Sea, compared to ~1% of total no-take zones) does not make them the most optimal research areas.
c) Platforms can be used for fisheries or maricultures. Fisheries of commercial rockfishes are more efficient when the fish is aggregated around hard substrates such as platforms. Platforms may have a function for mariculture systems with their continuous submerged conditions, lack of sediments in the upper layers and varying surfaces.
d) Platforms can be used for second-life opportunities. They can function as stations for i.e. wind, wave or solar energy, recreation, etc. (table 7.2. and IMSA Amsterdam, 2011b).

Table 7.2. Opportunities and threats of leaving (parts of) platforms offshore.

Theme	**Opportunities**	**Threats**
Nature	Habitat enhancement; increase of hard substrates	Habitat loss; unnatural situation
Fisheries	Opportunity for line fisheries	Overexploitation; safety issues; too far offshore
Mariculture	Opportunity for mussels	Safety issues
Recreation	Diving; fishing	Safety issues
Research	Hard substrate and no-take effects	Contamination at sites
Second-life uses	Wind, solar and wave energy; restaurant or hotel; research station	Structure integrity; maintenance costs; final liability; safety issues

7.2. Issues

In the discussion on leaving materials behind for reefing, the objective is to define the most positive outcome both for the North Sea ecosystem and the local platform sites. There are lists of issues that are uncertain or are differently interpreted. No single answer can be given. We expect that during the discussion on alternative options for decommissioning several questions will arise that have subjective backgrounds as well.

- Can we genuinely call the North Sea status a good environmental status, or have human impacts changed it too much overtime? And associated with this: is it wrong to actively change natural habitats with addition of reefs? Have we intervened too much already?
- Do artificial reefs fit in the natural character of the North Sea with its alternation of soft and hard bottoms?
- How can we quantify the impacts of artificial reefs at a large scale (which feedback loops are involved)? How can we value them within the frame of the North Sea ecosystem?

7.3. Recommended follow-up program

This study is mostly based on public information. Due to a lack of data on marine growth at platforms in the North Sea the analysis includes data of wind turbines and wrecks. In a follow-up phase the analysis can be extended with specific marine growth data from platforms throughout the North Sea, also including the southern part. Existing survey videos, samples and marine growth reports can be used for further analysis.

After analysis of existing reports it is recommendable to do sampling at several platforms, to create an up-to-date database. During this field study more attention can be paid to species composition and the abundances of mobile species. These are often under-exposed in the existing reporting, because the main objective was to manage the condition of the platform.

To quantify the effects of the local hotspots of biodiversity around platforms on the North Sea system, more research is needed. The actual productivity of e.g. fish around a platform, the stepping-stone function for epibenthic fauna and the interconnectivity of communities among platforms and reefs are not yet well understood. Long-term monitoring programs at platforms could help to improve the knowledge base. The current lack of evidence blocks conclusions on these subjects at this stage.

For suggestions for follow-up research, see annex V.

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Annex I. Greater North Sea (OSPAR)

Source: OSPAR, 2000

Annex II. Case studies marine growth

Overview of the cases:

A. Platform Montrose Alpha
B. Platforms in the central and northern North Sea
C. Wind farm Egmond aan Zee, The Netherlands
D. Wrecks at Dutch Continental Slope
E. Wrecks at the Belgian part of the North Sea
F. Offshore artificial reef experiment at the Dutch continental shelf

A. Platform Montrose Alpha

Introduction and geographical setting

Location	NNS, NE Scotland
Structure	Steel, 8 vertical legs
Age	Installed in 1975
Depth	90 m

The study started in 1977 and samples were taken annually up to 1980. The data of the Montrose Alpha platform is compared to the communities found on the jackets of the Forties oil field (Forteath *et al.,* 1982).

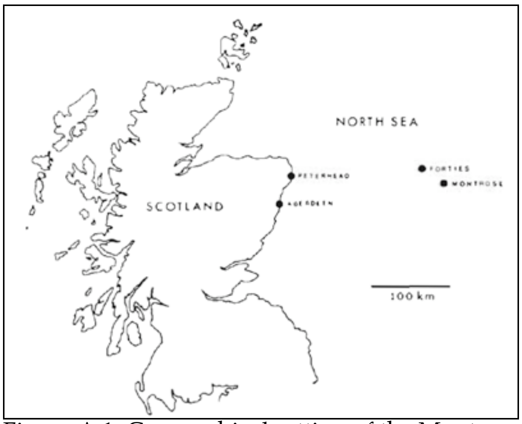


Figure A.1. Geographical setting of the Montrose Alpha and Forties platforms (Forteath *et al.,* 1982).

Diversity and occurrence of species

At the platform 45 species were recorded at the jacket structure of the platform. The majority of these were sessile (40). Marine growth was not uniform over the whole body, but showed a depth relation.

