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Rich Reefs in the North Sea

Exploring the possibilities of promoting the establishment of natural reefs and colonisation of artificial hard substrate

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North Sea; hard substrate; reefs; building with North Sea nature; biodiversity

Summary
This project, carried out on the instructions of the Ministry of Economic Affairs, is a preliminary study aiming to give an overview of possibilities and knowledge gaps pertaining to hard substrate in relation to ecological added value. It intends to provide input for the national policy on “Building with North Sea Nature”, which aims to bolster the conservation and sustainable use of species and habitats native to the Dutch section of the North Sea. As a result of various human activities, past and present, the North Sea is currently severely impoverished, not only in terms of the decline of species, but also in terms of loss of different types of habitat, in particular hard substrate. This particularly concerns the loss of extensive beds of flat oysters, which in the nineteenth century covered a substantial surface area the North Sea, including the Dutch Continental Shelf. On a much smaller scale, hard substrate has also disappeared because the fishing industry over the past centuries has removed many large rocks as they formed an obstacle to fishing.

This project examined the possible means of restoring natural structures native to the North Sea and the ways in which the ecological condition of the North Sea could be improved through the provision of artificial hard substrate. Regarding the latter, a distinction can be made between the creation of artificial reefs (hard structures whose principal function is nature development) and 'nature-inclusive design’ (optimising the design of hard infrastructure, such as oil and gas extraction platforms, monopiles for wind turbines, scour protection surrounding platforms and pipelines, in such a way as to create an attractive habitat for a rich biotic community). Potential negative effects such as the risk of introducing exotic species were also addressed.

A brief description is given of the habitats of various natural reef structures native to the Dutch continental shelf, such as flat oyster (*Ostrea edulis*), Ross worm (*Sabellaria spinulosa*), honeycomb worm (*Sabellaria alveolata*), sand mason worm (*Lanice conchilega*) and Northern horse mussel (*Modiolus modiolus*) reefs. This is followed by a description of the species communities occurring on natural and artificial hard substrate in deep and shallow parts of the North Sea. Fewer non-native species are found in deep parts of the North Sea (> -20 m) than in shallow parts.

Within this project a set of criteria has been drawn up, which projects aimed at restoration of the natural environment in the North Sea or nature-inclusive building should meet. They can be summarised as follows:

1. **Focus on species and structures that are native to the Dutch section of the North Sea**. Lists of species and habitats for which policy objectives have been drawn up are an important basis for this.
2. **Where possible, let nature do the work**. North Sea nature has been impoverished by various human activities in the system. Target measures primarily at reducing disruptive activities and only tackle active restoration in a second stage.
3. **Minimise the need to use non-native material**
4. **Reduce the probability of introducing exotic species**:

   a. Providing hard substrate in deeper water is less risky than in shallow water
   b. Avoid any unnecessary movement of living organisms between different parts of the ecosystem
5. **Formulate clear objectives and evaluate them effectively**:
   a. Formulate measurable objectives for each project in advance;
   b. Evaluate potential environmental risks or negative effects in advance;
   c. Implement an effective monitoring programme so that the objectives can be evaluated and negative effects can be identified;
   d. Take into account that it will often take years before a state of equilibrium is reached and that considerable time may pass before negative effects occur;
   e. Ensure that failure to achieve the objectives or the occurrence of negative effects will have clear consequences

Prospects for promoting the establishment of natural reefs as well as for the colonisation of hard substrate communities were investigated for:

- projects involving little effort (e.g., only introducing seabed protection measures and possibly providing some hard substrate, but allowing further colonisation to develop naturally);
- projects involving moderate effort (previously listed activities, including the addition of living reef structures from elsewhere);
- and projects involving a high degree of effort (where the desired species are bred in a laboratory environment or breeding units and then deployed)

The **natural reef builders** which we might be able to restore to or encourage on the Dutch continental shelf include the flat oyster (*Ostrea edulis*), the Ross worm (*Sabellaria spinulosa*) and possibly the Northern horse mussel (*Modiolus modiolus*). The sand mason worm (*Lanice conchilega*) is also regarded as a natural builder of reef-like structures in the North Sea, but it is thought there are few opportunities to encourage them on the Dutch continental shelf (except for ruling out seabed disturbance). The honeycomb worm (*Sabellaria alveolata*) does occur in the North Sea but not near the Dutch continental shelf.

The first boundary condition for settlement of all three afore mentioned species is that the seabed must be relatively undisturbed, in other words no seabed-disturbing activities such as sand extraction, dredging, fishing (including shrimp fishing) should take place. This means that sites within wind farms are potentially suitable locations. The three species have their own requirements with respect to their environment. For all three species, the presence of some hard substrate is required for initial establishment, but subsequently the reef structures or beds can develop over soft sediment. A *Sabellaria* reef can be created only in areas with a large quantity of sediment in the water – an environment which does not favour flat oysters or Northern horse mussels. An extremely dynamic seabed with mobile sand waves will cause problems for the establishment of all three species, although their tolerance limits with respect to sediment dynamics remain unclear. Species specific preliminary research into habitat requirements and site selection is required for projects aimed at facilitating natural reef structures.

It is well established that settlement can be accelerated for flat oysters and for *S. spinulosa* through the presence of living reef material. Importing reef structures from elsewhere in the

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North Sea may help, but also carries risks with respect to the introduction of exotic species. Breeding these species is not considered a method to ensure large-scale restoration, although some breeding experiments can sometimes provide useful insights into fundamental processes governing settlement and reef formation.

Various options are available for **artificial hard substrate** to test which designs will be attractive to a diverse biotic community. The basic principle is that greater diversity in habitat will also provide greater diversity in the biotic communities established in it. This means, e.g. that variation between large rocks and finer material for stone embankments will be more effective than if the same gradation of rocks is used throughout. Two species have been identified as potentially interesting for breeding and initial colonisation trials. They are dead man's fingers (*Alcyonium digitatum*) and the jewel anemone (*Corynactis viridis*). These species may be worth considering because they are perennials and provide the substrate with good protection against the accumulation of other (non-native) benthic species. However, preliminary studies are required before the transplantation of these organisms or captive breeding is considered. As yet, little is known about breeding such species in aquaria or breeding units. Also with the transplantation of pre-colonised substrate, the risk of introducing invasive species must be taken into account.

In addition to providing an insight into the level of knowledge and knowledge gaps, this report provides three general proposals for further pilot studies.

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Contents

1 Introduction

1.1 Introduction and research question

The North Sea, and the Dutch Continental Shelf, is exploited intensively for a wide range of functions. Research has revealed that such intensive use (changing range of nutrients, exploitation of resources such as fish, shellfish and sand) is having an impact on the functioning of the system. For instance, habitats that are rich in structures (such as oyster grounds) disappeared or reduced in area over the last century. However, new structures have also been added, whether by accident or design (wrecks, oil and gas installations, wind farms and a wide range of pipelines).

Over the last decade, Dutch parties have acquired experience in applying the 'Building with Nature' concept. One of its elements is the development of solutions to improve hard substrates of wet hydrological infrastructure (intertidal[1] and subtidal[2]) with a view to restoring absent habitats, and increasing habitat diversity and biomass production. The purpose of this is to generate added value beyond mitigation and compensation for the effects of hard structures. Several of those solutions have been put into practice both in the Netherlands (Rijke dijken [Rich revetments], Rijke havenkades [Rich quays], Rijke onderwaterbestortingen [Rich underwater embankments], oyster reefs) and beyond (ReefGuard technology, the cultivation of corals, construction of coral reefs, and restoration of mangroves). The Dutch government is developing policy which incorporates Building with Nature. This preliminary study ties in with this philosophy and will provide input for the substantive development of a nature-inclusive policy for activities in the Dutch section of the North Sea. The focus of this report is on the North Sea and to a lesser extent on the fringes of the North Sea, such as the Wadden Sea and the basins of the South-Western Delta. This means less attention is paid to intertidal zones.

The objectives of this project are as follows:

a) To provide an overview of the possibilities and knowledge gaps pertaining to hard substrate in relation to ecological added value
    i. to identify which species or groups in the Dutch section of the North Sea could potentially benefit directly or indirectly from hard substrates; a distinction is made between native North Sea species or groups (which are under pressure or have been extirpated; i.e. the ultimate target species or groups) and non-native (potentially invasive) species or groups;
    ii. to identify and list the promising building-with-nature technology available (i.e. related to encouraging natural reef formation and the establishment of species on artificial hard substrate);
    iii. to identify the potential applications envisaged, linked to infrastructure being developed or to be developed in the North Sea.

b) To design a framework for specific promising pilot studies (in the field or laboratory) which will fill key knowledge gaps and enable practical implementation with an emphasis on the Dutch Continental Shelf.

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1 *Intertidal: the area between high and low water that at each tidal cycle is submerged part of the time and dry for the rest of the time*

2 *Subtidal: permanently submerged area below the low tide mark*

1.2 Policy framework

The national government has outlined various visions for the future and formulated policy proposals for 'building with North Sea nature' and/or the use of artificial hard substrate in that context (Ministerie van Economische Zaken 2014a, Ministerie van Infrastructuur en Milieu & Ministerie
van Economische Zaken 2014, 2015a and b). The policy takes into account that on the one hand the North Sea is an intensively used area, space is limited and therefore a combination of functions is desirable and, on the other hand, that North Sea nature has been impoverished and reinforcement of its ecological values is needed. The policy actions include the initiation of 'research into combining the user functions and nature development on artificial hard substrate (building with nature)' (Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken 2015a). The present study will contribute to this.

The various policy documents show that the 'building with North Sea nature' concept aims to combine different user functions in the North Sea, and reinforce ecological values at the same time. Based on regulations in e.g. Wind Farm Site Decision I for the Borssele wind farm zone, the latter can be put into operation as a 'reinforcement of the conservation and sustainable use of species and habitats which are native to the Netherlands' (Ministerie van Economische Zaken 2016), or, more specifically, as a reinforcement of the conservation and sustainable use of species and habitats which naturally occur in the Dutch section of the North Sea. It should be stressed that turbine monopiles and their scour protection cannot be regarded as 'habitats which are native to the North Sea', but such artificial habitats can accommodate species which are native to the North Sea and have declined.

This prompts the question as to precisely which species (and habitats) naturally occur in the Dutch section of the North Sea and whether these include categories of policy-relevant species (and habitats) to which a higher priority should perhaps be assigned in the drive to bolster their conservation. There is also one category of species whose spread should not be promoted: invasive exotic species.

Exact clarification is still required as to which species are native to the Dutch section of the North Sea. An overview of species labelled 'marine' (including exotic species) in the Dutch Species Inventory (Pieterse, 2015) suggests that, excluding birds, the number will comprise somewhere in the region of 1600 multi-cellular animal species and 290 multi-cellular plant species. The number of common and rare native North Sea bird species (cf. Bijlsma, 2001) ranges around 80 (Van Roomen et al., 2013).

One category of policy-relevant species (and habitats) whose conservation and reinforcement obviously merit high priority are North Sea species (and types of habitat) covered by the EU Birds Directive and Habitats Directive. These two directives seek to establish a favourable conservation status for the species and habitats they cover. Moreover, one of the European biodiversity strategy's targets is to halt the decline in the status of such species and habitats and achieve a substantial and measurable improvement in their status by 2020 (European Commission, 2011). The Birds Directive covers about 80 North Sea species in the Netherlands, for 35 of these species areas have been or will be designated. The Habitats Directive covers six habitat types (excluding sub-types distinguished by the Netherlands) which belong to 'coastal and halophytic habitats', seven marine mammal species, and seven fish species (Annex A-1). Areas have been or will be designated for all these types of habitat, and also for three of the marine mammal species and four of the fish species (see also section 2.6.1). In 2013, all habitat types had the conservation status of 'moderately unfavourable' as did the three marine mammal species. Of the four fish species, one had disappeared and two had the status of 'very unfavourable' and 'moderately unfavourable' (Annex A-1). Additionally, the Dutch government sent an action plan based on the Marine Strategy Framework Directive (MSFD) to the Lower House for the restoration of vulnerable shark, skate and ray species in the North Sea (Tweede kamer, 2016). Other policy-relevant categories include species (and habitats) which are more generically known to not to be faring particularly well, such as species from the Dutch section of the North Sea which appear on red lists drawn up at national level (for example, for fish (Annex A-4)) or the OSPAR List of Threatened and/or Declining Species and Habitats (Annex A-3). That list shows, for example, 'flat oyster reefs' as 'Threatened or Declining'. Needless to say, it does not include artificial hard substrate.

From the policy perspective, therefore, it is important to find out (a) which species and habitats native to the Dutch section of the North Sea could potentially benefit directly or indirectly from artificial hard substrate, particularly those species and habitats belonging to policy-relevant categories, and (b) whether the unintentional encouragement of invasive exotic species could be prevented at the same time.

1.3 Restoration of the natural environment and 'nature-inclusive building'

In the past, a substantial area of the Dutch Continental Shelf was covered with hard substrate, largely in the form of flat oyster beds and a number of natural habitats composed of rocks, such as the Cleaver Bank, parts of the Dogger Bank and the Borkum Reef Ground near Schiermonnikoog (Coolen et al., 2015). Many rocks from these areas and other parts of the Dutch Continental Shelf were removed by fishermen in the past. However, even before the oyster beds disappeared and rocks were removed, the North Sea bed (and certainly the Dutch Continental Shelf) consisted largely of sand. The desirability of introducing alien substrate, from a conservation point of view, is therefore questionable.

It goes without saying that artificial hard substrate such as rock armour is an alien material. On the one hand, artificial substrate can accommodate a substantial number of the species and biotic communities which may occur on (former) natural hard substrate, but there will be differences as well. The installation of artificial material (whether this be rock armour or shipwrecks) cannot therefore be regarded as restoration of the natural environment. However, attempts to encourage the settlement of flat oyster populations or other natural structures native to the North Sea can be seen as such. The construction of artificial reefs (in the North Sea and elsewhere) is not universally considered positive, certainly not among ecologists (Wolff 1993). In some cases, the introduction of artificial reefs can have negative effects, or artificial structures after their introduction have not been adequately monitored to identify all the effects (Baine, 2001). It is certain that great caution should be exercised when considering the introduction of an artificial reef for the development of nature in an area where natural hard substrate has never been present. Clear objectives should be formulated regarding any such introduction and sufficient data have to be available to evaluate whether objectives have been met. The broader scale effects should also be included in this analysis.

The 'nature-inclusive building' or 'building with nature' concept is less controversial. It means that when necessary infrastructure requires the introduction of hard substrates (e.g., hard sea defences, scour protection for offshore wind farms, protection of pipelines, etc.) this is done in a way which is conducive to the desired natural development. This entails using materials which are not harmful to the environment and using structures that are attractive to a diverse community. One such example is the 'Rijke dijken' ('Rich revetments') concept (http://www.innovatielink.nl/veiligheid/Dijk:html). Sea defences and other structures at a number of sites in the Netherlands such as Yerseke, Ellewoutsdijk, IJmuiden and the port of Rotterdam have been designed in such a way that they provide a diverse range of habitats. Applying this concept in deeper parts of the North Sea will meet with fewer objections than the introduction of artificial reefs.

1.4 Structure of the document

This report distinguishes between two categories: natural reef-building species and species and communities[3] that use hard substrate. The following topics are addressed in the chapters below:

- Chapter 2 describes a number of physical system features which constitute crucial boundary conditions for reef-building species and species which use hard substrates. This concerns not only the natural system (hydrodynamics, light availability, sediment dynamics, etc.) but also human use (or the regulation thereof) which can limit or determine the development of biogenic structures and artificial hard substrate already in place.
- Chapter 3 describes a number of key species (in particular reef-building species) and typical habitats, as well as hard substrate-related communities of species. This chapter also deals with potentially invasive species.
- Chapter 4 describes promising technology which could be used for the creation of natural reefs, or to build artificial reefs in order to encourage the species and biotic communities desired, as well as technology which could be used to promote the settlement of specific species. This also includes possible cultivation and grafting technology.
- Chapter 5 contains a selection of possible areas of use to encourage reef-building species and species which use substrate.
- Chapter 6 contains several specific proposals for preliminary studies, projects and pilots.

[3] *(species) community: the various species that occur together in a particular area. Areas with similar physical characteristics, generally support communities with a similar composition*

2 Physical system description of the Dutch Continental Shelf

2.1 General description of habitats and ecotopes

The North Sea is a relatively shallow sea. Most of it is less than 150 metres deep and the Dutch Continental Shelf is mostly less than 50 metres deep (Figure B.1 in Annex B). At present, almost the entire Dutch section consists of soft sediment. (Figure B.2 in Annex B) shows the habitats in the Dutch section of the North Sea and the surrounding areas. This figure also shows that virtually no rocks or biogenic reefs occur on the Dutch Continental Shelf, unlike the areas along the British coast and in the north of Denmark.

Within the Dutch Continental Shelf some differentiation can be achieved by breaking it down into areas with coarse or fine sand, and into depth classes (Figure B.3 in Annex B).

The North Sea is relatively turbid compared with the open ocean. Consequently, there is a relatively high degree of light attenuation, with just a few places where sufficient light for photosynthesis to reaches the seabed. As a rule of thumb, photosynthesis is not possible at depths below the 1% at depths where less than 1% of the light at the surface penetrates' and therefore no plant or algal growth will be possible there either. Figure B.4 (in Annex B) shows that in fact it is only in some areas on the Dogger Bank that there is any primary productivity on the seabed, and that algal growth is only possible in the higher layers on other parts of the Dutch Continental Shelf.

2.2 Hard substrate present

Although there is presently virtually no natural hard substrate on the Dutch Continental Shelf, there is hard substrate of anthropogenic origin. The main structures are oil, gas and mining infrastructure, wind farms (including the scour protection surrounding the monopiles) and shipwrecks. Rocks placed around pipelines and cables and anchored floating buoys also provide hard substrate. In addition, there is a small number of artificial reefs which were created in 1992 approximately 8 km off the coast at Noordwijk. Those reefs comprise 112 tonnes of basalt rock armour from Norway (Jager, 2013). The first colonisers were hydroid polyps, which were already growing on the reef one week after it was built. In 1993, the artificial reefs were almost completely covered, with sea anemones being dominant. Approximately 30 North Sea crabs had established themselves on each reef after a period of time. In March 1996, Rijkswaterstaat decided to stop the experiment at Noordwijk. No exotic species were found on this artificial reef. The biodiversity on the reef, however, turned out to be lower than on comparable reefs in other parts of the North Sea. This was probably a result of its location in a very dynamic area with large amounts of suspended sediment (Jager 2013).

The key sites of the various structures are described in the figures below.

2.2.1 Oil and gas infrastructure

Of the roughly 160 production sites in the Dutch section of the North Sea, only a few are in territorial waters. The majority of the platforms are in the central part of the Dutch Continental Shelf. Oil and gas infrastructure comprises the platforms themselves and the accompanying pipework and cabling. Comprehensive information on the oil, gas and mining infrastructure sites on the Dutch Continental Shelf may be found on the web portal (http://www.nlog.nl/nl/pubs/maps/other_maps/other_maps.html).

In the North Sea as a whole, most oil infrastructure is located in the northern part. The Dutch Continental Shelf mainly involves gas. The sites with hard infrastructure on and around the Dutch Continental Shelf are indicated in Figure B.5 (in Annex B). Some of the pipelines are beneath the sediment and some are available as hard substrate. An analysis of the available hard substrate surface (including rocks placed around pipelines) falls beyond the objective of this study.

2.2.2 Wind farms

Off-shore wind farms have been the focus of much attention in recent years as a means of providing artificial hard substrate and areas where little other use and disturbance of the seabed takes place. The Netherlands has two wind farms at present (the Egmond aan Zee Offshore Wind Farm, approximately 8 km off the coast at Egmond, and the Prinses Amalia Wind Farm, approximately 23 km off the coast at Velsen (http://www.nwea.nl/offshore-Wind farmThe Netherlands)). Two other farms are under construction (the Luchterduinen Wind Farm, 23 kilometres off the coast between Noordwijk and Zandvoort, and the Gemini Wind Farm, 55 km to the north of Schiermonnikoog). The Borssele Wind Farm Zone (sites I and II), approximately 40 km off the coast of Walcheren, is currently in the tender phase. Other sites (III to V) will enter the tender process later, and more zones may follow in future Figure B.6 in Annex B). The monopiles also serve as hard substrate. Scour protection (a zone of at least 18 metres of rock armour surrounding each monopile) is not only hard but, owing to its complex form and the cavities between the rocks, forms an interesting substrate for various animal species.

2.2.3 Wrecks

The North Sea bed is littered with the wrecks of ships, war planes and other obstacles, some of them centuries old (Annex B, Figure B.7). Many (mostly older) wrecks are buried beneath the sediment, but there are also many that protrude partly or completely from the sediment. Where parts of a wreck protrude from the sandy bed they form a solid surface for plants and animals which are unable to settle on an unstable sandy bed (www.ecomare.nl). The Register of Wrecks for the North Sea and Westerschelde (Hydrografische Dienst, 2011) contains records of 1953 objects (mainly wrecks) on the Dutch Continental Shelf, but there are probably many more, possibly as many as 10,000 in the North Sea as a whole (Jager, 2013).

Of all types of hard substrate, wrecks are the most densely covered in marine growth and always have the highest numbers per taxonomic group compared with the other types of artificial hard substrate (Jager, 2013). Although a relatively large number of exotic species are found on hard substrate in coastal waters, wrecks lying further out to sea have a relatively low percentage of invasive species (Lengkeek et al., 2013).

2.3 Current and waves

For organisms living on or near the seabed, both maximum current and average current are important. Current can be beneficial: for filter feeders attached to the seabed (or hard substrate), a more powerful current means more passing food. However, too powerful a current or wave force can also dislodge organisms. The optimum flow velocity varies for different plants and animal species. On average, currents are stronger in the English Channel, around the coast of Norfolk in the UK and in the tidal inlets of the Wadden Sea (Figure B.8 in Annex B).

Wave height on the North Sea depends on the force and direction of the wind. The wave load on the substrate surface is important to organisms on hard substrate. Waves exert force on the seabed and cause a turbulent mixing near the seabed, but they do not transport food. Therefore, as far as most organisms are concerned, there is no optimum regarding wave load, but rather a maximum tolerance. Naturally, this is closely linked to depth. Figure B.9 (in Annex

B) shows the wave load on the North Sea bed in three categories. Different species can withstand different maximum wave loads before being dislodged from the substrate.

2.4 Sediment and sediment movement

In addition to sediment composition and silt concentration of the seabed, sediment movement is a crucial factor in determining suitability for the settlement of biota. Different morphological processes, in terms of time and scale, take place on the North Sea bed, resulting in complex interactions between sediment transport, waves and currents (Hasselaar et al., 2015). At the small end of the scale are sand ripples, which can be several centimetres high. Then there are 'mega-ripples': sand ripples which are at least several decimetres high, up to one metre. Sand waves are bigger still: their maximum height equals 25% of the water depth (McCave, 1971), they have wave lengths of hundreds of metres (Van Dijk and Kleinhans, 2005) and migration speeds of dozens of metres per year (Dorst, 2009; Dorst et al., 2011).

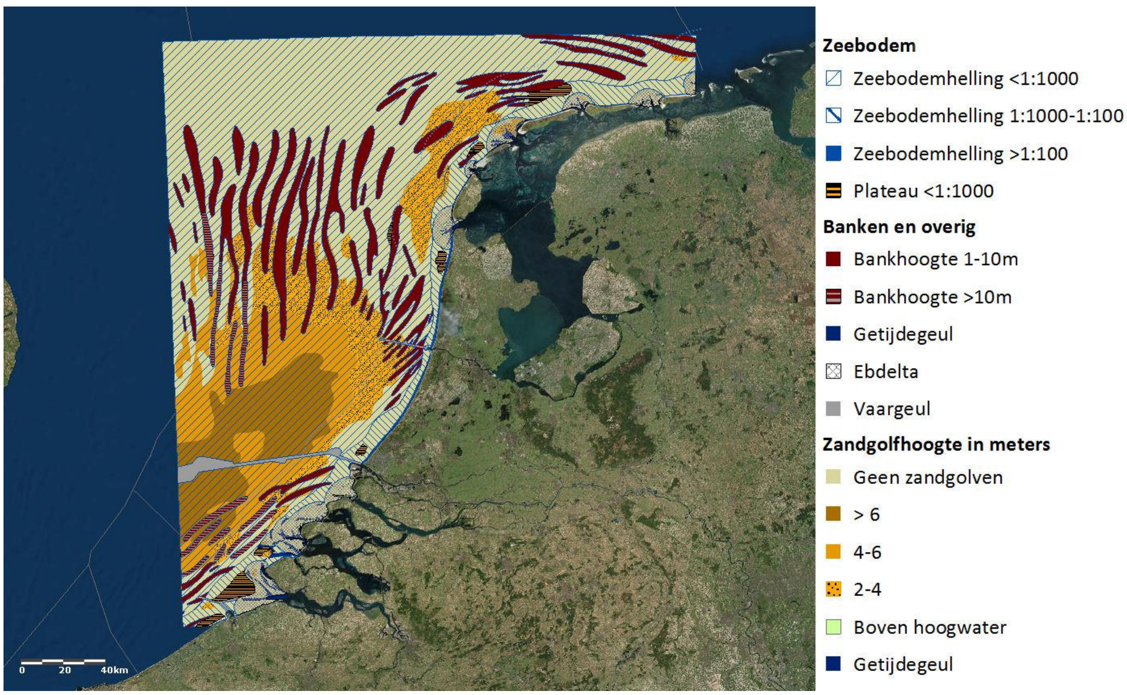

Figure 2.1 Geomorphology of the North Sea. Source: North Sea Atlas

Sand waves close to the coast migrate faster (6.5 to 20 metres per year); offshore, they migrate at a speed of between 3.6 and 10 metres per year (Van Dijk and Kleinhans, 2005). Sand waves in the North Sea can vary substantially in height (Figure 2.1). In very dynamic areas, influenced by significant tidal asymmetry, they can be more than six metres high (from crest to trough), although most areas tend to have lower sand waves. All sand waves move. No model analysis which can be used to accurately predict the height, migration speed and migration direction of sand waves is yet available, although knowledge in this area is developing apace (Borsje et al., 2013). The geomorphological map from the North Sea Atlas gives a reasonable impression of the dynamics on the North Sea bed, based on the classification of sand waves (Figure 2.1). For hard substrate dwellers, sand waves which may cover the substrate are disastrous. Areas of the seabed where there are many sand waves will generally not be suitable locations for an artificial reef. In such circumstances, only structures which protrude above the range of influence of sand waves are suitable sites for settlement.

Sand waves occur everywhere in the North Sea, but there are differences between locations, e.g. sand waves moving within wind farms may cause electricity cables to become exposed, which can be a risk to ships intending to anchor in that location (Röckmann et al., 2015). A study for the Borssele Wind Farm Zone shows that this is a very dynamic environment were a number of sites are regarded as ‘not recommended’ for support constructions and electricity cables (Hasselaar et al., 2015). The risk of structures such as artificial reefs or natural reefs being ‘overrun’ by sand waves is very real, certainly if they are low. Sand waves of more than five metres in height regularly occur on the future Borssele wind farm (Hasselaar et al., 2015). This environment is probably slightly less dynamic because the water is somewhat deeper, with lower flow velocities and hydrodynamic forces, although the force of the waves is slightly greater there and sand waves also occur. The farms off the Dutch coast (OWEZ, PAWP and Luchterduinen) are intermediate with respect to the dynamics of natural conditions (Röckman et al., 2015). It is difficult to estimate the magnitude of the actual risk for larger structures. In 1992, an artificial reef (consisting of four sections) was built near the old REM island. These artificial reefs are in an area with moderately large sand waves (2 tot 4 metres), whilst the reefs themselves were 1.6 metres high. Even though they are no longer monitored systematically, the reefs seem to be in a good state of preservation.

2.5 Anthropogenic disturbance of the seabed

The North Sea hosts human activity on a large scale. This includes sand extraction and fishing, which disturb the seabed, sharply diminishing or indeed fully eliminating the chance of natural biogenic reefs being established. Other areas, such as areas where wind farms have been established or areas with special seabed protection status, are far more suitable as potential sites for artificial reefs, because they are free from anthropogenic seabed disturbance.

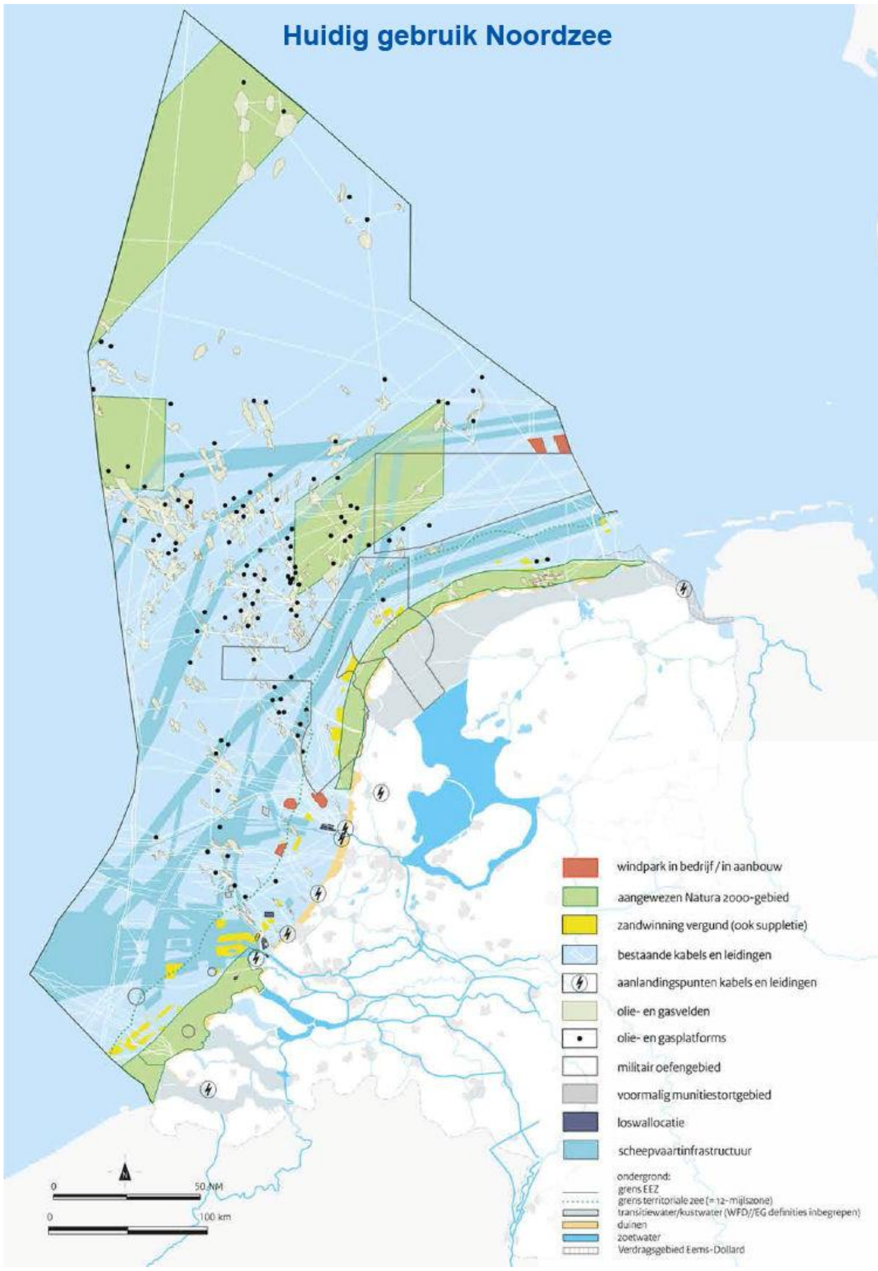

Figure 2.2 Current use of the North Sea (Source: Noordzeeloket)

2.5.1 Fishing pressure

A large part of the Dutch Continental Shelf is fished several times a year by bottom trawling (Figure B.10 and Figure B.11). The Natura 2000 sites in the North Sea were still being fished intensively in the period between 2007 and 2011, mainly in the coastal zone, the Frisian Front and the trough in the Cleaver Bank. The proportion of the surface of those areas where fishing takes place in an ecologically sustainable way remains low. The plans for offshore wind farm zones and the targets for Natura 2000 have also resulted in far-reaching spatial planning taking place at sea, providing for regulation of existing and future usage.

2.5.2 Sand extraction / coastal nourishments

Beach and underwater nourishment is taking place along virtually the entire Dutch coast, This activity is carried out close to the coast, from the beach to approximately the -10-metre line. On average, the Dutch coast is nourished once every four years. Clearly, areas where nourishments take place are unsuitable for longer-term projects related to hard substrate biota. The same applies to sand extraction sites. The areas where sand is extracted for coastal defences and building activities are fixed and are situated slightly outside the -20-metre line (yellow areas in Figure 2.2). There is some debate at the moment about improving the selection of extraction sites, also on the basis of silt content data; this means that the designation of such sites may change in future.

2.6 Measures to establish protected areas, fisheries arrangements, exclusion areas

A number of areas in the Dutch section of the North Sea (Dutch Continental Shelf) have been or are to be designated for the protection of specific species or habitats based on European regulations (the Birds Directive, Habitats Directive, and the Marine Strategy Framework Directive). In addition, under other formal regimes, seabed-disturbing activities (including fishing) have been or are to be limited or prohibited in certain areas. All these measures could be of potential or actual relevance to the chances of settlement by or survival of reef-building or hard substrate-using species, because disturbance of the seabed seriously limits those species' opportunities to establish themselves. A formal environmental objective of the Dutch government is that 10 to 15 per cent of the seabed of the Dutch section of the North Sea should be free from any significant disturbance by human activities by 2020 (Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken, Landbouw en Innovatie 2012).

2.6.1 Birds Directive and Habitats Directive (Natura 2000)

Three sites in the North Sea have been definitively designated Natura 2000 sites under the EU Birds Directive and Habitats Directive: the Noordzeekustzone (North Sea Coastal Zone), Voordelta and Vlakte van de Raan. The Doggersbank (Dogger Bank), Klaverbank (Cleaver Bank) and the Friese front (Frisian Front) are also set to be designated Natura 2000 sites. The protection concerns locations for specific species of birds, fish, marine mammals and specific (benthic) habitat types (see box).

Natura 2000 sites in the Dutch section of the North Sea

North Sea Coastal Zone

The North Sea Coastal Zone Natura 2000 area runs from Bergen aan Zee to Rottumeroog, between the high-water line and a water depth of 20 metres, covering approximately 1500 km² in all. As a zone under the Birds Directive it offers protection to 20 bird species and, under the Habitats Directive, it offers protection to, among others, habitat types H1110 (H1110B), H1140 (1140B), H1310 (H1310 A and H1310B) and H1330 (H1330A) (see Annex A-1), three fish species (the sea lamprey, river lamprey and the twaite shad) and three marine mammal species.

Voordelta

The Voordelta Natura 2000 site covers an area of more than 900 km² of the North Sea off the islands of South Holland and Zeeland. It extends from the Maasvlakte to the tip of the Walcheren peninsula. As a site under the Birds Directive it offers protection to 30 bird species and, under the Habitats Directive, protection to, among others, habitat types H1110 (H1110A and H1110B), H1140 (1140A and 1140B), H1310 (H1310 A and H1310B) and H1330 (H1330A) (see Annex A-1), four fish species (the sea lamprey, river lamprey, twaite shad and allis shad) and three marine mammal species.

Vlakte van de Raan
The Vlakte van de Raan is a Natura 2000 site of approximately 190 km². It is a Habitats Directive site which offers protection to habitat type H110 (H110B) (see Annex A-1), three fish species (the sea lamprey, river lamprey and twaite shad) and three marine mammal species.

The Dogger Bank
The Dogger Bank is a shallow area that extends across the UK, Dutch, German and Danish sectors of the North Sea. The future Dutch Natura 2000 site or SAC is a marine area of approx. 4,715 km² situated at the northern tip of the Exclusive Economic Zone, approximately 275 km to the north-west of Den Helder. As a Habitats Directive site it offers protection to habitat type H1110 (H1110C) (see Annex A-1) and to three marine mammal species.

The Cleaver Bank
The future Cleaver Bank Natura 2000 site or SAC covers an area of approximately 1,235 km² and lies some 160 km to the north-west of Den Helder. As a Habitats Directive site it offers protection to habitat type H1170 (‘open-sea reefs’; see also Annex A-2) and to three marine mammal species.

Frisian Front
The Frisian Front, situated roughly 75 km to the north of Den Helder, covers an offshore area of approximately 2,800 km². As a future Natura 2000 site or SAC it offers protection to one Birds Directive species and to three marine mammal species covered by the Habitats Directive.

Sources: 'Protected nature in the Netherlands: species and areas in legislation and policy' (http://www.synbiosys.alterra.nl/natura2000/) and additional information from the Ministry of Economic Affairs.

Activities in Natura 2000 sites are being and will be regulated through exemptions, permits and codes of conduct (Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken (2015b)).

North Sea Coastal Zone and Vlakte van de Raan
Partly with a view to conservation goals for habitat type 1110B (a subtype of ‘Sandbanks which are slightly covered by sea water all the time’), restrictive measures for fisheries have been in place for the North Sea Coastal Zone and Vlakte van de Raan Natura 2000 sites (based on, respectively, the Nature Conservation Act (*Natuurbeschermingswet*) and the Fisheries Act (*Visserijwet*)) since 2012. As a result, all forms of bottom trawling (including shrimp fishing) are prohibited in parts of these sites. The measures for these two sites are based on what is known as the VIBEG Agreement, which was concluded in December 2011 by a number of nature conservation organisations, fisheries associations and the Ministry of Economic Affairs, Agriculture and Innovation (today the Ministry of Economic Affairs) (see Tweede Kamer, 2011). The various parties involved are now again negotiating an amendment to the VIBEG agreement.

Voordelta
Parts of the Voordelta Natura 2000 site are closed to all forms of bottom trawling (under the Nature Conservation Act). Those measures are based in part on Natura 2000 objectives for the Voordelta and also on what is known as the Maasvlakte 2 Compensation Requirement

(compensatory measures for the effects of land reclamation by instituting seabed protection areas).

The Dogger Bank and the Cleaver Bank
There are also plans to close parts of the Dogger Bank and Cleaver Bank Natura 2000 sites to bottom trawling (Ministry of Infrastructure and the Environment & Ministry of Economic Affairs (2015b)).

2.6.2 Measures to establish protected areas (Marine Strategy Framework Directive)

As a supplement to Natura 2000 measures (section 2.6.1), there are plans to provide protection to the seabed ecosystem of the Frisian Front (which is also a planned N2000 site; see section 2.6.1) and the Central Oyster Grounds on the basis of the European Marine Strategy Framework Directive. This will also involve restrictions on bottom trawling (Ministerie van Infrastructuur en Milieu & Ministerie van Economische Zaken (2015b)). In collaboration with the Ministry of Economic Affairs, the Ministry of Infrastructure and the Environment is currently drafting concrete proposals.

2.6.3 Using existing structures (oil and gas installation safety zones)

There are 500-metre safety zones surrounding oil and gas installations that protrude above water and around wind turbines. Third parties (i.e. including fishing vessels) may not pass those zones. In addition, in the maintenance area of 500 metres on either side of pipelines and cables, sand extraction is prohibited. Until recently, any form of joint use (including passage) was prohibited within wind farms. From 2017, passage and joint use will become possible under certain conditions in all operational offshore wind farms, except those in the Gemini area, but disturbance of the seabed will be prohibited (Ministerie van Infrastructuur en Milieu 2015, 2015). Oil and gas installations can be found throughout the Dutch Continental Shelf (Figure B.5 in Annex B).

3 Knowledge of reef-building and substrate-using species

3.1 Reef-building species

To encourage the development of natural reefs and the use of (artificial) hard substrate it makes sense to identify the species which build reefs themselves and the species which use hard substrate as a habitat. If we focus on ecosystem engineers (i.e. on reef-building species), the choice appears to be relatively limited. When seeking species which are native to the North Sea we soon hit upon reefs of *Sabellaria* (polychaete worms), aggregations of the sand mason worm (*Lanice conchilega*; whether this truly is a reef-building species is a matter of debate) and the flat oyster (*Ostrea edulis*). In general, mussel beds occur mainly in the intertidal area and rarely further out in the North Sea. British waters include a number of other reef-building species such as the Northern horse mussel (*Modiolus modiolus*) and cold water corals such as *Lophelia pertusa*. The latter are limited to deeper, colder waters around the Norwegian Trough. In principle, the Northern horse mussel may occur as far south as the Bay of Biscay and the Irish Sea, but it is generally regarded as an arctic - sub-arctic species. The true beds or reefs for this species are mainly found in the northern North Sea (Dinesen & Morton, 2014). Species such as sea pens are not discussed further in this report. Although they occur in aggregations and may also attract other animal species, the structures they build are soft and do not qualify as 'reefs'.

Below is a description of the reef-building species which may be regarded as promising in the light of this project, including a description of their range, their habitat requirements and the threats they face.

3.1.1 Sabellaria reefs

The honeycomb worm (*Sabellaria alveolata*) and the related Ross worm (*Sabellaria spinulosa*) are two closely related polychaetes which can form relatively large reef structures on hard substrate, and also on sediment which has been consolidated to some extent and is fairly stable. These species may also be found as single individuals. Both species regularly occur singly and rarely as reef-builders in the Dutch section of the North Sea and the Wadden Sea, but *Sabellaria* reefs are quite common in the UK, Germany and France. As far as is known, there are few natural reasons behind the rare occurrence of these reefs in the Netherlands: it might have to do with disturbance of the seabed, which makes it difficult for the reefs to develop.

3.1.1.1 Honeycomb worm (Sabellaria alveolata)

The honeycomb worm (*Sabellaria alveolata*) owes its name to the structure of its reefs, which are built of sand and fragments of shell (Figure 3.3). The individual worms are between 30 mm and 40 mm long; the reefs can vary in height from between 30 cm to 2 metres but are usually up to 50 cm high. In the UK, the honeycomb worm occurs mainly on the west and south coasts, but there are also reported sightings at, among other sites, the Dogger Bank.