Overview of species occurrences per zone

Mean low water to -10 m	In this depth range different species of sea lettuce and green alga covered about 95% of the substrate, with kelps scattered along the legs of the platform. Lush carpets of seaweeds covered diagonal and horizontal elements of the platform. This community is only found if enough light is available; in the shaded areas hydroids and arborescent bryozoa have settled instead.
-10 m to -31 m	Hydroids and arborescent bryozoa extend to about -31 m, of which one specific bryozoan (*Electra pilosa*) dominated and covered about 95% of the substrate.
-31 m to -51 m	Arborescent bryozoa are replaced by calcareous bryozoa, which form dense patches and cover about 80% of the cover, alternated with some hydroids colonies.
-51 m to -71m	The calcareous bryozoa are largely replaced by encrusting bryozoa, with one specific species dominating: *Alcyonidium hirsutum*.
-71 m to the mud-line	Tubeworms become more abundant from -71m increasing with depth. This depth range is dominated by discrete masses of tubeworms and deep-water barnacles, though overall marine growth is significant less at this water level.

Some sessile species that were present, but not abundant enough to be included in the cover analysis were tubeworms (with greatest abundances below -71 m), a few individual anemones, soft corals (at all levels) and sponges (rarely below -51 m). It appeared difficult to include mobile species in the cover analysis, though the following species were recorded: amphipods, sea-slugs, polychaete and seastars.

Comparison of Montrose Alpha and Forties communities

Depth	Montrose Alpha jacket	Forties jackets
Mean low water to -30 m	Hydroids – seaweeds (upper); arborescent bryozoa (lower)	Mussels
-30 m to -70 m	Hydroids – bryozoa (from calcareous to encrusting with depth)	Solitary tubeworms – hydroids – anemones
-70 m to mud-line	Hydroids – aggregate tubeworms	Solitary tubeworms – aggregate tubeworms

Abundances and biomass

Between mean low water and -31 m the cover was most dense; between -71 m and the mud-line the cover was least dense. The study suggest that the colonization of the hard substrate below -31 m may have been slowed down because of the silts, provoked by the drilling activities; i.e. solitary tubeworms have difficulty surviving in silty areas and bryozoa avoid soft substrates.

The research shows large differences in abundances of colonies from the year of installation to year 5 of the study. There is a considerable competition for space. Abilities such as high larval dispersal and resistance to overgrowth are important in the colonization of new substrates.

Unique species

No information on exceptional species at the platform.

B. Platforms in the central and northern North Sea

Introduction and geographical setting

Location	CNS and NNS
Structure	4 platforms
Age	2006
Water depth	Varying per platform, from 80 to 169 m

The study took place in an eleven-year period from 1989 to 2000. Inspection videos were studied and multivariate analyses were applied (Whomersley & Picken, 2003).

Diversity and occurrence of species

The vertical zonation of marine growth was similar on all installations, despite the variations in depths. The colonization all showed overgrowth within the first five years. Hydroids and tubeworms dominated in the first three years at all depths below the mussel zone. During the five to nine years of the study, the hydroids got replaced in all cases. In the northern North Sea the overgrowth took more time than in the central North Sea (5 to 6 years, compared to 3 to 4 years).

- The upper zones of the platforms are all dominated by *M. edulis*. The mussels are the first colonizers in this part and are not replaced.
- While the middle zone of the northern platforms was dominated by *M. senile*, the middle zone of the central platforms had both *M. senile* and *A. digitatum* abundantly available and *A. digitatum* even became the dominant species.
- The deepest zone showed most diversity among the platforms, possibly due to the foot material of the platform and the re-suspension of sediments.

Species diversity observed in and around the platforms

Taxonomic composition	Species
Green algae	
Anemones	*Metridium senile*
Molluscs	*Mytulis edulis*
Soft coral	*Alcyonium* (Dead Men's Fingers)
Hydroids	First colonizers but overgrown
Worms	Tubeworms, first colonizers but overgrown

Overview of species dominance per zone (for the specifc species see table above)

Depth range	Tern Alpha (NNS, 167 m)	Eider (NNS, 158 m)	Gannet Alpha (CNS, 80 m))	Kittiwake Alpha (CNS, 85 m)
0 to -20 m	Mussel bands, green macroalgae	Mussel bands, green macroalgae	Mussel bands, green macroalgae	Mussel bands, green macroalgae
-20 to -40 m	Anemones	Anemones	Anemones	Anemones
-40 to -60 m	Anemones, soft coral (small colonies)	Anemones, soft corals (small colonies)	Anemones	Anemones
-60 to -90 m	Anemones, soft coral (small colonies)	Soft corals (small colonies)	Soft corals	Anemones, soft corals

C. Offshore wind farm Egmond aan Zee, The Netherlands

Introduction and geographical setting

Location	SNS, west of the Dutch coast
Structure	36 turbines placed on steel monopiles (diameter 4.6 m) at 650 m distance from each other
Age	2006
Water depth	15 – 20 m (total height 115 m)
Surrounding substrates	Soft sandy substrate

The study took place in 2008, with sampling in February and September, and included qualitative and quantitative assessments of three representative turbines (Bouma & Lengkeek, 2009; Brasseur *et al.*, 2008; Scheidat *et al.*, 2008; www.noordzeewind.nl).