Figure 3.1 Locations of known honeycomb worm reefs.
Source:http://www.theseusproject.eu/t/images/a/aa/S._salveolata_.jpg.

3.1.1.2 Reef structures

The largest reef structures of this species occur in Mont St. Michel Bay in France (Ayata et al., 2009), where they form extensive, irregular structures that cover more than 100 hectares. This means they are probably the largest marine reef structures in Europe (Dubois et al., 2006; Noernberg et al., 2010). Such reefs are true hotspots of biodiversity (Dubois et al., 2006; Ayata et al., 2009).

Figure 3.2 A reef of honeycomb worms (Sabellaria alveolata)*. Source: Wikipedia*

3.1.1.3 *Habitat*

The reefs usually begin on hard or consolidated substrate, but may also go on to develop on sandy bottoms. In the UK, reefs of honeycomb worms are found only in areas with moderate to strong wave loads. The species occurs mainly in the intertidal zone, but occasionally also in the shallow area which is permanently inundated (Maddock 2008a). In water temperatures below 5 °C the growth of the honeycomb worm is limited (Holt et al., 1998). Most descriptions of the species mention that some hard substrate is required to initiate reef formation, but that it needs a supply of sediment suspended in the water if it is to build reefs. It is also reported that beds of sand mason worm (*Lanice conchilega*) in Mont St. Michel Bay in Normandy are stabilising soft sediment to an extent sufficient to encourage reef formation by honeycomb worms. Although there needs to be sufficient water movement in the surrounding area to suspend sediment, honeycomb worms are generally absent from sites where the force of waves is extreme. Larvae prefer to settle near adult populations. Little is known about the species' preference for specific salinity. It is mainly found in fully marine environments, but there are also reports of reef structures in areas where there is freshwater intrusion.

3.1.1.4 *Threats*

The key threats to this species are large-scale changes in sediment supply, both insufficient suspended sediment and burial as a result of large-scale sedimentation following construction activities or burial by moving sand waves. Honeycomb worms and mussels are frequently found together. They can sometimes be crushed by humans walking on them in the intertidal zone. Pollution is sometimes reported as a cause of the disappearance of reefs from estuaries, but a clear causal link has so far not been demonstrated (Holt et al., 1998).

3.1.1.5 *Sabellaria spinulosa*

Sabellaria spinulosa (Ross worm) makes similar structures. The tubes are about 3 cm long and the reefs about 50 cm high. This species is found throughout the north-east Atlantic Ocean south to Portugal and the Mediterranean Sea. Ross worms usually live singly, although separate, non-aggregated specimens can sometimes be found in very high densities of hundreds of individuals per square metre.

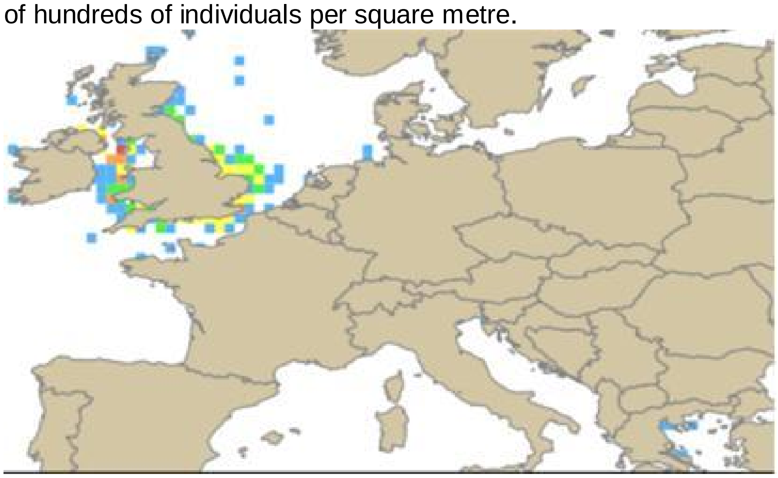

Figure 3.3 Known sites of Sabellaria spinulosa *reefs (Source: http://www.theseusproject.eu/wiki/File:S._spinulosa_.jpg)*

3.1.1.6 Reef structures

Reefs are formed only under specific environmental conditions. Reef structures of *S. spinulosa* are found in the German part of the Wadden Sea and off the British coast, especially at sites where the current is relatively strong and the sand is churned up. Reef structures on an artificial reef have been observed in the Netherlands, but there are no data for sediment concentrations in the water at that site.

Figure 3.4 Sabellaria spinulosa *reef in the German part of the Wadden Sea mudflats. Source: www.waddenzeeschool.nl)*

S. Spinulosa appears to need some hard substrate (a few rocks or shells) if it is to start forming a reef, but thereafter the structures are able to convert sandy substrate into hard, three-dimensional substrate.

3.1.1.7 Habitat

This species occurs in the intertidal zone as well as in deeper water, but is slightly more likely to be found in the subtidal zone (Maddock, 2008b). *S. Spinulosa* appears to be not particularly sensitive to changes in water quality (Holt et al., 1998). In the North Sea, the species occurs on sandy beds and gravel beds, around the edges of sandbanks and the edges of gullies. It favours areas with high levels of turbidity and moderate currents. In the past, it was also found on the artificial reefs at Noordwijk (Leewis et al., 1997).

3.1.1.8 Threats

The reef structures of *S. spinulosa* are sensitive to physical disturbances, with fishing being largely viewed as the greatest threat (Holt et al., 1998). Larger solid reef structures appear to be less sensitive to shrimp fishing (Vorberg, 2000), but even the lighter gear used by shrimp-fishing vessels may prevent the formation of such reef structures. In the Wash and the Thames Estuary pink shrimps (*Pandalus montagui*) were strongly associated with *S. spinulosa* reefs. Shrimp-fishing vessels therefore preferred to fish in areas near those reefs. This appears to have led to the virtual disappearance of *spinulosa* reefs in those areas in the 1970s (Holt et al., 1998).

Other forms of seabed disturbance, such as sand extraction or the construction of infrastructure, may also lead to the disappearance of this species. However, it can recover fairly quickly. A decline of *S. spinulosa* reefs was observed in the UK shortly after the Thanet

Offshore Wind Farm was built. Five years later, however, those reef structures were recovering (Pearce et al., 2014).

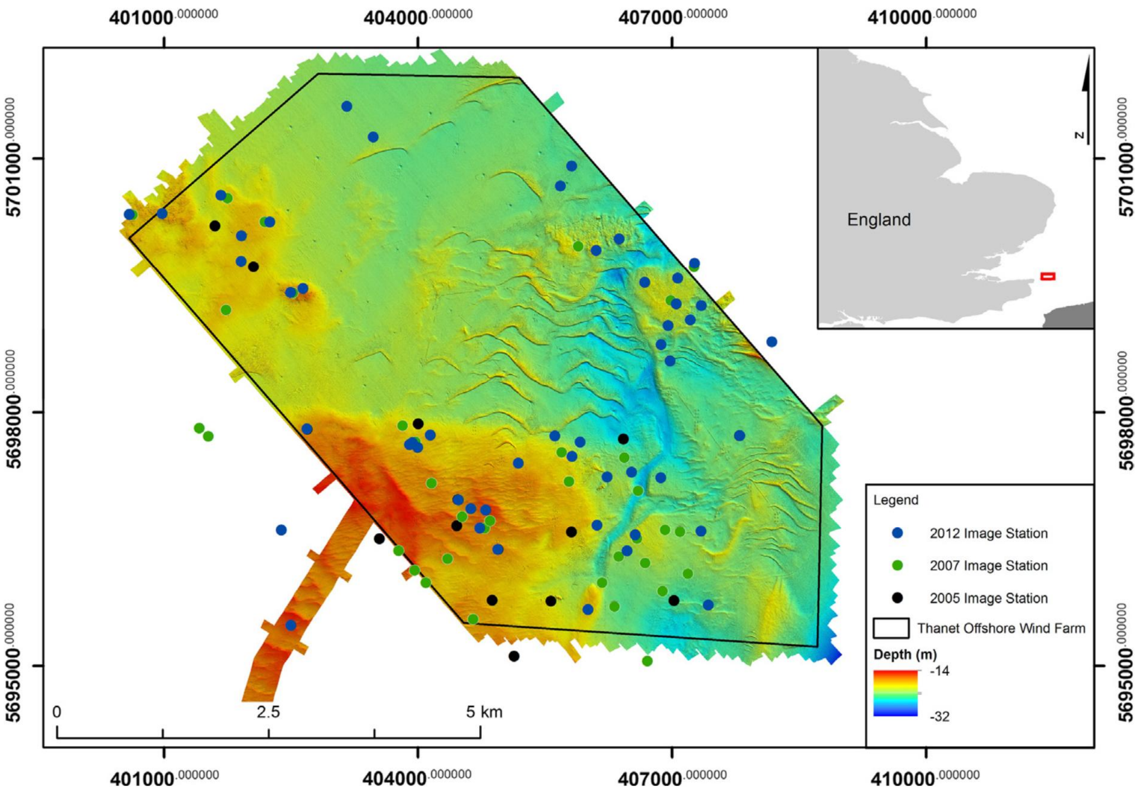

Figure 3.5 Study of the area within the Thanet Offshore Wind Farm, 12 km off the Kent coast (Pearce et al., 2014)

S. spinulosa is not particularly sensitive to water quality or pollution. Only chemical dispersants such as those used after a major oil leak may have a negative effect (Holt et al., 1998).

3.1.1.9 *Status in policy*

S. spinulosa is designated a policy-relevant species for the North Sea (see Annex A2). Remarkably, it is still officially designated an exotic species on the basis of a 2005 inventory (Wolff, 2005). Wolff concludes, based on an article by Korringa (1954), that this species was probably introduced in the Netherlands on oyster shells from France, but had not established itself in the Netherlands in the 1950s (Korringa, 1954). Wolff (2005) writes that the various sightings of the species in the Netherlands since 1990 might be the result of mild winters since that time. However, for over a century now the same species has been found in the intertidal zone of the North German Wadden Sea (Vorberg, 2000), where winter water temperatures fluctuate much more strongly than on the North Sea bed. According to the World Register of Marine Species (WoRMS, http://www.marinespecies.org/aphia.php?p=taxdetails&id=130867), this species can be found along all the coasts of the North Sea (with the exception of the Baltic Sea). Although there is no mention in the register of any literature from the Netherlands about this species, it does contain old references from all surrounding countries (Belgium, France, England, Scotland and Germany). Based on this information we conclude that *S. spinulosa* is a species which can indeed naturally occur in the Dutch section of the North Sea and that its designation as an exotic is incorrect.

3.1.2 Aggregations of the sand mason worm (*Lanice conchilega*)

The sand mason worm (*Lanice conchilega*) is a well-known ecosystem engineering species from the North Sea (including the Dutch part) and the Wadden Sea. It forms dense aggregations on the seabed and stabilises sandy sediment. Modelling has indicated that dense aggregations of sand mason worms can have a significant effect on the movement of sand over the seabed (Borsje et al., 2009; Borsje et al., 2014). The species is commonly found in the North Sea and the Wadden Sea, including in the Dutch part.

Figure 3.6 Close-up of the sand mason worm (Lanice conchilega)*, as it is usually found. Ecosystem engineering can be said to be taking place when very high densities are present, but it does not qualify as true reef formation.*

3.1.2.1 Reef structures

Whether the sand mason worm should really be regarded as a reef-building species is the subject of some debate (Callaway et al,. 2010). In general, the sand mason worm fields are higher than their environment owing to their sediment-stabilising effect. According to some definitions, very dense aggregations qualify as reefs, albeit in relatively low structures (Rabaut et al., 2009). The 'reefs' consist of individual tubes which (unlike *Sabellaria* reefs) do not knit together to form a hard structure. Large and dense aggregations of sand mason worms can continue to exist for several decades (Callaway et al., 2010).

Figure 3.7 Reef structure of the sand mason worm (Lanice conchilega*). Source: Ecomare website*

Reports have been received very recently (at the end of November 2015) through the Wadden Association stating that a striking number of sand mason worm reefs have been seen in the Dutch section of the Wadden Sea, particularly between the islands of Terschelling and Schiermonnikoog. This may have to do with a relatively mild winter. This species is unable to cope with very low winter temperatures. There are also some reefs off the Belgian coast which are designated as special biotopes (http://health.belgium.be/eportal/Environment/MarineEnvironment/TheMarineEnvironPolicy/WorkingInAnInternational/BirdsAndHabitats/AreaPolicy/HabitatsDirectiveAreas/19087737_EN?ie2Term=BELGIAN&ie2section=). Dense aggregations of sand mason worms can be very important to the establishment of *Sabellaria* reefs and of other biota, such as mussels (De Smet et al., 2015).

3.1.2.2 Habitat

Sand mason worms occur on sandy and muddy seabeds, often in places where seagrass and benthic algae (diatom frustules which grow on the seabed) are also found. The species can found in sites ranging from the intertidal zone out to a depth of 1700 metres and is very tolerant to a range of water quality parameters. It is well able to withstand low salinity levels, but often occurs in fully marine environments too. When present in high densities, sand mason worms can stabilise the seabed and reduce sediment movement. Nevertheless, their habitat is determined by the degree of seabed stability.

3.1.2.3 Threats

Seabed-disturbing activities (bottom trawling (fish and shrimps), sand and gravel extraction, dredging and construction work etc.) which compromise the integrity of sandbanks are the main threat facing dense aggregations of sand mason worms. Although offshore wind farms can have a negative impact at the time of their construction, the presence of wind farms in the Belgian section of the North Sea appears to have had a positive impact on the occurrence of sand mason worms, primarily in the vicinity of construction foundations (Coates et al., 2014).

3.1.3 Flat oyster (Ostrea edulis)

Originally, the range of flat oysters extended along the European coast from Norway to Morocco, across the Mediterranean Sea and the Black Sea (Figure 3.9). The flat oyster is native to Europe and has been traded intensively since antiquity owing to its culinary value. In the days of Agrippa (63 BC to 12 BC), English oysters were transported from Kent to Rome. Their popularity has resulted in over-exploitation in many regions: flat oysters have disappeared from certain areas in France (Heral, 1989), Spain (Figueras, 1970), the UK (Laing et al., 2005), the North Sea region and the Netherlands (Berghahn & Ruth, 2005). A few centuries ago, oyster beds were a characteristic feature of the ecosystems along the European and Mediterranean seaboard. The oyster population declined further partly as a result of the introduction of a protozoan parasite called *Bonamia*. Flat oyster beds currently rank among Europe's most threatened marine habitats (Airoldi & Beck, OSPAR Commission 2008; see also Annex A-3).

Figure 3.8 Flat oysters can reach a considerable age and size.

The spat (larvae) establishes itself on hard substrates, such as rocks, shell fragments or preferably oyster shells in existing beds. After attaching themselves to the substrate, they spread no further. Oyster bed development is a self-perpetuating process. Under a certain critical mass level, recruitment (spat settlement) can fail because of the limited availability of substrate (Berghahn & Ruth, 2005; Kennedy & Roberts, 2006). Flat oysters can live to over 20 years of age.

Oysters are important because of their contribution to the functioning of the ecosystem. They can form beds with a three-dimensional structure consisting of live oysters, oyster shells and all kinds of associated species.

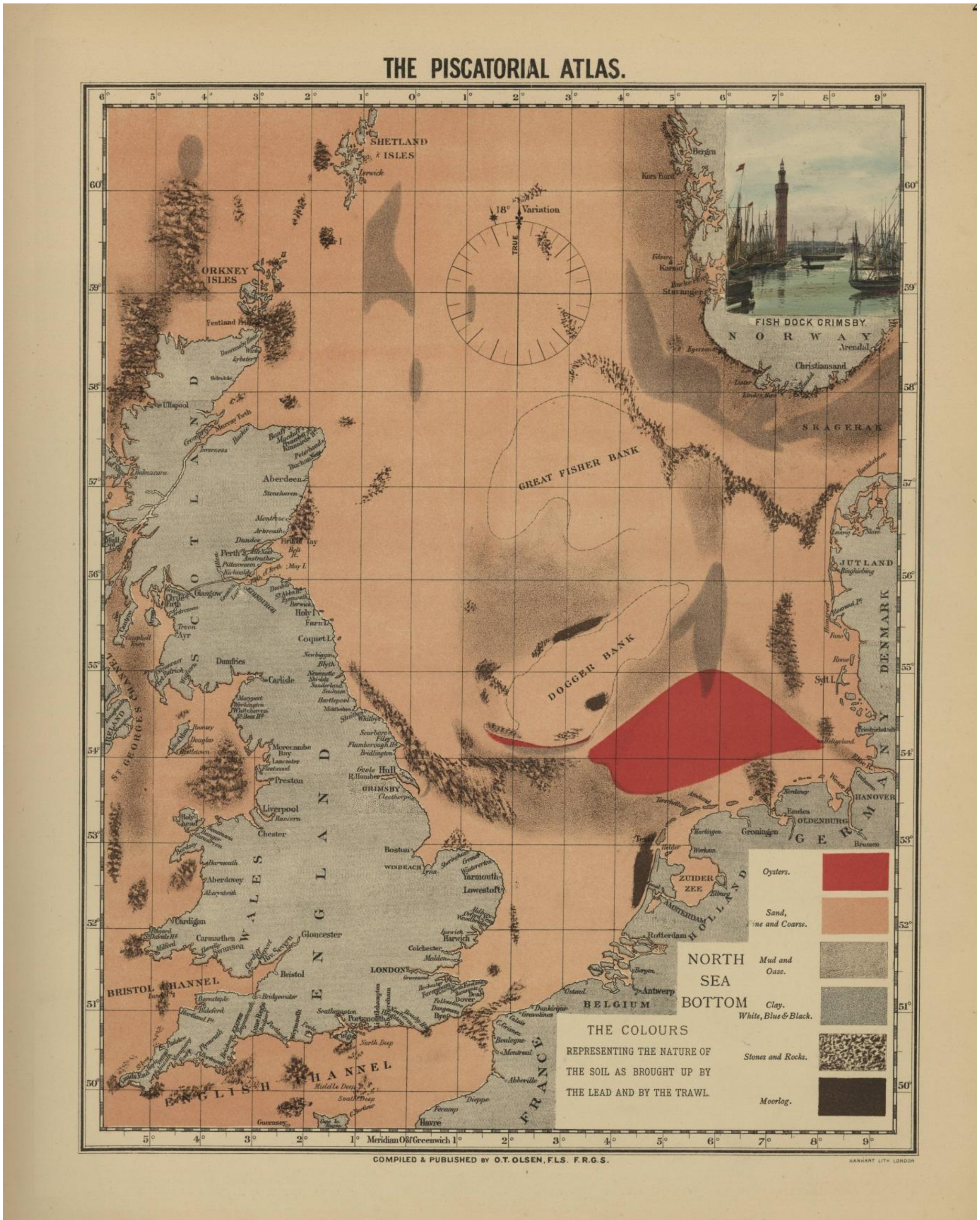

Figure 3.9 Areas containing flat oysters in the North Sea and adjoining areas. Source: Olsen (1883)

Until over a century ago, flat oyster beds (*Ostrea edulis*) formed an important habitat in the North Sea (Figure 3.9). According to a field study conducted in the nineteenth and early twentieth centuries, there were large areas containing flat oysters (more than 25,000 km^2)

(Olsen, 1883; Fischereikarte 1915 in Gercken & Schmidt, 2014; Houziaux, 2008). Over the course of the nineteenth century, fishing for flat oysters increased through the use of steamships. The yields waned and the oyster beds were decimated (Gercken & Schmidt, 2014; Houziaux, 2008). The subsequent advent of bottom trawlers, which disturb the seabed, sealed the fate of the oyster beds; they disappeared entirely from the North Sea (Houziaux, 2008). The large oyster area Figure 3.9 is still known as the Oyster Grounds.

3.1.3.1 *Reef structures*

The reef structures of Japanese oysters (*Crassostrea gigas*), a species not native to the Netherlands, are better known than those of the flat oyster. The Japanese oyster fares better in the intertidal zone and is therefore more easily visible (see Figure 3.21). This species is also more robust than the flat oyster. Nevertheless, the flat oyster can also form three-dimensional structures and therefore create a habitat for other species (Figure 3.10). Flat oysters fare better in calmer, deeper water than the Japanese oyster. Even without a true reef structure, flat oysters form a habitat for other species because their shells act as hard substrate and because of the three-dimensional structures they create.

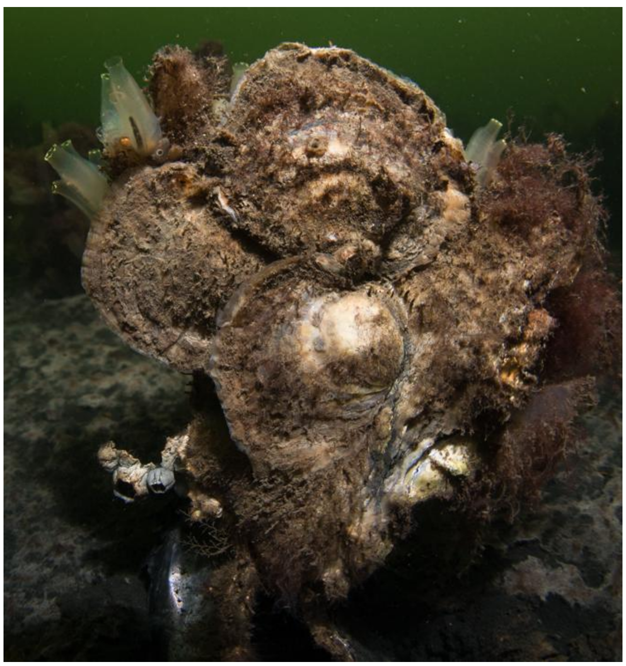

Figure 3.10 Reef-forming flat oysters (Joeri van Es, Grevelingenmeer 2014)

3.1.3.2 *Habitat*

In 1877, K. Mobius coined the term ‘biocoenosis’ on the basis of his research into flat oysters in the Wadden Sea. He described the rich diversity of species of an oyster bed and referred to it as biotic community, in so doing introducing a central concept into ecology. It was known early on, therefore, that flat oyster beds serve as a habitat for a large number of other species. Korringa (1954) described the flora and fauna associated with oyster beds and identified 250 species. Recent research in the Wadden Sea has revealed that the biodiversity of shellfish beds is much greater than that of the surrounding sandy substrates (Smaal et al., 2013). The restoration of flat oyster beds in the North Sea presents an opportunity, therefore, to create a habitat for a rich biotic community. Flat oyster habitat comprises a sandy seabed and shell fragments, in an environment with a salinity level of more than 15.5 g/l and moderate hydrodynamics.

3.1.3.3 *Threats and opportunities*

Disturbance of the seabed, including by bottom trawling, is considered the key threat to flat oyster beds. Natural factors such as predation, diseases and excessive hydrodynamic forces also impede the development of flat oyster beds. Attention should therefore be paid to the local dynamics when selecting a site. This can have a limiting effect on oyster bed development in wind farms in the shallower coastal zone, unless a degree of protection can be provided. Nevertheless, the restoration of flat oyster beds in the North Sea offers opportunities for the development of rich biotic communities (Smaal et al., 2015).

3.1.4 Northern horse mussel (Modiolus modiolus)

The Northern horse mussel (*Modiolus modiolus*) is a bivalve mollusc which is found throughout the world, mainly in deeper waters. Juveniles fix themselves with byssus threads to a hard substrate or to each other, but older animals are also found singly, sometimes partly buried in the seabed. The Northern horse mussel, which can live to 50 years of age, favours coarse sandy and gravel beds with good water exchange and high-salinity conditions. In the North Sea area, the species usually lives in waters deeper than 20 metres (De Bruyne et al., 2013). Smaller specimens are caught for consumption (De Groot et al., 1988). According to the OSPAR list (OSPAR Commission, 2008), Northern horse mussel beds are a threatened habitat.

Figure 3.11 The Northern horse mussel (Wikipedia, Magne Flåten)

The species is found occasionally in the Dutch section of the North Sea as single individuals (Figure 3.12), but no beds are known to exist in that area (OSPAR Commission, 2009).

Figure 3.12 Sampling of the Northern horse mussel in the North Sea (de Bruyne et al., 2013)

3.1.4.1 Reef structures

The Northern horse mussel can form characteristic beds or reefs in the North Sea, at depths between 30 and 60 metres, with a single community covering up to several dozen km^2 of the seabed. These reefs are associated with a species-rich community including sponges, hydroid polyps, sea mats, soft corals, brittlestars and serpent stars, slugs, bivalves and sea squirts (De Bruyne et al., 2013).

3.1.4.2 Habitat

In a recent article, Ragnarsson & Burgas (2012) describe the influence of Northern horse mussel beds on the abundance and diversity of epifauna (i.e., animal species living on top of the seabed or on top of other plants or animals) based on video observations in Faxaflói Bay (Iceland). Species richness was correlated exponentially with abundance of Northern horse mussels; the abundance acted synergistically with sediment coarseness. The conclusion is that Northern horse mussels can have significant effects on the functioning of ecosystems in coastal waters.

Although Northern horse mussels are adapted to life in the sediment, they do require hard substrate for the establishment of juveniles, which fix themselves to a surface with byssus threads. The species is found on a wide range of substrates, as epifauna on sandy beds, on rocky beds and on the pylons of offshore constructions. In Europe, Northern horse mussels are usually found in gravel and coarse sediment, and in soft mud containing shell fragments (Elsasser et al., 2013).

3.1.4.3 *Threats and opportunities*

Studies in Strangford Lough (Northern Ireland) clearly show that seabed-disturbing fishing methods have adversely affected Northern horse mussel populations, which were once very widespread there (Elsasser et al., 2013). The same article addresses attempts to restore Northern horse mussel stocks, and the conditions under which natural recruitment can take place. While opportunities for restoration do exist, just as is the case with the flat oyster, further research into the boundary conditions and restoration methods is needed.

3.2 Species using hard substrate

There are various different types of hard substrate-related biotic communities in the North Sea (Lengkeek et al., 2013ab; Van Moorsel, 2014; Schrieken et al., 2013), varying in biodiversity and abundance. The role of non-native species and policy-relevant North Sea species within those communities depends on the type of hard substrate and the geographical location (Jager, 2013; Van Moorsel, 2014). Parameters having an impact on the composition of species include the distance to the coast, the currents (tide/residual current), the presence of 'stepping stones', the sediment type on which the hard substrate is located (silt/mud/sand) and finally the location, shape and material of the hard substrate itself. Depth is particularly important. For example, species found in the sublittoral zones are different from those located in, e.g. the intertidal zone along the coast and on wind farms. Furthermore, there is an overall difference between communities living at a depth of up to roughly ten metres and those in deeper waters along the Dutch coast. Since sunlight does not penetrate well in deeper water, macroalgae and benthic microalgae do not occur there, or only in considerably smaller densities. The clarity of the water depends on the quantity of suspended sediment. Further off the coast, for example on the Cleaver Bank and the Dogger Bank, the water is clearer and algae are found at depths of 20 or even 30 metres, whilst close to the coast they only occur at depths of up to a few metres. In addition to depth, the species community associated with hard substrate also depends on the type of material (rock, metal, etc.), the roughness of the material (individuals have difficulty settling on smooth surfaces) and the shape and size of the material. For instance, the shape of the substrate can have a substantial impact on currents, creating places where there is a powerful current and sheltered spots where fish can seek refuge. Most marine species which live on, near and around hard substrates have a pelagic life stage (e.g., in the water column) allowing dispersal. Since most of the North Sea bed consists of sand, such species find it difficult to settle there and find their propagation inhibited. However, there are many wrecks scattered over the North Sea bed (Figure B.7 in Annex B) and, more locally, rocks which have been placed there (for instance to protect pipelines) or rocks which have naturally found their way there, for example on the Cleaver Bank and at the Borkum Reef Ground. Using those hard substrates as stepping stones, hard substrate-related species find it easier to disperse over the sandy North Sea bed. There are considerably fewer stepping stones available for hard substrate-related species which settle closer to the surface. In the open sea, these species depend largely on wind farms and navigation buoys.

The following sections deal in more detail with the various habitats and sites where hard substrate is located in the Dutch section of the North Sea. A description is given of the species communities present, and the policy-relevant species and habitats are highlighted (including the Natura 2000 habitat type H1170: 'open-sea reefs') that are associated with those communities. There are various different types of hard substrate along the Dutch coast, as illustrated in Figure 3.13. These include in particular wind farms, drilling platforms, pillars, buoys, rocks and wrecks. Cables, pipelines and rock armour are not included in the illustration, but may of course be colonised where they protrude from sediment.

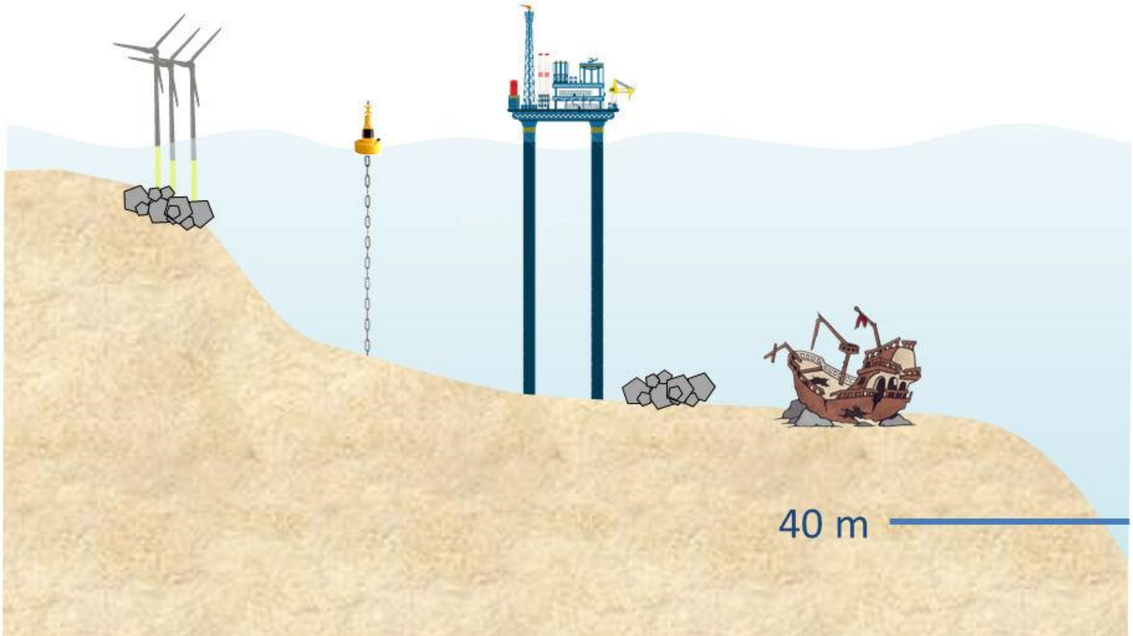

Figure 3.13 Types of hard substrate in the Dutch section of the North Sea. The hard substrates most commonly found in the North Sea are provided by wind farms, drilling platforms, pillars, buoys, rocks and wrecks (not to scale)

3.2.1 Species communities on natural hard substrate (deep)

The main natural hard substrates found in the deeper parts (> -20 metres) of the North Sea are the rocks and gravel on the Cleaver Bank (Figure 3.14; Figure 3.15) and the Borkum Reef Ground (Schrieken et al., 2013; Van Moorsel, 2014). Van Moorsel, 2014). Those rocks host a relatively great diversity of native species, with barely any non-natives present. Van Moorsel (2014) mentions the occurrence of just one exotic species, the orange-striped green anemone (*Diadumene lineata*). This is a relatively rare, small sea anemone species. These rocks also support several policy-relevant species which have been classified as typical species for habitat type H1170: open-sea reefs (Annex A-2). They include, for example, a soft coral species called dead man's fingers (*Alcyonium digitatum*) and the poached-egg shell (*Simnia patula*), which feeds on that soft coral (Schrieken et al., 2011). In addition, there are several exclusive species such as *Galathea intermedia*, a squat lobster species, and species rarely found in the Netherlands, including the blue-striped squat lobster (*Galathea strigosa*) (Figure 3.14) and the hairy hermit crab (*Pagurus cuanensis*) (Figure 3.15). Sponges and seaweeds which have been cast adrift and roll over the seabed are a natural type of hard substrate in the North Sea which is not, or only rarely, mentioned in the literature. Those sponges and algae accommodate a great diversity of crabs, hydrozoans, sea mats and other hard substrate-related species (Figure 3.16).

Figure 3.14 Species community on the rocks of the Cleaver Bank. In the centre is the blue-striped squat lobster (Galathea strigosa). Photograph: A. Gittenberger

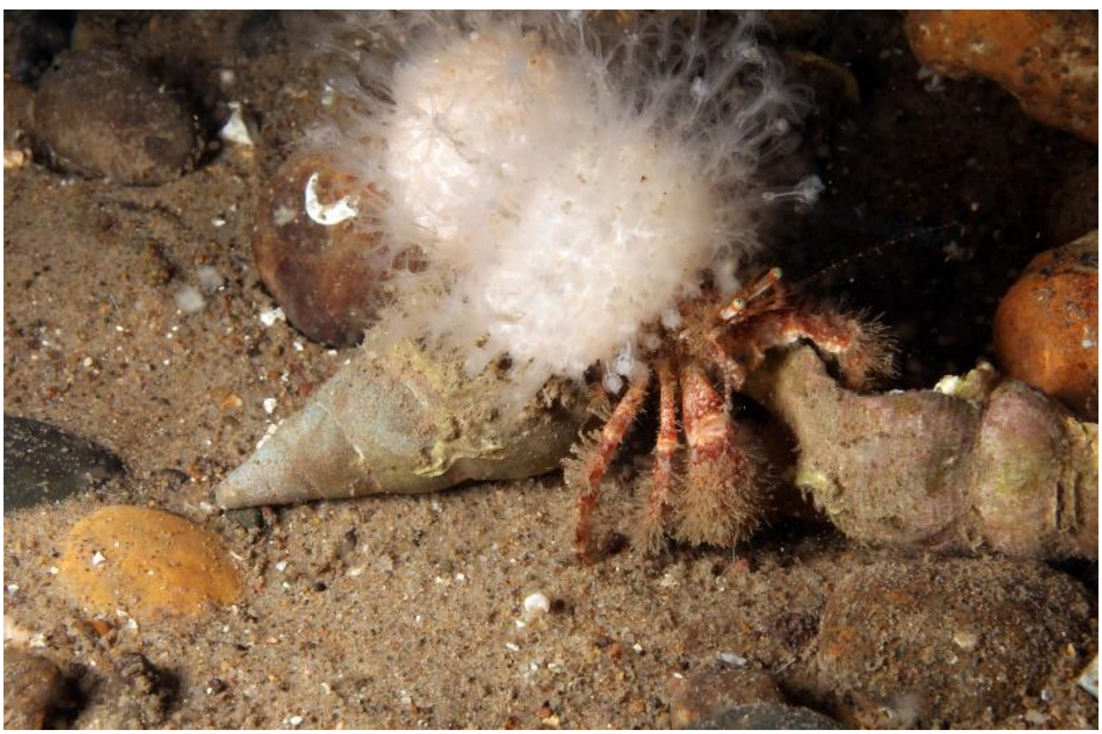

Figure 3.15 Species community on the rocks of the Cleaver Bank. This is the hairy hermit crab (Pagurus cuanensis) with a dead man's finger (Alcyonium digitatum) on its shell. Photograph: A. Gittenberger

Figure 3.16 : A close-up of an alga which rolls over the North Sea bed with the current. It supports a considerable diversity of species which rely on hard substrate. The photograph shows a flying crab, a common spider crab, a sea urchin, various sea mats, hydrozoans and nudibranchs with their eggs. Photograph: A. Gittenberger

3.2.2 Species communities on natural hard substrate (deep)

The main artificial hard substrates in deeper parts (>-20 metres) of the North Sea are wrecks, and scour protection on pipelines and around pillars of turbines and oil platforms on the seabed (Lengkeek et al., 2013ab; Schrieken et al., 2013; Van Moorsel, 2014). The biotic communities on those rocks are probably most similar to those on the natural rocks in the North Sea as discussed in the previous paragraph. However, wrecks are clearly a different type of habitat (Lengkeek et al., 2013a). They support a high diversity of native species, comparable with that found on natural hard substrate, but also a greater number of exotics (Van Moorsel, 2014) including the notorious invasive carpet sea squirt (*Didemnum vexillum*) (Figure 3.17; Gittenberger et al., 2007). Wrecks can therefore be used as stepping stones in the spreading of such species. In comparison with shallow-water communities, the number of exotics in deeper water has remained limited to just a few species, though. Just like natural hard substrate, wrecks host several policy-relevant species which have been classified as species typical of habitat type H1170: 'open-sea reefs' (Annex A-2). For example, a soft coral called dead man's fingers (*Alcyonium digitatum*), the poached-egg shell (*Simnia patula*) and the squat lobster (*Galathea intermedia*) are all commonly found on wrecks (Schrieken et al., 2011). Alongside those species, wrecks support several native species which are never or rarely found on natural hard substrate. For instance, the sea squirt species *Ascidiella aspersa* was found in high densities on the inside of a wreck on the Brown Ridge. This species produces floating eggs which are caught in the cavities of the wreck, enabling the animals to settle there. Individual specimens also hosted many small shells of the marbled crenella species *Modiolarca picta*, which otherwise were known only from a site on the Cleaver Bank (Gittenberger et al., 2013a). Finally, it was recently discovered that the jewel anemone (*Corynactis viridis*) (Figure 3.18) has settled in the North Sea (Gittenberger et al., 2013b). This species, historically native to areas neighbouring the North Sea in North-western Europe, has probably succeeded in settling in the North Sea as a result of climate change. Within a period of ten years, the species was observed for the first time, separately, in the British, Belgian, Dutch and German parts of the North Sea, which means it is safe to conclude that it has now settled in the North Sea (Gittenberger et al., 2013b). With the exception of the sighting in the German part of the Wadden Sea, all the other sites where the species had established itself were artificial hard substrates, in particular wrecks. Various fish species also favour wrecks over natural hard substrate. As far as the Dutch North Sea species on the Red List (Annex A-4) are concerned, those classified as 'near threatened' in particular are frequently found in wrecks. Examples include the poor cod (*Trisopterus minutus*) and the Atlantic cod (*Gadus morhua*). In addition, some rare fish species native to the Netherlands seem to have become almost entirely dependent on wrecks: the goldsinny wrasse (*Ctenolabrus rupestris*) (Figure 3.19) and the leopard-spotted goby (*Thorogobius ephippiatus*) (Figure 3.20; Lengkeek et al., 2013a).

Figure 3.17 The invasive carpet sea squirt (*Didemnum vexillum*) on a wreck on the Dogger Bank. Photograph: A. Gittenberger

Figure 3.18 The jewel anemone (*Corynactis viridis*) on a wreck on the Brown Ridge. Photograph: A. Gittenberger

Figure 3.19 The goldsinny wrasse (*Ctenolabrus rupestris*) in a wreck in the Dutch part of the North Sea. Photograph: A. Gittenberger

Figure 3.20 The leopard-spotted goby (*Thorogobius ephippiatus*) immediately adjacent to a wreck in the Dutch section of the North Sea. Photograph: A. Gittenberger

3.2.3 Species communities on natural hard substrate (in shallow waters)

The Dutch coastline features natural hard substrates in the shallower parts (< 20m deep) of the North Sea, mainly comprising shellfish beds. A distinction can be made between native species and exotics and between sublittoral beds and beds in the intertidal zone. The latter are mainly found in the basins of the Delta (Oosterschelde and Grevelingen) and in the Wadden Sea. Other than those in the basins, the intertidal shellfish beds in the North Sea are of no importance.

Native shellfish beds mainly comprise mussel beds (*Mytilus edulis*) and, in and near the Grevelingen, flat oyster reefs (*Ostrea edulis*; Figure 3.10.) or mixed shellfish reefs. In general, the diversity of species on those shellfish reefs is greater than on hard substrates in the deeper parts of the North Sea. In addition to the large number of native species, there are considerably (dozens) more non-native species here than in deeper waters of the North Sea. Furthermore, these shellfish reefs are home to several fish on the Red List (Annex A-4), including the tadpole fish (*Raniceps raninus*; classified as 'endangered'), the common sea snail (*Liparis liparis*) (classified as 'vulnerable') and the shanny (*Lipophrys pholis*) (classified as 'near threatened'). Further away from the coast in the Dutch section of the North Sea there is no natural hard substrate in shallow waters, apart from drifting seaweeds and pieces of timber on which many southern European species hitch a ride and thus find their way, borne on the south-north residual current, from the coasts of France and southern England into the Dutch section of the North Sea. Finally, large Japanese oyster reefs can be found along the Dutch coast (in particular in the intertidal zone), where they originally did not occur (Figure 3.21).

Japanese oysters may transform sandy beds into reefs on which a great variety of native and non-native hard substrate-related species are able to settle.

Figure 3.21 Typical hard substrate community in the littoral zone along the Dutch coast. It comprises mainly Japanese oysters (Crassostrea gigas), which in turn form a substrate for a great variety of non-native species. Photograph: A. Gittenberger

3.2.4 Species communities on artificial hard substrate (in shallow waters)

Artificial hard substrates, in particular those created by revetments and coastal defences, hug the Dutch coastline. Further away from the coast, oil platforms, buoys and wind farms constitute the main hard substrates. The revetments support species communities comparable with those found on shellfish reefs. Since the surface of revetments tends to be relatively smooth compared with that of shellfish reefs, the diversity and abundance of species on those reefs is usually slightly greater. As for the artificial hard substrates further away from the coast, floating objects such as buoys are particularly rich in species, with communities often dominated by mussels mingling with a great variety of native and also non-native species such as the New-Zealand acorn barnacle (*Elminius modestus*; Figure 3.22). Alongside macroalgae, non-native species such as the Japanese oyster and the marine splash midge (*Telmatogeton japonicus*) also play an important role in intertidal zones and in the shallower parts of the wind farms and on the pillars of drilling platforms (Van Moorsel, 2014). These habitats do not appear to play an important role for policy-relevant species.