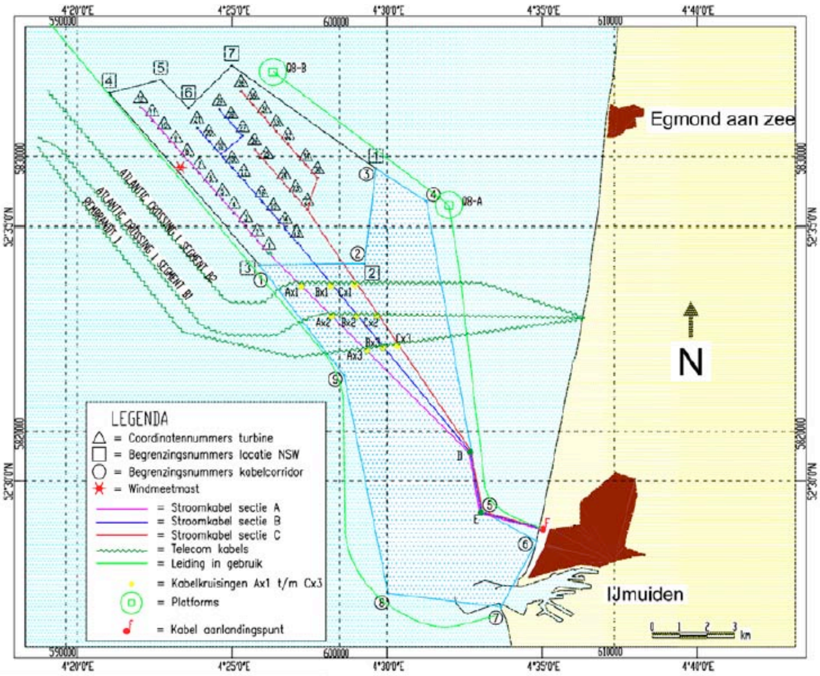


Figure C.1. Geographical setting of turbines at the Dutch coast (Dekkers, 2007).

Diversity and occurrence of species

On and around the turbines 33 species were registered. The turbines have two types of hard substrates: the monopiles and the rock around the foundation (scour protection). The number of species on the scour protection was lower than the number of species found at the monopiles.

Species diversity observed in and around the wind farm area

Taxonomic composition	No species	Species
Green algae	1	
Anemones	4	Red beadlet anemone (*Diadumene cincta*), orange anemone (*Actinia equine*), plumose anemone (*Metridium senile*), *Sargatia spp.*
Barnacles	3	Crenate barnacle, titan acorn barnacle, rock barnacle
Molluscs	5	Slipper limpet, Japanese oyster, common mussels, nudibranch, pullet, carpet shell
Crustaceans	8	Skeleton shrimp, mud shrimp, aquatic sowbug, *Jasa spp*., hairy crab, porcelain crab, velvet swimming crab, North Sea crab
Echinoderms	3	Common starfish, common brittlestar, green sea urchin
Bryozoa	4	Sea mat, orange crust (encrusting bryozoa)
Hydroids	2	Ringed tubularia, *Obelia spp.*
Worms	4	Scale worm, *Nereis spp*., *Annelida* (group), keel worm
Fish		Most common fish: dab, whiting, plaice, solenette, goby, dragonet, sprat, poor cod, scaldfish, sandeel.
Sea mammals		Harbour porpoise, harbour seal

At the scour-protection rock no zoning was recognized. Most abundant species at the rock: sea mat, plumose anemone, *Sargatia spp., Jassa spp* and ringed tubularia. At the monopiles a clear zoning was recognized, especially in February (see table below).

Zoning at the monopiles

Upper zone	Dominated by common mussel and associated species (barnacles, common starfish, worms, crabs, encrusting sea mat). The mussels cover 80–100%, with bare patches colonized by anemones and crustacean *Jassa spp.*
Deeper zone	Dominated by crusteancean *Jassa spp.,* anemones and patches of ringed tubularia. In smaller numbers also green sea urchins and common starfish are present. The community covers 100% of the monopiles, from below the mussel zone to the sea floor.

Abundances and biomass

Monopiles: during the assessment in September the zoning was still visible, but the abundance of mussels had increased, both in horizontal (thickness cover) as in vertical (expansion to greater depth) sense. Mean abundance in September: 8047 individuals/m^2, biomass of 1100 g AFDW/m^2 (ash-free dry weight). The total biomass, including all species, for the three turbines reached 1100 g AFDW/m^2 in September.

Scour protection rock: only the biomasses of anemones and molluscs were determined. The three turbines show varieties of 104 to 3736 g AFDW/m^2, with a mean biomass of 1637 g AFDW/m^2.

Unique species

No significant new fish communities were encountered in the area. The lumpsucker has been observed, but in very low numbers.

D. Wrecks at the Dutch continental shelf

Introduction and geographical setting

Location	SNS, 51–54º north latitude
Structure	22 objects
Age	Ranging from '40–'45 to '85
Depth	14–34 m
Surrounding seabed	Soft bottom

The study took place from 1986 to 1990. Again in 1991 (July / August) samples were taken at three wrecks (C, K, M) during seven dives (Van Moorsel *et al.*, 1991; Van Moorsel & Waardenburg, 1992).

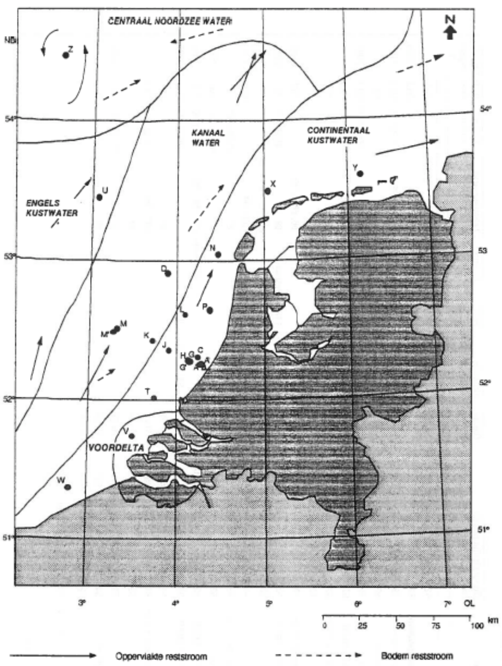


Figure D.1. Geographical setting of the studied objectives (Van Moorsel *et al.*, 1991).

Diversity and occurrence of species

On and around the wrecks 138 species were registered. The macrobenthos was mainly represented by animal species. The dominating species are described in the table. The most common species at the wrecks were the plumose anemone, sea star, barnacles, shrimp-like crustaceans (*Gammaridea*) and North Sea crabs.

One of the wrecks (M) has been observed directly after the ship was found. After the first year only six species were registered, but already in the second year the epifauna and flora grew strongly and large amount of cod and pout aggregated around the wreck. After four years the biodiversity reached an optimum and after five years the cover density was very high. During the study 53 species were spotted.

Overview of species observed

Taxonomic composition	No species	Examples of species
Sponges	9	*Halichondria panicea*
Cnidaria	18	*Diadumene cincta* (anemone), hydroids
Bristle worms	10	
Shellfish	23	*Mytilus edulis* (mussels, sometimes cover of > 50%), 11 species of nudibranches
Crustaceans	25	*Gammaridea, Caprellidae, Cirripedia*
Bryozoa	10	*Cellepora pumicosa, Electra pilosa*
Echinoderms	4	*Hydracitinea echinata*
Filter feeders	5	*Tunicates*
Fishes	19	*Trisopterus lucsus* (pout), *Gadus morhua* (cod), *Pollachius virens* (pollock)

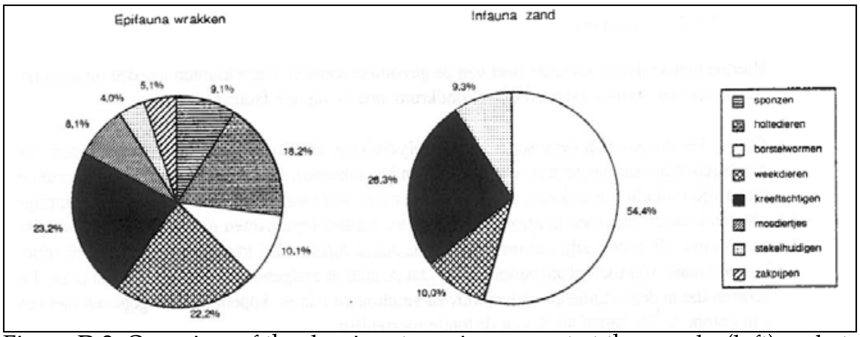


Figure D.2. Overview of the dominant species present at the wrecks (left) and at the sandy bottom around the wrecks (right). The legend matches the above table (Van Moorsel *et al.*, 1991).