Figure 3.22 New-Zealand barnacle *(Elminius modestus)*. Photo: A. Gittenberger

3.3 Non-native hard substrate-related species in the North Sea

Non-native, hard substrate-related species do not occur in equally high densities on all hard substrates. Figure 3.23 gives an indication of the relative abundances of non-native species on hard substrates in the North Sea. The largest numbers of non-native hard substrate-related species (several dozen) are found along the coast in the intertidal zone and just below the low-water line on floating objects, in particular in marinas. The next largest numbers of coastal hard substrate-related species are found on shellfish reefs, with oyster reefs, probably owing to their irregular shape, being richer in such species than mussel beds. Finally, some non-native species are commonly found on revetments (Gittenberger et al., 2010), provided the construction material is irregular in shape, with holes and rough surfaces. In general, fewer non-native species are found further away from the coast than in areas just off the coast. The greatest diversity is to be found on floating objects (buoys etc.), followed by the intertidal zone, the area just below the low-water line in wind farms and on the pillars of drilling platforms. Deeper waters in the North Sea host only a few non-native species living on hard substrate, which mainly settle on artificial material such as wrecks. Non-native species are rarely found on natural hard substrates, such as the rocks on the Cleaver Bank (Van Moorsel, 2014).

The spread of non-native species within the North Sea is difficult to stop because most of them, and in particular those known for their invasive behaviour, can travel great distances during their larval pelagic stage. For instance, the Japanese oyster has spread along the entire European coast, reaching even the fjords of Norway and areas far removed from any human activity. Using stepping stones such as wind farms, oil platforms and navigation buoys, most non-native, hard substrate-related species can probably soon be found throughout the North Sea. Nor is there any lack of potential stepping stones for the few non-native, hard substrate-related species which favour deeper water. Apart from the wind farms, oil platforms and anchor structures of navigation buoys, those species also have countless wrecks and rocks (natural rocks and rocks deposited by humans for pipelines, for example) at their disposal to help them disperse.

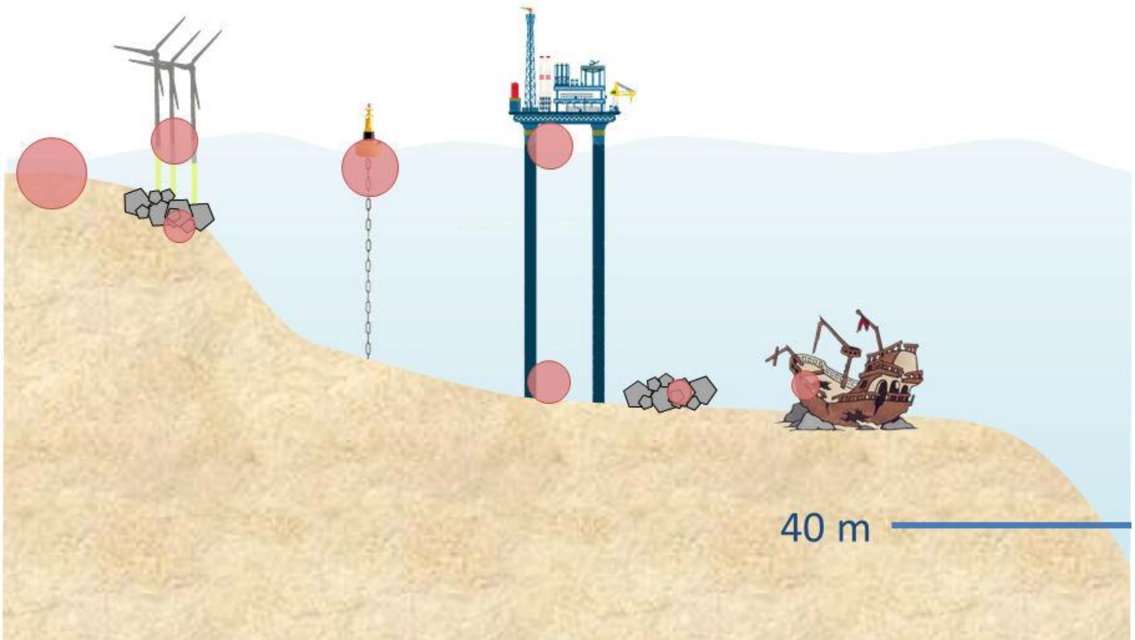

Figure 3.23 Non-native, hard-substrate-related species in the Dutch section of the North Sea. The red dots indicate the abundance of non-native species in shallow water and on the seabed within wind farms and near drilling platforms, monopiles, buoys, rocks and wrecks (pipelines and rocks placed on pipework and cables are not indicated in this figure).

3.4 Added value of reef structures

Worldwide, the loss of habitat complexity and in particular the simplification of structures in the living environment is a key cause of loss of biodiversity (St. Pierre and Kovalenko, 2014), but also of other ecosystem functions. Today, the integrity of the underwater landscape with all its geomorphological structures is seen as a key quality criterion for marine ecosystems (St. Pierre & Kovalenko, 2014; Thorin et al., 2014). It is clear that a varied underwater landscape with soft and hard substrates will be richer in benthos than a relatively uniform area with just soft sediment (Clare et al., 2015). However, the presence of a varied habitat also has a positive effect on mobile biota such as the diversity of fish populations (Kristensen et al., 2015). Certain fish species (such as the Atlantic cod) prefer to forage on hard-substrate biota (Reubens et al., 2013). Other species, including some ray species, use areas with alternating sand and rock or stone features as nurseries (Serra-Pereira et al., 2014), and still others benefit from the 3-dimensional structures for protection (Neudecker et al., 2006).

For many species under pressure in the North Sea, the extent to which enhanced availability of hard substrate may or may not have a positive impact on their conservation is not clear. Most shark and ray species are not doing well in the North Sea (although in the last few years the thornback ray has been on the increase (ICES, 2015)). It is practically certain that the main cause of their decline is last century's intensive fishing (Rogers and Ellis, 2000; Stevens et al., 2000; Lotze, 2007), but changes in (coastal) habitats as a result of human exploitation may also play a role (Simpfendorfer, 2000). For example, the former Zuiderzee in the Netherlands was a very important spawning ground for skate and rays (Heessen, 2010). Most of these species have a long life cycle, taking years to reach sexual maturity and producing relatively few young, making them particularly sensitive to over-fishing (Stevens et al., 2000). It is quite conceivable that hard substrate can benefit some species, on the one hand because food is to be found there and, on the other, because it offers a surface where eggs can attach themselves. We know that in a number of species such as the nursehound (*Scyliorhinus stellaris*) and the lesser-spotted dogfish (*S. canicula,* also known as the small-spotted catfish) the tendrils on the egg cases serve to attach the egg to the substrate (Mabragaña et al., 2011). In offshore areas, egg cases are commonly deposited on macro-algae sponges, hydroid polyps, bryozoans and soft corals (Ellis Leneman et al., 2004). We also know that in the past, Horns Rev (a reef structure in the Danish section of the North Sea) was an important area for skate fishing (Walker and Hisplop, 1998). Skate and rays mainly use estuarine coastal zones to deposit their eggs (Ellis et al., 2004). However, since relatively little is known about the habitat used by most North Sea sharks, skates and rays (Serra-Pereira et al., 2014), it is difficult to estimate the effect of a greater amount of hard substrate on the ability of sharks and rays to thrive. It is clear that protecting areas from fishing pressure will always be beneficial to those species.

Apart from the direct effects of habitat complexity and biodiversity of sessile and mobile fauna, reefs have other functions too. Complex, varied habitats appear to be more stable and also far more resistant to invasive species than impoverished, simplified habitats (Alexander et al., 2014). Other functions influenced by habitat complexity and biodiversity include productivity and resilience (an ecosystem's ability to deal with disturbance Frid & Caswell, 2015).

Particularly in marine ecosystems (which have usually been less extensively studied than terrestrial or freshwater areas), the effects of reduced habitat complexity have not yet been properly quantified. In marine areas the emphasis, therefore, tends to be on protecting habitats for rare species or species under pressure, whereas the other functions of habitat complexity remain neglected (Snelgrove et al., 2014). As stated in section 1.2, from a policy perspective it is important to find out which species and habitats whose natural range includes the Dutch section of the North Sea – mainly species and habitats belonging to policy-relevant categories – could potentially benefit directly or indirectly from reef structures. Annex A contains a list of species relevant to North Sea policy and habitats.

North Sea habitats are severely impoverished and simplified compared with the situation several centuries ago. The oysters of the oyster grounds have virtually disappeared, and over the decades fishermen have removed large rocks from the seabed which formed an obstacle to their nets. At the same time, a great deal of hard substrate has been added in the form of wrecks, platforms and other artificial structures. Different types of hard substrate provide different habitats. An oyster bed is not the same as a boulder or a shipwreck and a surface made of rock armour will not perform the same ecological function as an oyster bed. We should therefore proceed with caution when introducing artificial structures alien to the area.

The ecological values and diversity (both species richness and diversity in the underwater landscape) of the North Sea are under severe pressure. This is by no means a consequence of habitat loss alone, but can also be attributed to fishing and disturbance of the North Sea. It remains difficult at present to say exactly what type of impact specific structures would have on the species richness and the ecosystem of the Dutch section of the North Sea. A *Sabellaria* reef (both species) will perhaps not be as rich as an oyster reef, largely due to the fact that *Sabellaria* favours sites where there is much suspended sediment (Dubois et al., 2006). Not many species feel comfortable in such an environment. However, the habitat created by *Sabellaria* reefs is richer than a habitat without reef structures in physically similar circumstances (Dubois et al., 2006). The Dutch Continental Shelf with its *Sabellaria* reefs and oyster reefs will as a whole be richer in species than it would be with oyster reefs only, even if oyster reefs are home to more species than *Sabellaria* reefs. Even though no reports exist of *Sabellaria*-reefs in the Dutch part of the North Sea, such reefs do occur in other parts of the North Sea. For the North Sea in its entirety, it is difficult to estimate the precise added value of *Sabellaria* reefs on the Dutch Continental Shelf.

4 Promising technology to encourage reef-building and substrate-using species

This chapter begins with an overview of the various options available to improve the chances of natural reefs being created. They range from low-effort activities, such as selecting the right sites and possibly creating boundary conditions (section 4.1.1), after which the settlement of the targeted species can be left to nature, to high-effort activities such as cultivating the targeted reef structures *ex situ* (in a laboratory or another artificial environment) and then releasing them at selected sites (section 4.1.2). Needless to say, the two approaches differ significantly in terms of cost. From the perspective of restoring the natural environment as well as from a financial perspective, low-effort options (i.e. leaving the bulk of the work to nature) are usually preferred over cultivating and releasing organisms.

The same approach is taken when it comes to building an artificial reef, although this always requires a more substantial investment. A low-effort approach starts with nature-inclusive building - i.e. ensuring that the hard substrate which is being introduced anyway is designed to ensure optimum development of the natural environment. Artificial reefs may also be introduced with the principal objective of developing the natural environment. As stated in section 1.3, when introducing artificial reefs it is very important to carefully consider the objective that this is intended to achieve, as the introduction of alien substrate does not automatically qualify as 'restoration of the natural environment', even if it increases biomass and species richness at the local level.

Finally, a separate chapter examines which of the target species we might be able to cultivate *ex situ* and then release into the environment.

4.1 Technology which can be used to allow a natural reef to develop

4.1.1 Substrate selection for natural reef-builders / to promote settlement

4.1.1.1 Sabellaria

The two *Sabellaria* species (*S. spinulosa* and *S. alveolata*) are dealt with jointly in this chapter because the conditions for their settlement and the knowledge concerning their cultivation and settlement are very similar. To create *Sabellaria* reefs it is essential to select a site with an adequate supply of suspended material. Field observations and laboratory tests have indicated that this species will thrive only when there is an adequate (> 20 g m^{-3}) supply of suspended material in the water (Davies et al., 2009). There are not many surface waters along the Dutch coast where this is the case (Pietrzak et al., 2011), but there are areas there where high concentrations of suspended materials are transported over the seabed (Van der Hout et al., 2015).

Substrate is not a particularly critical factor as far as *Sabellaria* is concerned. Some hard substrate is required for its initial settlement, but thereafter it can establish on the reef structure and spread across soft substrate (Maddock, 2008b). *Sabellaria spinulosa* was also found on the artificial reefs introduced into the North Sea in 1993 (Leewis et al., 1997). The presence of adult populations makes settlement a much easier and faster process (Foster-Smith & Hendrick, 2003). The presence of tubes of adult *Sabellaria* has a more significant impact on the likelihood of settlement than purely physical factors. This means that in order to encourage settlement it is advisable to take steps to ensure that sections of a *Sabellaria* reef are present in a suitable zone as an incentive for the species to establish itself there. These adult structures may originate in wild populations (e.g. from UK reefs or any *Sabellaria* present around platforms in the North Sea) or from cultivated structures (see section 4.1.2.1). UK studies concerning drilling platforms in the southern part of the North Sea have shown that *Sabellaria* reef structures are regularly found around pipelines and other oil and gas infrastructure structures (Spence, 2015).

4.1.1.2 Sand mason worm (Lanice conchilega)

Very little is known of the factors which contribute to the successful establishment of reef structures or dense aggregations for this species. However, *Lanice* is known to prefer to settle near adult conspecifics (Callaway, 2003). During a trial conducted in the intertidal zone in the German part of the Wadden Sea, a large population of *Lanice* was found to settle once lugworms had been removed. Substantial bioturbation appears to limit their settlement. Firstly, the large-scale removal of worms and shellfish which work the sediment in the open North Sea is undesirable and, secondly, it would not be feasible either. This means we do not know at present which drivers should be taken into account and it is not really possible to design activities or measures to create such structures either.

4.1.1.3 Flat oyster (Ostrea edulis)

A feasibility study and a preliminary study concerning the recovery of flat oyster stocks (and other species) identified a number of promising sites for oyster reefs (Smaal, 2015; Kamermans et al., 2015). The key condition for the restoration of the flat oyster is the absence of seabed-disturbing fishing. Areas where this factor is limited include 1) wind farms, 2) safety zones surrounding oil and gas installations, 3) robust artificial structures such as dismantled oil and gas infrastructure (provided they are well marked so that they can be avoided by fishing vessels) and 4) protected areas and no-take-zones as defined in the Marine Strategy Framework Directive (MSFD). Since at the present time dismantled installations still have to be removed in their entirety and there are no protected zones in the North Sea where all forms of seabed fishing are excluded, the first two options are among the best opportunities available in the short term (Smaal et al., 2015). In the case of oyster reefs, too, settlement will more readily take place on structures where adult oysters are already present.

4.1.1.4 Northern horse mussel (Modiolus modiolus)

The Northern horse mussel favours gravel and sediment containing coarse sand. Although this species is occasionally found in shallower waters, true reef structures are usually situated at depths exceeding 30 metres. The species is regularly found within the Dutch Continental Shelf, but there are no known reef structures, nor are there many areas within the Dutch Continental Shelf that appear to qualify as promising habitats for the creation of reef structures of this species. Figure 4.1 shows the search area that offers the best opportunities for the creation of Northern horse mussel reefs. This area is located on the Cleaver Bank.

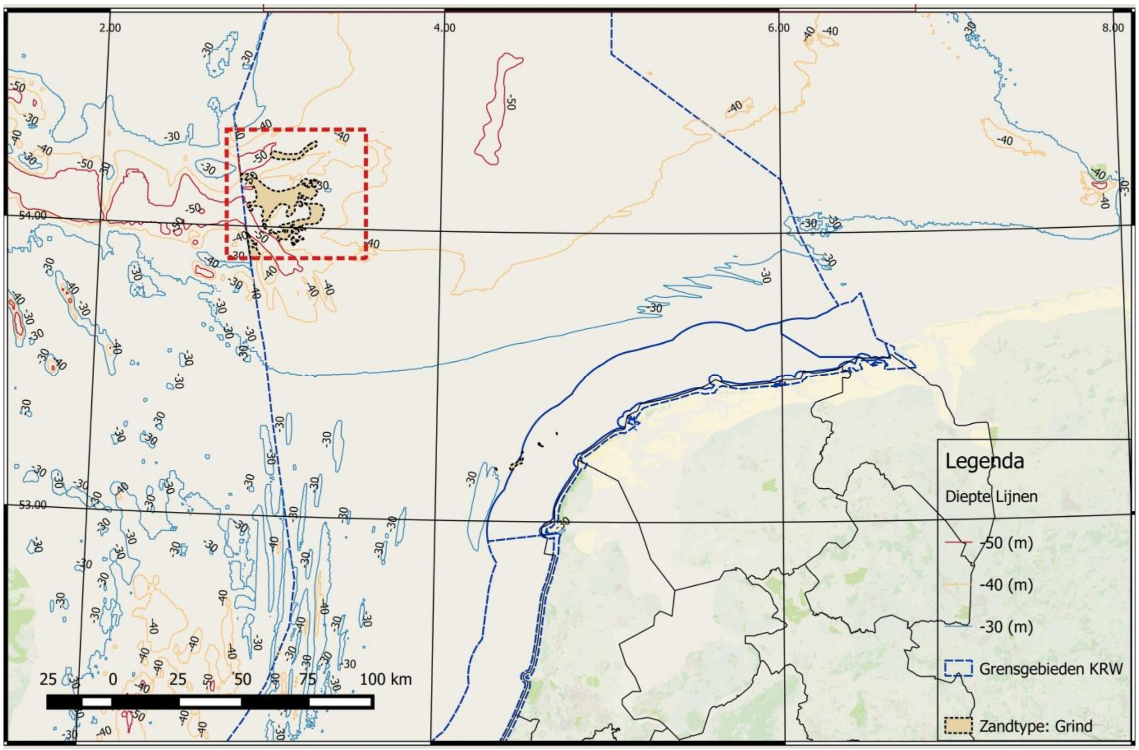

Figure 4.1 Potentially suitable habitat for Modiolus beds on the Dutch Continental Shelf (within the dotted section, gravel and coarse sandy floors at a depth of >30m)

As Figure B.10 (in Annex B) shows, part of the Cleaver Bank is among the most intensively fished parts of the North Sea (the Botney Cut in particular). The Cleaver Bank is due to be classified as a Natura 2000 zone (see section 2.6), but in parts of the area fishing will continue to be permitted. For as long as this remains the case, the possibilities for the creation of *Modiolus* reefs within the Dutch Continental Shelf appear limited. Further protection of the Cleaver Bank could well provide opportunities. It should be noted that knowledge about the circumstances required for *Modiolus* reefs to form is limited, and that not all information related to this species was consulted within the scope of this study. It is possible, therefore, that the options available to stimulate reef formation by Northern horse mussels have been underestimated.

4.1.2 Cultivation techniques or procedures, and transplantation

4.1.2.1 Honeycomb worm (Sabellaria species)

There are a few reports in the literature of *Sabellaria* species having been cultivated and of attempts to release it. The species may occur as single individuals and also as a reef structure. However, reef structures are formed only in environments with very large quantities of suspended sediment (Maddock, 2008b; Callaway et al., 2010). This means that cultivation requires a facility where the water motion is considerable and a large quantity of sediment is kept suspended. One example of this is the Vortex Resuspension Tank (VoRT), which uses the airlift principle (Davies et al., 2009).

In 2013, Bangor University (Wales, UK) conducted experiments involving the cultivation of honeycomb worms (*Sabellaria alveolata*) in laboratory conditions, with the intention of releasing them into the field. The researchers succeeded in getting honeycomb worms to settle on shale, but one week after those structures had been introduced into the field, all worms had disappeared (http://ukbars.defra.gov.uk/action/show/5926). Several factors may have played a key part in the failure of the field introduction:

1) the time of year might not have been ideal. The worms had not been released during the natural larval settlement period;
2) the tube structures cultivated in the laboratory may have been less robust and inadequate for natural field conditions.

No publications concerning this experiment have (yet) been published. If the cultivation of *Sabellaria* species is under consideration, we recommend that contact be made with Dr Andrew Davies of Bangor University so that experiences can be exchanged.

4.1.2.2 Flat oyster (Ostrea edulis)

Flat oysters can be cultivated (Laing et al., 2006). However, cultivating oysters for restoration purposes is probably unfeasible owing to the large quantities required. Nor is it necessary, because older populations are already available (Smaal, 2015). A pilot project is currently being conducted at two sites in the Voordelta in order to generate knowledge of techniques which can be used to reintroduce the flat oyster, including the use artificial hard substrate such as ‘reef balls’. As is the case with most shellfish, oyster larvae prefer to settle on substrate where adult oysters are already present. Further research is required into the extent to which flat oysters can be made to colonise pieces of hard substrate and then be transplanted to the sea to serve as initial anchor points for subsequent settlement of oysters.

4.1.2.3 Northern horse mussel (Modiolus modiolus)

Northern horse mussels also find it very difficult to settle in sites other than beds of adult specimens; settlement on live adults is significantly more successful than on empty shells (Roberts et al., 2011). Roberts et al. conclude that the use of artificial hard substrate alone is probably not a viable restoration approach. They also conclude that given the high costs and great uncertainties involved, setting up hatcheries for Northern horse mussels in order to prepare hard substrate in a laboratory, as is customary in oyster cultivation, is not a viable option at this stage. The question is whether this is necessary at all in view of the restoration approach for the Northern horse mussel in, for instance, Strangford Lough (Roberts et al., 2011).