In geographical sense there is a clear variation between the species at offshore wrecks and those in more coastal areas. The main driver for this is found in the water stratification and influences from other water bodies (Atlantic Ocean). The wrecks offshore show more correspondence than the coastal objects.

Abundances and biomass

Biomass measures of sessile fauna at the wrecks present a mean variation among the biomass samples of 260 g/m^2 – 1954 g/m^2. This implies a mean biomass of 475 g/m^2, which is about 33 times higher than the biomass at sandy seabeds in the southern North Sea (14.5 g/m^2). The mean biomass at horizontal versus vertical surfaces did not differ much.

In the shallower depths there are dense growths of mussels, which are also recognized at platforms offshore. This can also be a result of the substrate characteristics, accommodating hydroids and algae and providing food for the mussel community. After colonization at small depth, migration to deeper parts also occurs.

The fish aggregating around the platforms probably largely feed on sand bottom organisms, shown by research of the stomach contents of cod and pollock only containing very small amounts of typical hard-substrate organisms.

E. Wrecks at the Belgian part of the North Sea

Introduction and geographical setting

Location	SNS, N 51º , E 02º
Structure	10 objects
Age	Ranging from '06 to '66
Depth	9 – 37 m
Surrounding seabed	Soft bottom

The study took place from 2001 to 2005, during which a 108 samples were collected and a review of historical records of the species was done (Zintzen & Massin, 2010).

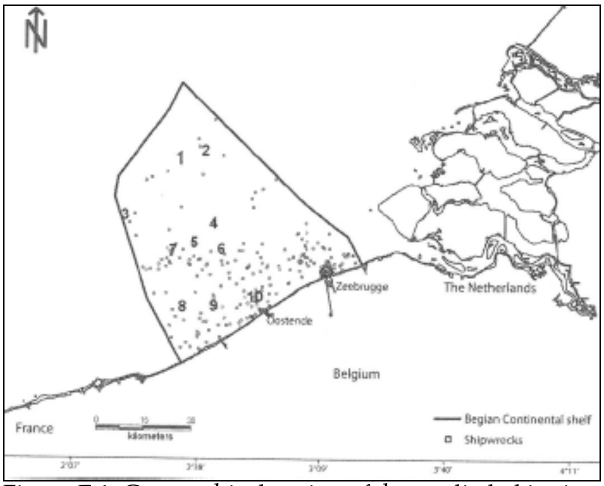


Figure E.1. Geographical setting of the studied objectives (Zintzen & Massin, 2010).

Diversity and occurrence of species

The species richness at the wrecks is 224, which includes twelve fish species. This is comparable to the species richness at the soft sediments. However, based on the amount of samples (1/6th of the sampling at the soft substrate), the species richness at the wrecks is regarded higher. Of the recorded species 46 are new to the Belgian fauna. Therefore Zintzen & Massin assume the shipwrecks to be an opportunity for the regional distribution of these species, which need hard substrate for habitat.

The mobile fauna at the shipwrecks shows similarities with the fauna at gravel beds in the Dover Strait area: *Ophiothrix fragilis* and *Pisidia longicornis*. The sessile species are different with a dominance of cnidarians at the wrecks, compared to dominance of bryozoa, hydrozoans and anthozoans.

Overview of most occurring species at the wrecks

Taxonomic composition	**No species**	**Examples of species**
Porifera	10	*Sycon ciliatum*
Cnidaria	18	*Tubularia indivisa Linnaeus* (hydrozoa), *Actiniaria* (anthozoa)
Platyhelminthes	2	*Turbellaria*
Nemertea	3	*Oerstedia dorsalis*
Annelida	59	*Harmothoe, Lepidonotus squamatus*
Molluscs	32	*Mytilus edulis, Epitonium clathratulum, Dendronotus frondosus*
Sipuncula	1	*Golfingiida*
Crustaceans	41	*Jassa hermani, Balanus crenatus Bruguiere*
Chelicerata	4	*Achelia sp.*
Bryozoa	11	*Electra pilosa*
Echinodermata	8	*Asterias rubens juv. Linneaeus, Ophiotrix fragilis*
Chordata	4	*Tunicates*
Fish	12	*Trisopterus luscus, Pollachius pollachius, Gdus morrhua*

Abundances and biomass

No information.

Unique species

Eight species were observed that are rare for the Belgian part of the North Sea, including two species of porifera, one cnidarians, three crustaceans, one pycnogonide and one tunicata. Moreover three species were observed that are enabled to settle in the Belgian part by the hard substrate specifically:

Anemone Actinothoe sphyrodeta	Normally only occurring more northwards.
Barnacle Acasta spongites	This study gives first observations of this species at the Belgian part of the North Sea
Paguridae Anapagurus chiroacanthus	Present from Norway to Azores, but normally not present in the southern North Sea.

F. Offshore artificial reef experiment at the Dutch continental shelf

Introduction and geographical setting

Location	NCP, 52º N and 04º E, 8.5 km west of Noordwijk
Structure	4 reefs of 12 m diameter and 1.5 m high, formed of basalt blocks
Age	1992
Depth	17.3 – 18.2 m
Surrounding seabed	Flat and sandy (fine to coarse sands)

The study took place from 1992 to 1995, shorter than originally planned (1997), due to opposition against the reef. During the study the seabed, mobile fauna, hard-substrata macrofauna, biomass and colonization were monitored in 1992, 1993, 1994 and 1995 (Leewis *et al*., 1997; Leewis & Hallie, 2000).

Diversity and occurrence of species

The baseline assessment (before reefing) showed an infaunal species composition typical for the near-coast ecosystem off the Dutch coast, with prominence of marine ringed worms (polychaete), marine catworms (nephtiydae) and sea urchins (echinocardium).

Within twelve days a colony of hydroid had settled at the reef. Swimming crabs, sea stars and hermit crabs occurred on the reef with abundances similar to the surrounding seabed. A moth later the hydroids had increased, nudibranches were observed and plumose anemones had attached to the reef.

In 1992 the surface was covered up to 50%, while in 1993 the surface cover reached 100% by seven different species, with hydroids dominating. This composition changed within some months to a bryozoa-dominated community with presence of amphipoda and gammaridea.

Taxonomic composition	**Examples of species**
Cnidaria	Plumose anemone (*Metridium senile*), hydroids (*Tubularia indivisia*), benthic stage of moon jelly (*Aurelia aurita*)
Bristle worms (polychaete)	Tube-dwelling polychaete (*Spiophanes bombyx*)
Shellfish	Barnacles, 2 species of nudibranches (*Tergipes tergipes, Facelina bostoniensis*), 2 species of cephalopods (*Aloteuthis subulata, Loligo vulgaris*)
Crustaceans	Amphipoda, gammaridea (shrimp-like crustaceans), swimming crab, hermit crab, North Sea crab
Moss animals (bryozoa)	*Electra pilosa*, *Bowerbankia cf gracilis*
Fishes	Pout (*Trisopterus luscus*), eel (*Anguilla anguilla*), catfish (*Trachyglanis minutus*), dragonets (*Callionymus lyra*), sand gobies (*Pomatoschistus minutus*), common dab (*Limanda limanda*), mackerel (*Trachurus trachurus*)

From the seabed cores no observations were made that could indicate changes in the faunal species composition at more than twenty meters away from the reef.

Abundances and biomass

In 1993 seven species were recorded at the reef, increasing to seventeen species in 1994. Due to heavy weather conditions the composition went down to fifteen species in 1995.

In the first year the mean biomass of epifauna at the reef grew to 40 g/m^2, which was three to four times the biomass sampled at the surrounding seabed. This value is comparable to other pioneering communities, such as found on shipwrecks. In 1995 values were measured between AFDW 120 and 150 g/m^2. This is still an immature habitat; the biomasses measured at mature habitat of shipwrecks have mean values of about 500 g/m^2.

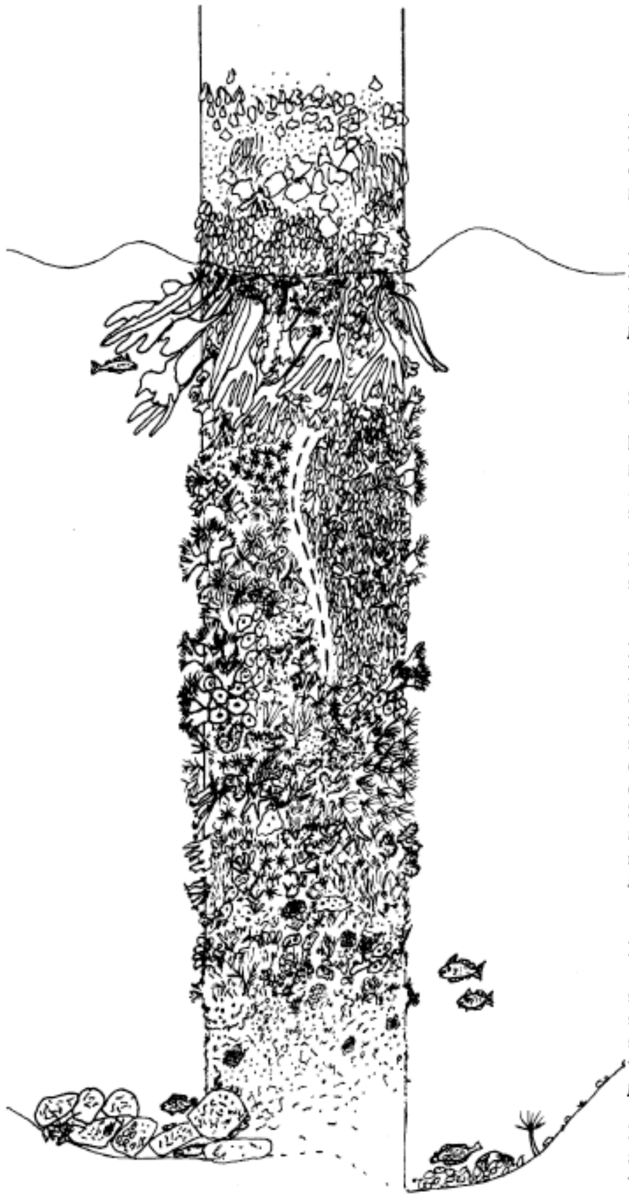
The production of biomass at the reef is estimated to be six to eight times higher than the benthic biomass of the surrounding seabed. If fish feeds from the structure with an ecological efficiency of 10%, the fish production around the reef would be five times higher than the average fish production in the southern North Sea.