4.2 Making and introducing artificial hard substrate

4.2.1 Nature-inclusive construction

The Dutch national government has outlined various visions of the future and formulated policy proposals for ‘building with North Sea nature’ and/or the use of artificial hard substrate in that context (see section 1.2). It is important to bear in mind that most hydraulic engineering projects are awarded on a lowest-price basis. To be competitive, reinforcements of revetments and rock armour for pipelines proposed by potential builders must always be of as minimal a design as possible. Introducing variations in shapes in order to create added value for the natural environment or other functions is possible in practice only if the design provides for more than is strictly necessary in view of its primary function in some areas. Viewed in this light, adding an artificial reef to an existing design will nearly always involve additional costs.

To keep additional costs as low as possible, reef designers should take account of the equipment already available for the project and use standard execution technology where possible. If the desired added value is known at a very early stage in the design process, it could possibly be taken into account in the selection of building materials and equipment required. The earlier nature-inclusive alternatives are incorporated in the design process, the more execution can be optimised.

An essential element of nature-inclusive building is a convincing argument showing that the proposed alternative does what it promises to do. Creating a conceptual landscape sketch of a building-with-nature project is an excellent way of producing an appealing and acceptable plan with a highly diverse range of stakeholders. However, it is quite another thing then actually to create a design based on (a part of) the plan which can reasonably be expected to develop as predicted. In particular, there is no supporting database as yet for the targeted creation of specific flora and fauna on and around an artificial reef. Although there are general design rules, much more research is required for the targeted incorporation of ecological (added) values into a design.

De Vriend et al. (2015) describe a method by which conceptual building-with-nature designs can be created. De Vries et al. (2016) supplement that method with a step-by-step plan to create an engineering design with pre-defined objectives for parts of the conceptual design. 'Ecosystem services' are a central design concept in nature-inclusive building. The challenge is to set clear objectives in advance for ecosystem services to be determined later, and to specify the technique for measuring whether or not those objectives have been achieved. To be able to create an effective design or to devise a sound interim intervention, we need to develop and gather more knowledge which can be used to estimate the potential consequences.

More knowledge is also required for the building of reefs in the North Sea in the effort to support native North Sea species in particular (see section 1.2). We can assume that flora and fauna will naturally colonise introduced substrate, but it is not easy to predict which species will do so and on what time scale. It could also be assumed that bare substrate introduced close to a biotic community of healthy species will be colonised faster. But if that is the case, how close is close enough? It could be assumed that the cultivated pieces of substrate on or near rock armour will ensure faster colonisation. But what are the conditions required for that to work and exactly how effective is it?

The challenge for nature-inclusive building is to remain open to new possibilities and to seek to answer the questions that arise within the context of ongoing projects.

4.2.2 Techniques used to construct artificial reefs

Human interventions have affected the ecology of the North Sea in a variety of ways. Interventions can be ‘hard’ or ‘soft’ in nature.

Examples of measures which involve hard substrate intentionally being introduced in the North Sea include the installation or introduction of:

- platforms for oil and gas extraction;
- monopiles in offshore wind projects;
- rock armour to protect the seabed around wind turbines;
- rock armour covering cables and pipelines;
- anchored floating buoys to mark shipping channels and shallows and to perform measurements;
- fixed pilings for performing measurements;
- etc.

There is of course also a large amount of hard substrate that has been unintentionally introduced in the North Sea in the form of shipwrecks, many of have been there for years.

Soft measures largely involve the introduction or extraction of sediment for coastal protection purposes and for use as building material. E.g. the method used to remove sediment, can affect the way in which the natural environment subsequently recovers (Borsje et al., 2009; De Jong et al., 2015, 2016). Leaving behind a textured sand extraction pit instead of a smooth bed, an experiment conducted in one of the Maasvlakte 2 extraction pits, appears to produce a richer seabed community and to attract more fish. Measurements showed that two years after the dredging activities had ended, the textured surface created had resulted in significant differences in sediment composition and that the biomass of bottom-dwellers was approximately five times greater in the deepest parts (De Jong et al., 2015). However, this project also revealed a risk of oxygen depletion in the longer term in the deeper parts of the sand extraction pits, mainly as a result of the increased densities of fauna and higher concentrations of silt rich in organic material (De Jong et al., 2016).

Various studies have shown that hard substrate provides an attractive habitat for flora and fauna to settle (Van Koningsveld et al., 2010; Paalvast et al., 2012; De Vriend et al., 2015). Not surprisingly, shipwrecks are a favourite destination for divers and fishermen alike. In addition to the availability of substrate, a limited amount of disruption is key to the development of biotic communities (Lindeboom et al., 2011). Shipwrecks appear to be the most diverse of all artificial substrate (Jager, 2013). However, they are, of course, not a natural phenomenon in the North Sea and introducing hard substrate (even if it is rich in species) does not automatically qualify as restoration of the natural environment.

The design of a hard substrate measure can have an impact on the way in which nature responds. Techniques used to create artificial reefs usually focus on increasing biodiversity and ecological productivity by varying the type of substrate, its shape and the quantity and type of shelter it offers (Van Koningsveld et al., 2010).

Techniques used to introduce substrate in a particular shape vary sharply, depending on water depth and the size of the target reef. Where the water is not too deep, a few large sections of substrate can be introduced quite precisely and in a controlled manner at a reasonable cost, with the aid of a crane for example. This is of particular interest for solutions where substrate of a specific type or shape is delivered (large rocks, specific shapes, etc.). As the depth and the surface area to be covered increase, it will no longer be economically feasible to place objects individually in specific sites, and execution will switch to targeted dumping instead, with the aid of a crane vessel and a gabion for example. As the depth and surface increase further still, a side-dumping vessel or dynamically positioned fall-pipe vessel will be required to keep costs at an acceptable level.

Substrate of highly specific design (such as reef balls, 3-D printed structures etc.) can be used for a reef of limited size (in the region of 1 to 10 metres long). As long as mass production remains possible, specially designed substrate can also be used for larger reefs (in the region of 10 to 100 metres long). As dimensions increase, however, using dumped rock of a pre-determined grade will soon become a more affordable method. For even larger reefs (> 100 metres long), dumping is the only economically feasible method. Choosing the right grade of rock is important when using methods involving the dumping of rock, as it will ensure that the size of the spaces between the rocks (places of shelter) and gradients are as required. On a larger scale, variation can be increased by 'playing' with shapes. Needless to say, combinations of measures are also possible. For example, on the largest diving reef in the Netherlands, constructed on top of the foreshore reinforcement structure next to the Zeeland

Bridge in the Oosterschelde, in addition to large shapes made of dumped rubble a collection of large rocks was deposited which act as underwater landmarks that recreational divers can use to find their bearings.

4.3 Techniques used to promote the colonisation of artificial hard substrate

Colonisation of (recently introduced) artificial hard substrate by dead man's fingers (a leather coral species (*Alcyonium digitatum*), Figure 3.15) or by the jewel anemone (*Corynactis viridis* of the Corallimorphidae family, Figure 3.18) is a promising approach because these perennial species provide the substrate with good protection against the growth of other (non-native) benthic species. This section deals with the natural colonisation of substrate by these two species, and discusses techniques which can be used to accelerate colonisation by means of *ex situ* colonisation and aquaculture.

4.3.1 Dead man's fingers (*Alcyonium digitatum*)

4.3.1.1 Natural colonisation of laid hard substrate

Establishing whether dead man's fingers is a suitable candidate for colonisation of new hard substrate in the North Sea requires knowledge of the biology of the species, in particular with regard to its dispersal strategy and, in this connection, its reproductive cycle. There is relatively little recent scientific literature concerning dead man's fingers. A great deal of information has been provided by Budd (2008) in a review publicly available at www.marlin.ac.uk. It and many other descriptions of the species on the Internet and in popular-science books are largely based on the earlier work of Hartnoll (1975), which describes the life cycle of dead man's fingers in detail. The species disperses mainly through sexual reproduction: egg and sperm bundles are released during mass spawning in December and January. Fertilisation takes place in the water, producing free-swimming larvae that look for somewhere to settle on the substrate. Since the planktonic larvae can survive for up to 30 days or more, the species can spread over considerable distances within a single life cycle. The settled juveniles have a competitive advantage over many other juvenile benthic filter-feeders because they are able to forage on plankton early in the season and therefore derive maximum benefit from the spring plankton bloom in the North Sea. Settled dead man's fingers juveniles reach sexual maturity within two to three years.

Budd (2008) characterises dead man's fingers as sensitive to detachment of the substrate. Hartnoll (1975) too describes the reluctance of adult dead man's fingers to attach themselves to substrates in his experimental system, which suggests that the species hardly ever multiplies through asexual reproduction (fission).

Dead man's fingers will settle in particular in places where there is little light, down to a depth of approximately 50 metres. Closer to the surface, the species favours the underside of hard substrates; it is also found on slopes at depths of between 10 and 20 metres and, below 20 metres, on horizontal surfaces too. Preferred substrates include rocks, stones and shells, but the species is also commonly found on wrecks. This information is highly relevant to natural colonisation: substrate type and location will determine to a large extent the optimum conditions for colonisation by dead man's fingers. Another factor that is relevant to successful colonisation by dead man's fingers is the presence or absence of the European nudibranch (*Tritonia plebeia*), which is known to feed exclusively on this leather coral species and can therefore limit the chance of success (Swennen, 1961).

4.3.1.2 *Ex situ colonisation and transplantation*

Very many species which live on hard substrate prefer to settle on substrate where conspecifics are already established. Ex situ colonisation is one option for accelerating the colonisation of new substrate. A great deal of knowledge of this concept has already been acquired in its application to tropical stony corals (Amar & Rinkevich, 2007; Edwards, 2010; Guest et al., 2014) and to commercial shellfish such as mussels and oysters. An essential element is the collection of natural reproductive material in the field. Mass spawning, the simultaneous release of sperm and egg packages by an entire population, makes this a lot easier. The Dutch company Van Oord BV recently applied this concept to tropical, reef-building stony corals: during a mass spawning event, divers collected thousands of sperm and egg bundles which were subsequently taken to the laboratory for fertilisation. This way, millions of larvae were produced, followed by thousands of juvenile corals (M. van Koningsveld and R. Osinga; unpublished data). Since dead man's fingers also reproduce by mass spawning and external fertilisation, this species would appear to be a suitable candidate for the ex situ colonisation concept. If the attempt to produce viable dead man's fingers' larvae in the laboratory succeeds, suitable sections of hard substrate can then be incubated with larvae in culture tanks where conditions can be optimised for the juveniles to fix themselves to the substrate and for their early development (see subsection on cultivation). The substrates containing juvenile dead man's fingers can then be placed at suitable sites (see information in the previous subsection on favoured settlement locations) in early spring to enable the juveniles to derive optimum benefit from the spring bloom, as they would have done had they colonised naturally. The added value of this approach (if the process runs smoothly) is that the degree of cover provided by the dead man's fingers will be much greater than in the case of natural colonisation. The question, however, is to what extent facilitating the establishment of one specific species might adversely affect the overall diversity on the substrate.

4.3.1.3 *Cultivation*

Knowledge about keeping and cultivating dead man's fingers in aquaria or in mariculture is limited, although the species has been kept successfully in various North Sea aquaria for decades. Cultivation and management protocols will have to be developed on the basis of general biological knowledge of the species and knowledge acquired in relation to other leather coral species. The cultivation of leather corals is particularly successful when it involves species which live symbiotically with phototrophic organisms (which use photosynthesis for nutrition). Such organisms grow relatively fast (up to 1% to 2% a day if enough light is available (Khalesi et al., 2009; Rocha et al. 2013)). Wholly heterotrophic species (species that are not dependent on symbiosis with phototrophic micro-organisms) are much harder to cultivate because it has proved difficult to develop and apply an adequate nutritional regimen for them. In general, intensive feeding with live zooplankton produces the greatest success, but this is relatively expensive and labour-intensive. One advantage of heterotrophic cultivation is that the absence of light means there will be few problems in the system as a result of the growth of algae (fouling).

Like most other leather corals, dead man's fingers feed mainly on zooplankton. In an experimental study it was found that dead man's fingers consume both zooplankton (nauplius larvae of the brine shrimp (*Artemia*)) and phytoplankton (the diatom *Skeletonema costatum*), but feed more efficiently on zooplankton (an intake of 0.79 mg C per gram of coral per hour) than on phytoplankton (0.16 mg C per gram of coral per hour). (Migné and Davoult, 2002) conducted an experimental study into the food intake of dead man’s fingers which could serve as a basis for developing an experimental nutritional regimen for aquaculture. It is also important to ensure an adequate current regime. Dead man's fingers prefer areas with relatively fast current speeds (0.5 m to 3 m s^{-1}; Budd 2008), where they have a constant supply of food particles. Both too slow and too high a current speed can reduce corals' chances of catching plankton particles (Wijgerde et al., 2012), so a way of achieving an optimum current speed will have to be found.

Dead man's fingers is not a light-loving species. Mainly with a view to preventing the growth of algae, it is therefore important to limit the quantity of light as far as possible in ex situ systems (both when larvae are adhering to the substrate and when attached juveniles hatch).

Hartnoll (1975) described a period of inactivity and cessation of growth for dead man's fingers. The polyps become less active in the months before spawning (August-December) and food intake is much lower in that period, when dead man's fingers is also much more susceptible to overgrowth by other organisms. Although the assumption is that this cessation of activity has to do with the simultaneous maturing of the reproductive organs (which block the alimentary canal), a similar cessation has also been observed in sexually immature dead man's fingers. Cessation of activity could therefore be a genetic feature and, as such, it is a factor to be borne in mind when cultivating this species.

4.3.2 Jewel anemone (Corynactis viridis)

4.3.2.1 Natural colonisation

As with other species, an understanding of the biology of the jewel anemone is required in order to be able to assess its suitability as a coloniser of new hard substrates. We know even less about this species than about dead man's fingers: a search in Scopus for '*Corynactis viridis*' produces just five hits. An overview of the available biological information can be found at www.marlin.ac.uk (Ager, 2007). There is no information concerning the sexual reproduction of the jewel anemone. A study into the life cycle of a related species from a similar environment (*C. californica* from North America) shows that this species has a similar strategy to that of the dead man's fingers: mass spawning in December/January and development of juveniles early in the season (Holts & Beauchamp, 1993). It seems likely, therefore, that the jewel anemone has the same sexual reproduction strategy as dead man's fingers, but this will require further research.

Unlike dead man's fingers, the jewel anemone is known for its rapid asexual reproduction through fission (cell division without fertilisation), which enables it to colonise new surfaces relatively quickly. The species is characterised as being fiercely competitive when it comes to taking over space, a feature that speaks of its suitability as a coloniser of new substrates (Maughan & Barnes, 2000). The ability to use the fission method also makes the species an interesting candidate for ex situ colonisation techniques through aquaculture.

The jewel anemone favours the same type of substrate and positioning as dead man's fingers, and is found in water as deep as 80 metres (Ager, 2007).

4.3.2.2 Ex situ colonisation and aquaculture

Since there are no data on the reproduction cycle of the jewel anemone, there is no point in speculating about the scope for ex situ colonisation of substrates through sexual reproduction at present. In principle, the jewel anemone's ability to reproduce asexually by fission means it should be possible to propagate this species through fragmentation, a method frequently used with tropical stony corals and leather corals. Fragmentation of jewel anemones could possibly be used as a technique to cover substrates with jewel anemones in ex situ (or in situ, field) culture systems. However, at present no information whatsoever concerning jewel anemone cultivation is available. Since many heterotrophic Cnidaria can be fed on commercially available zooplankton such as brine shrimp (*Artemia*), it seems likely that this nutritional regimen could also be used for the jewel anemone. It would be fairly simple, therefore, to design a study to test this species' culturability. However, it should be added that asexual reproduction leads to genetic impoverishment of the population. Where sub-cultivation takes place using too small a number of genetically different individuals, there may be consequences as regards the fitness of the species.

4.3.3 Conclusion - feasibility and follow-up studies

Despite the fact that they commonly occur in European waters, there is fairly limited reference in the literature to either of the targeted species, the dead man's fingers and, in particular, the jewel anemone. Based on the knowledge that is available, both species appear to offer realistic opportunities for active substrate colonisation. Similar to earlier studies involving tropical stony corals, a pilot study could be carried out aimed at actively colonising substrate with dead man’s fingers. This would involve collecting gametes in the field, followed by fertilisation, development of larvae and attachment of the larvae to hard substrate in the laboratory (ex situ). Substrates with juveniles attached to them could then be placed in the sea or sub-cultivated under controlled conditions in tanks on land. Such a pilot cold provide the data for a protocol and cost estimate for the active colonisation of substrate using dead man's fingers.

The jewel anemone also appears to be a suitable candidate for active colonisation, but several essential knowledge gaps will first need to be filled for this species before a pilot experiment can be designed. A key first step is to obtain sound information about the reproductive cycle and culturability of this species.

5 Scope for encouraging reef-building or promoting substrate-using species

5.1 Summary of key aspects concerning choice of site

Limited seabed mobility and absence of seabed disturbance are important factors to be taken into account when selecting sites for projects involving artificial or natural reef structures. At present, it is difficult to find areas that are or will remain free of seabed disturbance, other than wind farms, unfished (parts of) Natura 2000 and MSFD sites (existing sites and areas scheduled to be designated as such) and oil and gas infrastructure protection zones. For example, shrimp fishing is still permitted in many areas where fishing is restricted. There are certain zones where any form of shared use is prohibited and where disturbance of the seabed as a result of fishing, dredging activities or sand extraction is permanently ruled out. These are mainly areas which have been designated as wind farms. Projects within zones which are protected from seabed disturbance will, of course, always have to be conducted in close cooperation with the operators of those zones.

Sand waves occur at all wind farms, but vary from farm to farm and also within farms. This is an important factor to bear in mind when looking for sites within wind farms. It is almost certain that frequent sand waves will limit the probability of the successful establishment of natural or artificial reefs. However, basic knowledge of the extent to which seabed mobility restricts the establishment of specific species or the lifespan of specific structures remains limited. The artificial reef installed on the Dutch Continental Shelf in 1992 is also in an area with some seabed mobility, but nevertheless became overgrown fairly quickly and as far as is known is not buried beneath sand waves.

The present wind farms and concession areas are all situated relatively close to the coast (Figure B.1). This sets limits as regards the range of available habitat types, as those areas are all in relatively shallow water and largely within the sphere of influence of the net south-north current. Species and communities which favour deeper water will therefore have little chance of success within those areas. Artificial hard substrate will necessarily be present on wind farms and other surrounding infrastructure, but the safety zones also contain soft substrate which enjoys a high degree of protection.

5.2 Criteria

A number of factors determine the choice of the species and communities on which this project should focus. First, we have the policy frameworks (N2000 and MSFD) which define the desirable and undesirable characteristics (see also section 1.2), including elements such as fostering biodiversity and avoiding invasive species.

The function performed by a species is another important category of criteria. For projects aimed at improving ecological assets it is logical first to examine the opportunities to restore natural hard substrates which naturally belong in the North Sea, such as flat oyster beds. Consideration should also be given to developing habitats using native species which are not necessarily known as species which have ever formed reefs in the Dutch section of the North Sea before, but which do have the potential to create biogenic reefs with the associated biodiversity. One example is the Northern horse mussel (*Modiolus modiolus*).

Projects aimed at the creation of biogenic reefs will also require knowledge of, or in any event substantiated hypotheses concerning, effective methods to encourage reef-building among such species. The sand mason worm *(Lanice conchilega*) can be ruled out for the time being because this species cannot be managed with the knowledge currently available. Naturally, where dense aggregations of these worms are found, a decision can be made to preserve the structures using measures such as seabed protection. However, creating sand mason worm reefs does not appear to be a particularly promising option.

A second approach would be to create ecological value by using artificial hard substrates such as infrastructure which has been placed in the North Sea for other reasons, or substrates which have been installed specifically for certain species. This will involve not only the sessile species on the reefs themselves. Fish stocks in the North Sea are under great pressure from fishing (fishing which targets specific species, or by-catches) and as result of habitat changes. As stated in section 1.3, installing artificial structures simply to create ecological assets is controversial.

The general rule is that a more diverse and more complex environment will contribute to a more diverse and more complex species community.

The availability of a suitable habitat is an effective argument for reef-building species and also for species on artificial hard substrate. In any case, if the habitat is *un*suitable, there is no point in trying to encourage species to settle there. However, it is perfectly possible that certain species will not occur at a particular site because human activities are making the habitat unsuitable. The present distribution of species and what is known about their historical range can serve as a useful point of reference here.

Within the current framework, new structures should not increase the chance of the establishment and spread of invasive species (see section 1.2). In general, the chance of settlement by invasive exotics is greater in the intertidal zone and on structures in the upper few metres of the water column. At greater depths, where light does not penetrate, the number of invasive species is markedly smaller. Experts are gathering knowledge in this regard within the Netherlands and beyond (Annex C). One factor which must be taken into account is that the transportation of living organisms between ecosystems has been an important vector for invasive species (Thomsen, 2016). For example, the transportation of large quantities of mussels or oysters from other parts of Europe to the Netherlands almost certainly played a role here (Eno, 1998). Transportation of living animals was limited to shallow sections; it occurred much less extensively in the deeper parts of the North Sea. This goes some way to explaining why there are far fewer exotic species in deep parts than in shallow water. Although we cannot quantify this, it is possible that transplanting natural or artificial reef structures from elsewhere involves an additional risk of exotic species spreading. At the same time, research is being conducted elsewhere into the scope for inoculating new hard substrate with (cultivated) species in order to accelerate colonisation and thus ensure that invasive species are prevented from settling. Initial results were presented at the Marine Bio-Invasions Conference in Sydney, in January 2016 (http://www.marinebioinvasions.info/files/abstracts_main.pdf). The opportunities and risks associated with this approach are not yet clear.