The number of mobile species increased over time: from 25 species in 1992 to 50 species in 1993. In 1992 four fish species were observed at the reef, while in 1993 this increased to twelve species. Large schools of pout circled around the reef units, while dragonets are highly abundant just beside the reef, at the seabed. After 1993 no more monitoring was done on the mobile animals, due to lack of funding.

Unique species

Eel Anguilla anguilla	Last 5 years not observed in shipwreck monitoring in the SNS
Nudibranch Polycera sp.	First record of this species at the Dutch coast
Ross worm Sabellaria spinulosa	Used to form banks in the German Wadden Sea, but disappeared at the beginning of the 20th century.

Annex III. Community zonation at wind mills



Intertidal
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+. 2m-6m 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 anti-scour 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 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.

Source: Hiscock *et al.,* 2002

Annex IV. Reefing programs

Gulf of Mexico

In the northern Gulf of Mexico the hard substrates from platforms add about 4% to the total hard substrates. The silty basin has about 2800 km^2 naturally occurring hard substrates. However, the platforms are considered of significant importance from recreational and commercial perspectives. In 1986 the Louisiana Artificial Reef Program (LARP) was founded, followed by the Texas Artificial Reef Program (TARP) in 1988. In 2003 they managed 150 artificial reefs from oil and gas platforms. The programs were stimulated by the sport fishing industry, catching more and larger fish around the platforms. This recreational fishing has also considerable economic impacts for the region (Picken *et al.*, 2000; Wilson *et al.*, 2003).

The Mineral Management Service (MMS) has been closely involved in the developments of the reef programs. The small and simple structures can easily be removed and structures in water depths of less than thirty meters are almost always brought ashore. But for the larger structures it is worthwhile from a cost beneficial point of view to consider a leave-behind option. Onshore disposal is still most common in the Gulf of Mexico, which is the case for more than 80% of the structure removals so far. The structure must be in or towed to one of the selected reef areas, defined by the reef program. They finally decide whether a structure is allowed or not. The operators donate the structure and add a financial donation that increases with platform size (Kaiser & Pulsipher, 2005; Kaiser, 2005).

Annex V. Recommended follow-up studies

Suggestions for follow-up studies based on this report results (input for discussion).

Research (question)	**Estimated time**	**Experts**	**Priority**
Integral strategy for a dynamic and healthy North Sea, allowing human activities. Collection of existing knowledge and historical data on the North Sea. Prioritization of negative human impacts and urgent changes.	1 year	Stichting de Noordzee, North Sea Commission, IMSA, etc.	+++
Detailed data interpretation of existing information on a) platforms, b) other artificial hard substrates, c) natural substrates.	6 months	BMT Cordah, Ecosub, Naturalis	+++
Data collection and interpretation of marine growth at different platform sites, including both sessile and mobile species attracted by the structure.	1 – 2 years	Waardenburg, AWI, MUMM, IMARES	+++
Data collection at the seabeds around platforms to determine ecosystem health and the impact of these small no-take zones.	1 – 2 years	NIOZ, IMR, Serpent	+++
DNA testing of mussels or other species at several platforms to understand the interconnectivity (stepping-stone function).	6 months	IMARES	+++
Quantification of the amounts of hard substrates in the North Sea (artificial, natural).	6 months	MUMM	++
Ongoing monitoring at and around platforms to measure long-term effects and to increase the understanding of large, vertical, artificial reefs.	1 – several years	National marine institutes	++
Behaviour of fish and mammals around platforms (hard substrates).	1 – several years	SMRU, Univ. Kopenhagen	++
Study on fish production and role of aggregation near hard substrates: fish population dynamics.	Several years	Experts on fish population dynamics	++
Larval dispersal study to understand the stepping-stone function of hard substrates offshore, especially structures covering the whole water column.	Several years	NIOZ, MUMM	++
Impact of industrial noise, with a focus on large-scale decommissioning activities, on marine life. Buoy instruments for measurements.	1 – 2 years	IMARES, SMRU	++
Assessment of the current and future impact of hard substrates on invasive species spreading.	6 months – 1 year		++
Comparison of the existing knowledge on artificial reefs and the applicability for platform decommissioning (design, distances, sizes).	6 months		+
What are the interests and opinions on artificial nature conservation by different stakeholders?	6 months	IMSA	+
Analysis of the effect on local ecosystems of whirling up drill cutting piles by fisheries (after total removal). What can be the effect on human health by contaminated fish?	6 months		+
Impact of pipelines on marine life: do they function as corridors to interconnect habitat? How are the pipelines situated at the sediment (what kind of sediment)?	1 – several years		+