5.2.1 Overview of criteria for projects

1. Focus on species and structures native to the North Sea.
2. As far as possible, let nature do the work. Nature in the North Sea has been impoverished by various human activities in the system. Target activities primarily at reducing disruptive activities and only tackle active restoration in a second stage.
3. Minimise the need for non-native material.

4. Reduce the likelihood of exotic species being introduced:
    a. providing hard substrate in deeper water carries fewer risks than in shallow water;
    b. avoid any unnecessary transport of living organisms between different parts of the ecosystem.
5. Ensure clear objectives and evaluation:
    a. formulate measurable objectives for each project in advance;
    b. evaluate potential environmental risks or negative effects in advance;
    c. set up a sound monitoring programme so that the objectives and negative effects, if any, can be evaluated;
    d. when doing so, bear in mind that it may take years before a state of equilibrium is reached and that considerable time may pass before negative effects occur;
    e. ensure that failure to achieve the objectives or the occurrence of negative effects will have clear consequences.

5.3 Reef-building species

5.3.1 Species

In principle, three species can be considered for projects aimed at the creation of natural reefs, ranked according to the likelihood of success:

1) Flat oyster (*Ostrea edulis*). This species was characteristic of the North Sea until around a century ago. As flat oyster reefs are associated with increased biodiversity, the species is given high priority in various policy frameworks. There are well-substantiated hypotheses regarding successful restoration strategies for this species, too (Smaal et al., 2015). A pilot project with flat oysters is being run at two promising sites in the Voordelta (selected on the basis of Kamermans et al., 2015). The knowledge accumulated in the process is relevant to the development of oyster reefs in the North Sea. The Voordelta project will not provide any information related to site-specific questions (such as the specific habitat factors at sites in the North Sea); targeted research will be required for this.
2) *Sabellaria spinulosa*. This species is fairly widespread in the southern part of the North Sea and there have been some sightings of reef formation on the Dutch Continental Shelf. It is classified as a typical species for habitat type H1170 (‘open-sea reefs’) under the Habitats Directive/Natura 2000 (Annex A-2). *Sabellaria* reefs are widely seen as important eco-engineers which add topographical complexity and biodiversity to the North Sea environment (Dubois et al., 2006; Pearce et al., 2012; Braeckman et al., 2014). Control factors have been identified which could facilitate reef formation by this species, and the reef structures have been identified as fostering biodiversity. Few invasive species associated with this reef-builder have been identified.
3) The Northern horse mussel (*Modiolus modiolus*). Reefs made by this species are known to be very diverse and attractive both to sessile biota and to various fish species. Individual specimens, but no large reef structures, have been observed in the Dutch section of the North Sea. It appears from an initial literature scan that the only habitat suitable for *Modiolus* reefs is situated in the Cleaver Bank area. Projects could perhaps be conducted there provided the sites are not fished. A closer study of the literature might provide greater insight into the factors which foster reef formation among this species and thus extend the search area for it.

5.3.2 Areas

Seabed disturbance (mainly caused by fishing, including shrimp fishing) is a huge impediment to the survival or settlement of all natural reef-building species. This is why projects in areas where disturbance of the seabed is restricted (see also section 2.6) are the most likely to succeed. Only a few marine reserves have so far been designated on the Dutch Continental Shelf where fishing, including shrimp fishing, is completed banned (see also section 2.6), but there are areas such as wind farms where shipping and all forms of seabed disturbance are prohibited.

At the moment, virtually all forms of shared use within wind farms is banned. The government would like to facilitate shared use of wind farms within safe limits (for example, for gill-netting or aquaculture, as well as navigation). In addition to relieving some of the pressure on the space available in the North Sea, shared use of offshore wind farms could increase public support for wind energy. However, wind farm operators have major reservations and have objected strongly to ships and other users being allowed to enter wind farm sites (Hoefakker et al., 2015). At the final symposium of the EU's MERMAID project (Innovative Multi-purpose offshore platforms: planning, design and operation"; http://www.mermaidproject.eu/), the attending operators expressed interest in the installation of artificial reefs and the accompanying protective measures (prohibiting seabed disturbance, which effectively restricts shared use). During the stakeholder consultation that was conducted within this project, reef structures that formed on the scour protection of turbines were identified as worthy of receiving protection (Rasenberg et al., 2014). It might provide a useful point of reference for encouraging the development of the natural environment in collaboration with wind farm operators, either through the adaptation or installation of additional artificial structures or the fostering of natural reef structures.

5.4 Artificial hard substrate

5.4.1 Areas

As far as encouraging species which are associated with hard substrate is concerned, we could consider areas where artificial hard substrate has already been installed or is due to be installed. As stated in chapter 4, rocky hard substrate is regularly introduced into the North Sea in the form of scour protection around monopiles in wind farms and to protect cables and pipelines. Linking any pilots to be conducted with ongoing projects would seem the obvious move to ensure maximum use is made of existing logistics when introducing and monitoring the hard substrate.

5.5 Overview of knowledge gaps and questions to be addressed

There are still many knowledge gaps pertaining to the settlement of natural reefs and the introduction of hard substrate. The most fundamental question is not purely scientific, yet must be based on science: what, in the context of North Sea nature, is 'good' or 'desirable'? What are the objectives and which arguments are used to define those objectives?

In addition to this question, there are several wide-ranging questions which cannot be answered with a targeted study alone. They include, for example, the question as to which design characteristics could provide the greatest ecological added value for artificial reefs. Ultimately, this is a quite fundamental question for policy and management but it can only be answered by examining various design variants in different environments. In order to be able to create a good design or to devise a sound interim intervention, we need to develop or gather more knowledge which can then be used to estimate the likely consequences.

Below is a list of identified knowledge gaps. Targeted and relatively limited research will suffice to deal with these topics. In many cases, it would definitely be advisable to conduct such research before deciding to introduce structures.

5.5.1 Natural reef structures

Flat oyster (*Ostrea edulis*)

Further research is required into the extent to which it is possible to have flat oysters colonise pieces of hard substrate and then transplant them to the sea to serve as an initial anchor point for oysters. This is something which should be tested on a small scale before launching large-scale oyster restoration projects at sea. Targeted research into specific habitat factors at sites in the North Sea is required for the flat oyster. Nor is it yet clear what impact diseases and parasites such as *Bonamia ostrea* and *Marteilia refringens* will have on the chances of large-scale restoration.

Sabellaria spinulosa reefs

A preliminary study into habitat suitability for *S. spinulosa* reef structures is essential. Such a study could also include identification of the sites (in the Netherlands, the UK or Germany) from which it might be possible to obtain donor material in order to accelerate establishment.

Northern horse mussel (*M. modiolus*)

There are opportunities for restoration, but just as is the case with the flat oyster, further research into the boundary conditions and methods required in order to achieve this is needed. A closer study of the literature might provide greater insight into the factors which foster reef formation in the case of this species and thus extend the search area for it.

Sand mason worm (*L. conchilega*)

Little is known about the ecological added value of reef-like structures, including the expected lifespan, of this species. In nature such structures seem to appear and disappear with some regularity. The fundamental question, therefore, is whether there is much point in efforts to foster the settlement or transplantation of this species, if such measures exist at all. Very little is known about the factors which contribute to the successful establishment of reef structures or dense aggregations for this species. These questions will have to be answered before any (transplantation or other) measures are considered.

5.5.2 Artificial hard substrate

The introductory paragraph already identified the most fundamental knowledge gaps. A key question concerns the benefit of cultivating and installing hard substrate biota, and the extent to which this may be a means of preventing the settlement of non-native species. Specific knowledge gaps regarding the cultivation of certain sub-species are listed below:

Dead man's fingers

There is virtually no knowledge available concerning the cultivation of dead man's fingers in aquaria or in a mariculture process. That said, limited information about the keeping of this species in aquaria is available. It could be useful to conduct tests to find out whether the species can be cultivated.

Jewel anemone

This appears to be a suitable candidate for active colonisation, but several essential knowledge gaps will first need to be filled before a pilot experiment can be designed. A key first step is to obtain sound information about the reproductive cycle and culturability of this species, as there is no information whatsoever in this regard. We do not even know exactly how to feed jewel anemones were they to be kept in an aquarium. Since many heterotrophic Cnidaria can be fed on commercially available zooplankton such as brine shrimp (*Artemia*), it seems likely that this nutritional regimen could also be used for the jewel anemone.

6 Proposal for conducting pilots

This study has revealed that although some knowledge is available regarding the use of reef-building organisms and encouraging organisms to settle on artificial hard substrates, most of that knowledge concerns coral reefs and species which are not considered potential target species in the North Sea. At present, there are no off-the-shelf projects which could be launched in the North Sea with any substantial degree of confidence. However, there are several options for pilots and smaller-scale tests through which, with limited means, knowledge concerning potential ways of improving North Sea nature could be acquired.

6.1 Overview of promising species or groups relative to selection criteria (table)

6.1.1 Reef-building species

The table below provides a brief overview of the scope for encouraging reef-builders, species by species, ranked by the amount of effort and the budget required. The colours indicate the potential success of the measure.

Sabellaria spinulosa and the flat oyster offer the best prospects. An initiative for a local pilot in the Voordelta has now been launched for the flat oyster. Larger-scale restoration projects further offshore in the North Sea have not yet begun. No efforts are being made at present in respect of either of the two *Sabellaria* species.

‘Seabed protection’ means that activities which disturb the seabed will be banned in the area concerned. This usually involves fishing and shrimp fishing, but may also concern other activities. Seabed protection is a precondition for virtually every project.

‘Seeding and transplantation’ mean

- either the introduction of (a limited quantity of) living reef structure to encourage the further settlement of reef-builders;
- or the introduction of hard substrate with recently settled individual specimens which will encourage further colonisation of the substrate.

‘Cultivation and introduction’ means cultivating reef structures in a laboratory setting or in a culture setting in the field (usually just off the coast for easy access) which are then introduced into the field in the target location.

Reef builders			
	intervention		
	extensive construction of hard substrate / seabed protection	**moderately intensive** Seeding / transplantation	**very intensive** Cultivation / introduction
Ross worm *Sabellaria spinulosa*	Seabed protection is essential. Best opportunities within wind farms or exclusion zones, if sites with sufficient suspended sediment can be found. Provide some hard substrate for initial settlement	Probably has an accelerating effect, provided that local conditions are favourable. Source populations in the Netherlands are poorly documented; anecdotalreports of reef structures in exclusion zones around gas platforms are available	Theoretically possible, but no successful attempts reported to date. Cultivation is not a feasible strategy for large-scale restoration. Small-scale tests may be useful to identify boundary conditions
Sand mason worm *Lanice conchilega*	Providing hard substrate is not known to promote settlement. Only useful approach is seabed protection	Transplantation not effective	No cultivation techniques known
Flat oyster *Ostrea edulis*	Sites within windfarms or within exclusion zones provide suitable substrate - research is ongoing	Current study into acceleration settlement via hard substrate in Voordelta; possibilities for seeding hard substrate with cultch under investigation	Oyster cultivation for restoration purposes only for pilots; probably not suitable for large-scale restoration
Northern horse mussel *Modiolus modiolus*	Sites below -30 m met gravel / stones and protected seabed. Only Cleaver bank appears suitable, but is currently heavily fished	Living shells encourage settlement, few source populations available in the Netherlands	No known cultivation of *Modiolus*

Sand mason worms (*Lanice conchilega*) appear to be very difficult to manage. 'Reef structures' involving this species are found on a regular basis, but it does not seem particularly worthwhile to use them for transplantations, especially in view of the fact that it is by no means certain whether such structures will stabilise in time and/or become capable of relocation. The Cleaver Bank is the most promising site for Northern horse mussel reef development. However, it is intensively fished at the moment and this makes the establishment of beds in this part of the North Sea unlikely. According to the OSPAR list of threatened and declining habitats, there is no favourable habitat for the Northern horse mussel on the Dutch Continental Shelf at all (http://www.ospar.org/work-areas/bdc/species-habitats/mapping-habitats-on-the-ospar-list-of-threatened-or-declining-species-and-habitats).

The flat oyster (*Ostrea edulis*) and the Ross worm species *Sabellaria spinulosa* offer the best chances of successful establishment for reef-building species.

6.1.1.1 Flat oyster (*Ostrea edulis)*)

This species offers the best prospects for the North Sea. A pilot at two sites has been set up for flat oysters and new pilots are planned. New initiatives can build on the knowledge acquired.

6.1.1.2 Sabellaria spinulosa

The most promising approach for this species is to encourage in situ settlement by choosing sites with strong currents and high concentrations of suspended sediment, no major migrating sand waves and in areas where seabed disturbance (through fishing, sand extraction, etc.) is excluded. Some hard substrate, possibly with some pieces of *Sabellaria spinulosa* reef attached, must be present at those sites. Preliminary studies will be required before any such pilot project is carried out in the field, and should also address the risks of relocating living reef structures from other parts of the North Sea. A logical first step would be to conduct a targeted study into the occurrence of *S. spinulosa* on existing wind farms, since some of those farms probably already provide fairly suitable conditions.

Potential pilot study to encourage *S. spinulosa* reefs

Preliminary studies
A detailed preliminary study into suitable habitat will first have to be conducted before any pilots are carried out. The maps available based on satellite images, for example, or model data which provide mean depth data are not sufficient to measure habitat suitability for *Sabellaria spinulosa* reefs, and will have to be combined with data on geomorphology and use of the seabed.

Secondly, a preliminary study will need to be conducted into the possibility of obtaining pieces of adult *Sabellaria spinulosa* reef. An obvious step to make at this stage is to pay a working visit to Bangor University (UK), one of the few institutions in Europe to have acquired direct experience of active restoration of *Sabellaria* reefs (see also section 4.1.2.1). This preliminary study should include an inventory of areas on the Dutch Continental Shelf which might be home to existing reef structures, such as on oil and gas infrastructure. If it is not possible to obtain sufficient *Sabellaria spinulosa* reef in the Netherlands, it will be necessary to explore 1) whether or not transplantation will involve avoidable risks in respect of the introduction of exotics, and 2) whether it is practically and legally feasible to transplant reef material from the UK to this country or first to place additional artificial substrate in the UK or next to any existing reef structures in the Dutch section of the North Sea alongside an existing reef as source material to be harvested at a later stage.

Necessary test structures and materials for a pilot study
A vessel with diving facilities will be required for the harvesting of material (and, if applicable, the initial introduction of artificial hard substrate) in the UK and its introduction into the Dutch section of the North Sea. The selection, acquisition and transport of suitable artificial substrate will have to take place within the contect of a preliminary study. In any event, diving facilities will be required to monitor developments over time.

Budget estimate for a pilot study
Harvesting, transport and introduction will largely determine the costs of a pilot study, which are estimated to be somewhere in the region between €50,000 and €100,000.

6.1.2 Artificial hard substrate

Various different approaches can be adopted to exploit the opportunities provided by artificial hard substrate to encourage substrate-using species. These approaches presuppose varying degrees of complexity and necessary knowledge levels.

Hard substrate communities			
	intervention		
	extensive	**Moderately intensive**	**Very intensive**
	construction of hard substrate / seabed protection	Seeding / transplantation	Cultivation / introduction
soft substrate	Apply rock armour/ artificial substrate on top of soft sediment within protected area (wind farms, exclusion zones, safety zones	Harvest and transplant of material and deploy this at restoration site; research required into suitable donor material (B)	Cultivate dead man's finger or jewel anemone on substrate and transplant to the field (D)

	surrounding infrastructure (A)	Temporarily apply hard substrate in the vicinity of hard substrate communities and transplant this after colonisation to restoration site (C)	
near existing hard substrate	Apply substrate connected to existing substrate with established communities (A)	Harvest and transplat of material and deply this at restoration site; research required into suitable donor material (B)	Cultivate dead man’s finger or jewel anemone on substrate and transplant to the field (D)
		Temporarily apply hard substrate in the vicinity of hard substrate communities and transplant this after colonisation to restoration site (C)	

A) Where an ecological community is present, an approach involving supporting the existing community (possibly including a specifically targeted species) through the introduction of additional substrate material would seem the most logical choice. This is line with the nature-inclusive approach to designing new infrastructure. The location on the Dutch Continental Shelf will then determine which species communities are present and qualify for reinforcement on the basis of policy visions. The size chosen for the additional area to be added, relative to the depth of the site, will determine which techniques can be used. Finally, knowledge of the effectiveness of any such approach is limited. For example, little is known about the impact the choice of specific material parameters will have on the speed and success of colonisation. This could be tested during a pilot. The development of species communities on a number of existing artificial substrates could also be analysed this way.

B) and C) Where an ecological community (including a specifically targeted species) is absent from a site but a suitable habitat has been identified, it may be possible to harvest a community elsewhere. In that event we propose that a good quantity of covered hard substrate is harvested and relocated to the target site (case B). In case C) it is not possible to harvest colonised hard substrate, and clean substrate material will be temporarily introduced at a site where the target community is present so that colonisation can take place there. The colonised substrate material will then be removed and introduced at the target site, where it can be combined with method A). Very little is known about the most effective harvesting methodology, transport method and method of introduction.

D) In certain cases where a species community cannot be harvested, or where autonomous colonisation on artificial substrate is not successful, a potentially effective method is to collect established juveniles and larvae and graft them onto artificial hard substrate under controlled ex situ conditions. In such a case, the product of cultivation can be introduced to a suitable target site in a favourable season and at a favourable stage of growth. A plan of action for dead man's fingers is described as an example of this. Cultivating and releasing such species will require considerable effort and the outcome remains quite uncertain, leaving aside the potential risk of importing exotic species.

In all scenarios, seabed disturbance will have to be minimised if interventions aimed at encouraging the long-term settlement of species are to have a beneficial effect.

Potential pilot study for the natural colonisation of artificial hard substrate

One conceivable initial experiment involves introducing identical artificial substrate configurations over a range of physical boundary conditions, e.g. from the shallow, sediment-rich coastal zone to deeper and clearer parts of the North Sea. This could help to determine the impact of changing conditions on the development of species communities. This approach could be used to test the hypothesis that reefs with a relatively low variety of species, dominated by *S. spinulosa,* will develop in sediment-rich areas and that calmer, clearer conditions will produce reefs with greater biodiversity. This experiment could be extended to include the introduction of additional material with adapted substrate characteristics. Success is conditional upon finding sites where the seabed is not disturbed, such as wind farms or infrastructure safety zones.

Budget estimate
The costs of such a study are determined by the scale of the pilot, the costs of acquiring material, transporting it and introducing it at the site (various methods are available which will be accompanied by specific costs, but also depend on specific qualities of the substrate; for example, sorting). The artificial reef introduced at the REM island in 1991 cost NLG 70,000 (± €32,000), excluding monitoring, at the time. Today, we are looking at a minimum of €100,000. The pilot can be linked to the construction of offshore infrastructure. The costs of the monitoring which will be ultimately be necessary are certainly relevant, too. Monitoring activities could be linked with maintenance work and inspections already performed for marine infrastructure.

6.1.2.1 *Grafting artificial hard substrate (for example, with dead man's fingers)*

If new reefs are to be created with artificial substrate in Dutch waters, active colonisation of that substrate with dead man's fingers (*Alcyonium digitatum*) is a possible option for accelerating the development of such a reef (see section 4.3). Expectations are that the plan of action for the jewel anemone (*Corynactis viridis*) will largely involve the same approach. Active colonisation could possibly be carried out by collecting gametes in the field followed by fertilisation, development of larvae and the larvae's attachment to hard substrate in the laboratory (ex situ). Substrates with juveniles attached to them could then be reintroduced in the sea or further cultivated under controlled conditions in tanks on land. Attention should be given to the donor and release sites: if these are relatively close to one another, the risk of importing exotic species will be relatively low, but that risk will have to properly examined where hard substrate containing live growth is transported over long distances.

A pilot study should be carried out in order 1) to test the technical feasibility of this option; 2) obtain protocols for active colonisation; 3) obtain an idea of the costs such an operation would entail, and 4) to be able to compare this strategy with natural colonisation.

Potential pilot study involving the grafting, cultivation and/or release of dead man's fingers

The pilot study could be structured as follows:

- Phase 1: A short preliminary study into two relevant aspects of the biology of dead man's fingers. In addition, a **suitable site** for the collection of gametes will have to be selected.
- Phase 2a: The **collection of gametes** and **ex situ fertilisation** (i.e., fertilisation in the laboratory) and the production of free-swimming larvae. Those larvae will then be offered various substrates on which to **settle**, such as ordinary rubble, reef balls (eco concrete), surfaces coated with shells, and sandstone.
- Phase 2b: The substrates could also be introduced in the sea in the area surrounding the population being sampled so that a comparison can be made between natural colonisation and active colonisation.
- Phase 3: Some of the settled larvae can be raised in seawater aquaria during this phase. Juvenile dead man's fingers could be exposed to different feeding regimens (*Artemia*, phytoplankton and combinations of the two). Groups of juveniles could be released into the field at various points during phase 3, and their survival rates could be monitored by divers.