Annex VI. Glossary of acronyms and terms

AFDW	Ash free dry weight.
Benthic	Concerning the lowest level of the water column of ocean, sea or lake, including the sediment surface and sub-surface layers.
Biomass	Weight of organisms.
Biota	Living organisms.
Bryozoa	Commonly known as moss animals, a phylum of aquatic invertebrate animals. Filter feeders that are about 0.5 mm long.
CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora. Roughly 5,000 species of animals and 28,000 species of plants are protected by CITES against over-exploitation through international trade. They are listed in the three CITES Appendices.
CNS	Central North Sea.
Demersal	Concerning the zone of the water column of ocean, sea or lake that is near the seabed, just above the benthic zone.
Epibenthic	Organisms living on the surface of substrates (seabed or reef).
gC/m^2	Grams carbon per square meter sediment.
Hydroid	Small, predatory organism of the phylum Cnidaria (related to jellyfish and coral).
Infauna	Organisms that mostly live in the sediments (muds, sands, gravel) and which are often mobile.
LARP	Louisiana Artificial Reef Program.
MPA	Marine protected area, protected area whose boundaries include some area of ocean.
NNS	Northern North Sea.
No-take zone	Zones where fishing is not allowed.
OBM	Oil-based muds, drilling muds of which the base fluid is a petroleum product.
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic, which combines and up-dates the 1972-Oslo Convention on dumping waste at sea and the 1974 -Paris Convention on land-based sources of marine pollution.
PAH	Polycyclic aromatic hydrocarbons.
Polychaete worm	Class of annelid worms, generally marine. Polychaetes are sometimes referred to as bristle worms. They are segmented worms, generally less than 10 cm in length, although ranging at the extremes from 1 mm to 3 m.
Protozoa	Group of monocellular organisms, of which many are mobile.
Pelagic	Concerning any water in the sea that is not close to the bottom or near to the shore.
SBM	Synthetic-based muds, drilling muds of which the base fluid is of synthetic composition.
SNS	Southern North Sea.
TARP	Texas Artificial Reef Program.
Tubularia	Genus of hydroids that appear to be furry pink tufts or balls at the end of long strings.
Tunicate	Also known as urochordates (members of the subphylum Tunicata or Urochordata) is a group of underwater saclike filter feeders. Most tunicates live on the ocean floor and others live above in the pelagic zone as adults.
WBM	Water-based muds, drilling mud of a mix of water, clays and other chemicals to create a homogenous blend.

Annex VII. Interviews

Contact	Organisation	Main topics	Remarks
Han Lindeboom	IMARES	North Sea system, availability of hard substrates	Interview
Gerard Duineveld	NIOZ	No-take zones around platforms	Interview
Rogier Daan	NIOZ	Oil-based muds around platforms	Interview
Rob Leewis	Naturalis	Hard substrates and artificial reefs	Interview
Carlo Heip	NIOZ	North Sea strategy	Interview
Wouter Lengkeek	Bureau Waardenburg	Hard substrates	Interview
Joop Coolen	North Sea Foundation	Impact on North Sea ecosystem	Interview
Ian Boyd	SMRU, St Andrews	Sea mammals	Interview
Gordon Picken	Shell UK, BMT Cordah	Biodiversity around platforms North Sea	Interview
George Wintermans	NAM	Biodiversity around platforms	Interview
Wanda Zevenboom & Milton Horn	Rijkswaterstaat	OSPAR, Integral North Sea strategy	Interview
Francis Kerckhof	MUMM	Biodiversity around wind parks	Telephone
Lars Gutow & Roland Krone	AWI	Biodiversity around wind parks	Mail
Godfried van Moorsel	Ecosub	Biodiversity and wrecks	Interview
Leo Henriquez	SodM	Environment, health and safety	Telephone
Moya Crawford	SUT	Submerged man-made structures	Mail