Necessary test structures and materials for pilot study
A vessel with diving facilities and a laboratory with aquarium facilities, preferably with flowing seawater and plankton cultures, will be necessary for phases 2 and 3.

Budget estimate
Phases 2 and 3 will largely determine the costs of the pilot study, which are estimated to be somewhere in the region between €150,000 and €200,000.

6.2 Relevant projects and knowledge

Haringvliet Dream Fund project
As part of the 'Haringvliet Dream Fund Project' by WWF, ARK Natuurontwikkeling and others, pilot experiments involving oysters, mussels and artificial hard substrate were launched in March 2016 at two sites in the Voordelta to find out whether there are any opportunities for the restoration of shellfish beds in this area and elsewhere. The pilots focus on the survival, growth and spat settlement of the specified species in this area, and on associated species which develop on hard substrate. Some of the knowledge generated by the pilot is to be used for North Sea pilots. However, pilots will be required for the development of oyster reefs in the North Sea to address site-specific questions which the Voordelta pilots have not answered.

Experts in the UK on Northern horse mussels and *Sabellaria*
Various studies into the habitat requirements and reproduction of Northern horse mussels have been conducted in the UK (Holt et al., 1998; Jasim, 1986; Jones et al., 2000). The University of Belfast has a Northern horse mussel restoration group: http://www.qub.ac.uk/research-centres/ModiolusRestorationResearchGroup/. Several projects aimed at the restoration of *Sabellaria* reefs are being conducted in the UK, in particular at the University of Bangor (Dr Andrew Davies; see also sections 4.1.2.1 and 6.1.1.2).

Other links

During the Marine Bio-Invasions conference in Sydney (2016), Laura Airoldi and Elisabeth Strain gave presentations which might be relevant to this study (see http://www.marinebioinvasions.info/files/abstracts_main.pdf).

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A Overview of a number of categories of policy-relevant species and habitats for the North Sea

A.1 Habitat types and species of the Dutch part of the North Sea which are covered by the Habitats Directive

Explanatory note: Habitat types: the types qualifying as ‘coastal habitats and halophyte vegetations’; (A, B, C): subtypes differentiated by the Netherlands; CS = Conservation status: U1 = unfavourable-inadequate, U2 = unfavourable-bad: (+) = but improving, (=) = stable, (-) but declining, (x) = unknown; Natura 2000 sites have been designated for Habitats Directive Annex-I habitat types and Annex-II species. Source CS (trend): Ministerie van Economische Zaken (2014 c and d); source for Annex-I habitats and Annex-II species relevant to the Netherlands: European Topic Centre on Biological Diversity (2015 a and b).

	CS trend	Habitats Directive Annex			
		I	II	IV	V
Habitat type					
H1110 (A, B and C): "C): “Sandbanks which are slightly covered by sea water all the time”	U1: (+)	×			
H1140 (A and B): “Mudflats and sandflats not covered by seawater at low tide”	U1: (x)	×			
H1170: “open-sea reefs”	U1: (x)	×			
H1310 (A and B)): “*Salicornia* and other annuals colonising mud and sand”	U1: (=)	×			
H1320: "Coastal saltmarsh"	U1: (-)	×			
H1330 (A): “Atlantic salt meadows"	U1: (=)	×			
Species					
sea lamprey (*Petromyzon marinus*)	U2 (=)		×		
river lamprey (*Lampetra fluviatilis*)	U1: (x)		×		×
twaite shad (*Alosa fallax*)	U2 (=)		×		×
allis shad (*Alosa alosa*)			×		×
salmon (*Salmo salar*)					×
houting (*Coregonus oxyrinchus*)				×	
European sea sturgeon (*Acipenser sturio*)				×	
harbour porpoise (*Phocoena phocoena*)	U1: (+)		×	×	
grey seal (*Halichoerus grypus*)	U1: (+)		×		×
common seal (*Phoca vitulina*)	U1: (x)		×		×
short-beaked common dolphin (*Delphinus delphis*)				×	
common bottlenose dolphin (*Tursiops truncates*)				×	
Atlantic white-sided dolphin (*Lagenorhynchus acutus*)				×	
white-beaked dolphin (*Lagenorhynchus albirostris*)				×	

A.2 Species typical of habit type H1170: ‘open-sea reefs’

Explanatory note: typical species are not, or not necessarily, protected species; typical species categories: Ca = constant species indicative of good abiotic conditions; Cb = constant species indicative of good biotic structure; Cab = constant species indicative of good abiotic conditions and good biotic structure; K = characteristic species; E = exclusive species; sources: Ministerie van Economische Zaken (2014b), Nederlands Soortenregister (2016), De Bruyne et al. (2015), Heessen et al. (2015).

Species	Species group	Category
- (*Lithothamnion sonderi*)	red algae	K
Mermaid's glove (*Haliclona oculata*)	sponges	Cab
Dead man's fingers (*Alcyonium digitatum*)	anthozoa	Cab
- (*Urticina* sp.)	anthozoa	Cab
- (*Sabellaria spinulosa*)	polychaetes	K + Ca
- (*Chone duneri*)	polychaetes	K
blunt tellin (*Arcopagia crassa*)	molluscs	Cab
common whelk (*Buccinium undatum*)	molluscs	Cab
rayed artemis (*Dosinia exoleta*)	molluscs	Cab
ribbed saddle-oyster (*Pododesmus patelliformis*)	molluscs	K + Ca
pelican's foot (*Aporrhais pespelecani*)	molluscs	Cab
poached-egg shell (*Simnia patula*)	molluscs	Cab
queen scallop (*Aequipecten opercularis*)	molluscs	Cab
squat lobster (*Galathea intermedia*)	crustaceans	E
Norway bullhead (*Micrenophrys lilljeborgii*)	fish	E
two-spotted clingfish (*Diplecogaster bimaculata*)	fish	E
angler (*Lophius piscatorius*)	fish	Cab

A.3 Habitats and species of the Dutch section of the North Sea which included in the OSPAR list of threatened and declining species and habitats

Explanatory note: Sources: OSPAR Commission (2008) and Bos et al. (2012).

Habitat
“Intertidal *Mytilus edulis* beds on mixed and sandy sediments"
"Intertidal mudflats"
“*Ostrea edulis* beds”
"Sea-pen and burrowing megafauna communities"
“*Zostera* beds”
Species
ocean quahog (*Arctica islandica*)
dog whelk (*Nucella lapillus*)
flat oyster (*Ostrea edulis*))
black-legged kittiwake (*Rissa tridactyla*)
European sea sturgeon (*Acipenser sturio*)
allis shad (*Alosa alosa*)
European eel (*Anguilla anguilla*)
whitefish (*Coregonus lavaretus*)
common skate (*Dipturus batis*)
spotted ray (*Raja montagui*)
Atlantic cod (*Gadus morhua*)
long-snouted seahorse (*Hippocampus guttulatus*)
short-snouted seahorse (*Hippocampus hippocampus*)
sea lamprey (*Petromyzon marinus*)
thornback ray (*Raja clavata*)
salmon (*Salmo salar*)
spiny dogfish (*Squalus acanthias*)
angelshark (*Squatina squatina*)
Atlantic bluefin tuna (*Thunnus thynnus*)
bowhead whale (*Balaena mysticetus*)
harbour porpoise (*Phocoena phocoena*)

A.4 Marine species on the Dutch national Red list of fish (2015)

Explanatory note: Red list status: EX = ‘extinct in the Netherlands’, CR = ‘critically endangered’, EN = ‘endangered’, VU = ‘vulnerable’, NT = ‘near threatened’; [diadromous] = a species which migrates between the sea and fresh water; sources: Ministerie van Economische Zaken (2015), Nederlands Soortenregister (2016). Tien et al. (2016); Gmelig Meyling & Van Moorsel (2013) and Kranenbarg & Spikmans (2013).

Species	Red list status
twaite shad (*Alosa fallax*) [diadromous]	EX
broadnosed pipefish (*Syngnathus typhle*)	EX
common skate (*Dipturus batis*)	EX
sea stickleback (*Spinachia spinachia*)	EX
spiny dogfish (*Squalus acanthias*)	CR
spotted ray (*Raja montagui*)	CR
greater weever (*Trachinus draco*)	CR
garfish (*Belone belone*)	EN
thornback ray (*Raja clavata*)	EN
tadpole fish (*Raniceps raninus*)	EN
Atlantic horse mackerel (*Trachurus trachurus*)	VU
mackerel (*Scomber scombrus*)	VU
viviparous eelpout (*Zoarces viviparus*)	VU
common seasnail (*Liparis liparis*)	VU
European smelt (*Osmerus eperlanus*) [diadromous]	VU
poor cod (*Trisopterus minutus*)	NT
Norwegian topknot (*Phrynorhombus norvegicus*)	NT
houting (*Coregonus oxyrinchus*) [diadromous]	NT
Atlantic cod (*Gadus morhua*)	NT
big-scale sand smelt (*Atherina boyeri*)	NT
short-snouted seahorse (*Hippocampus hippocampus*)	NT
river lamprey (*Lampetra fluviatilis* [diadromous]	NT
shanny (*Lipophrys pholis*)	NT
lemon sole (*Microstomus kitt*)	NT
whiting (*Merlangius merlangus*)	NT
sea lamprey (*Petromyzon marinus* [diadromous]	NT
two-spotted clingfish (*Diplecogaster bimaculata*)	NT
corkwing wrasse (*Symphodus melops*)	NT

B Maps physical system characteristics

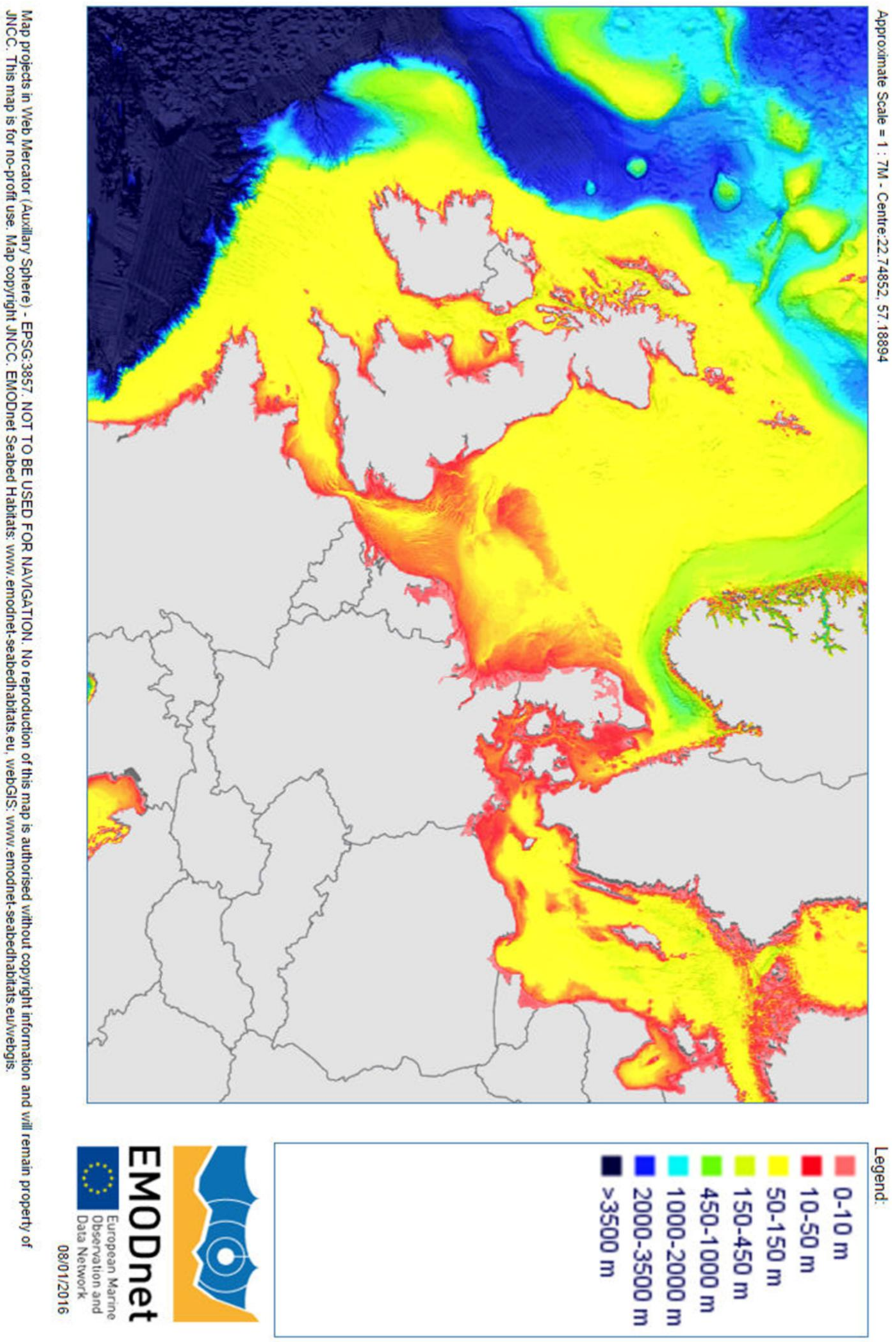


Figure B.1 Bathymetric map of the North Sea. Source: http://www.emodnet-seabedhabitats.eu/default.aspx?page=1974.

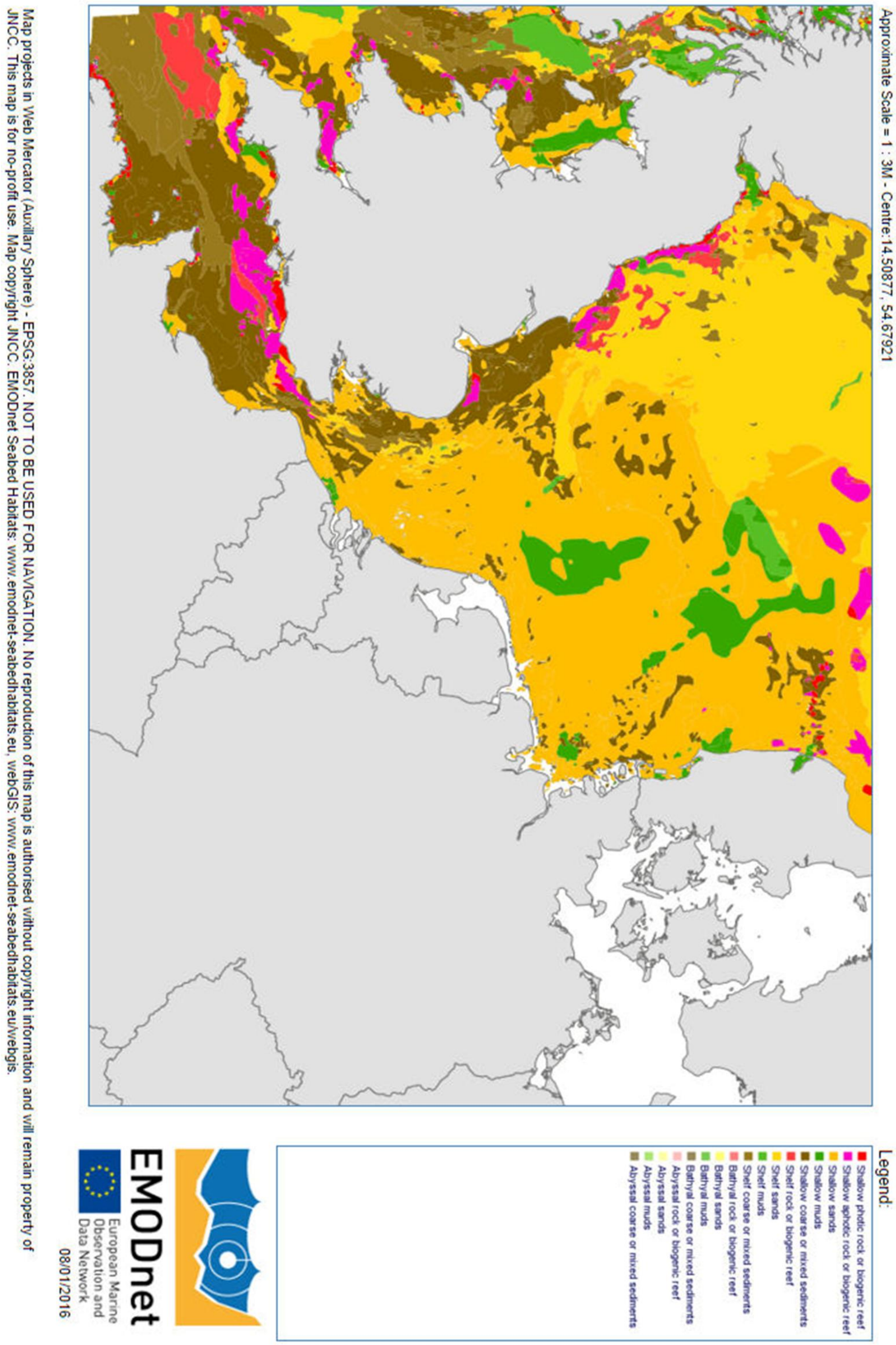


Figure B.2 North Sea benthic habitats. Source http://www.emodnet-seabedhabitats.eu/default.aspx?page=1974. light amber: shallow sandy, orange: shelf, sandy, green: muddy sediment, brown: mixed course. pink and reds: rock and biogenic reefs.

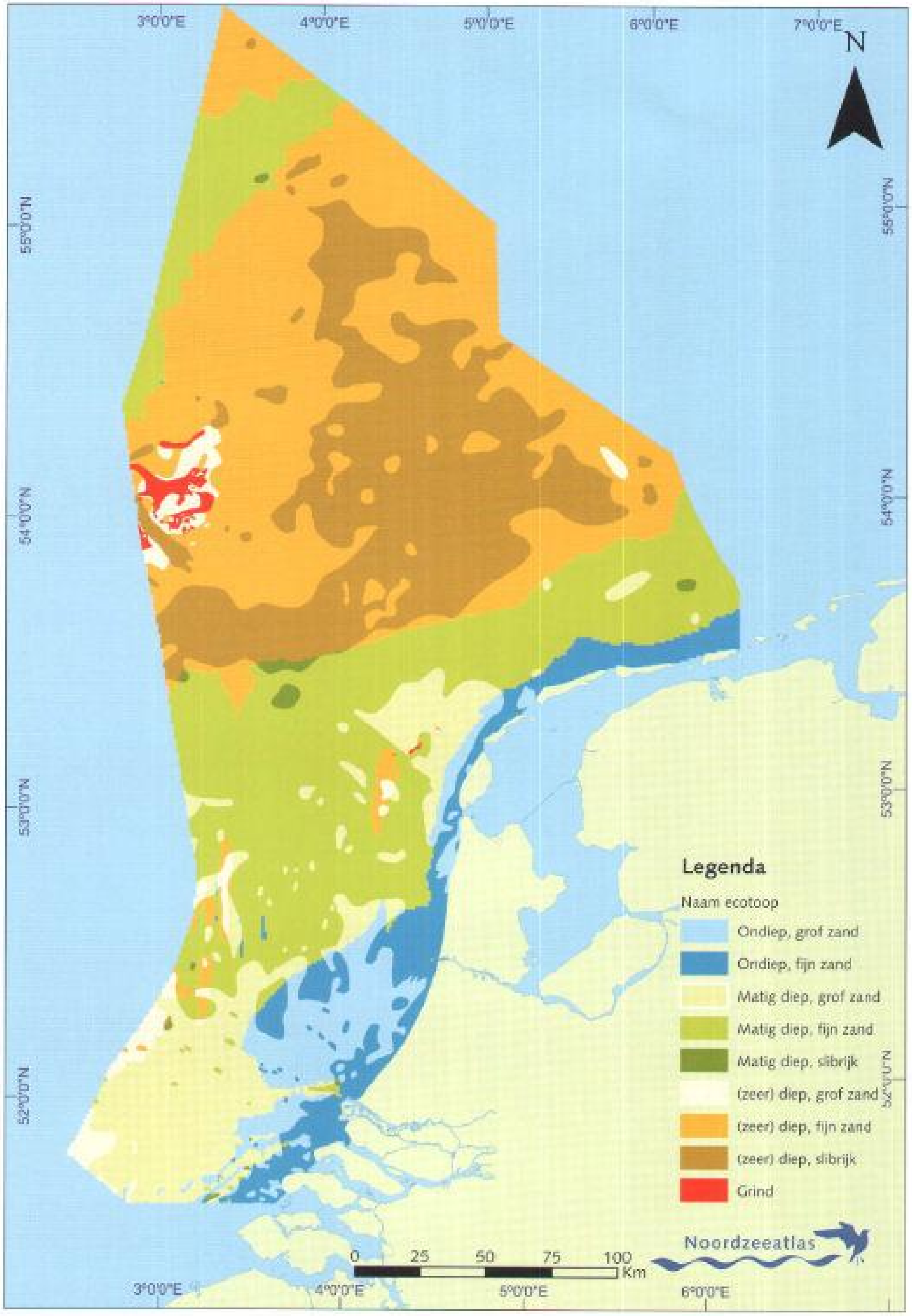


Figure B.3   Ecotope map Dutch continental shelf (Source North Sea Atlas)

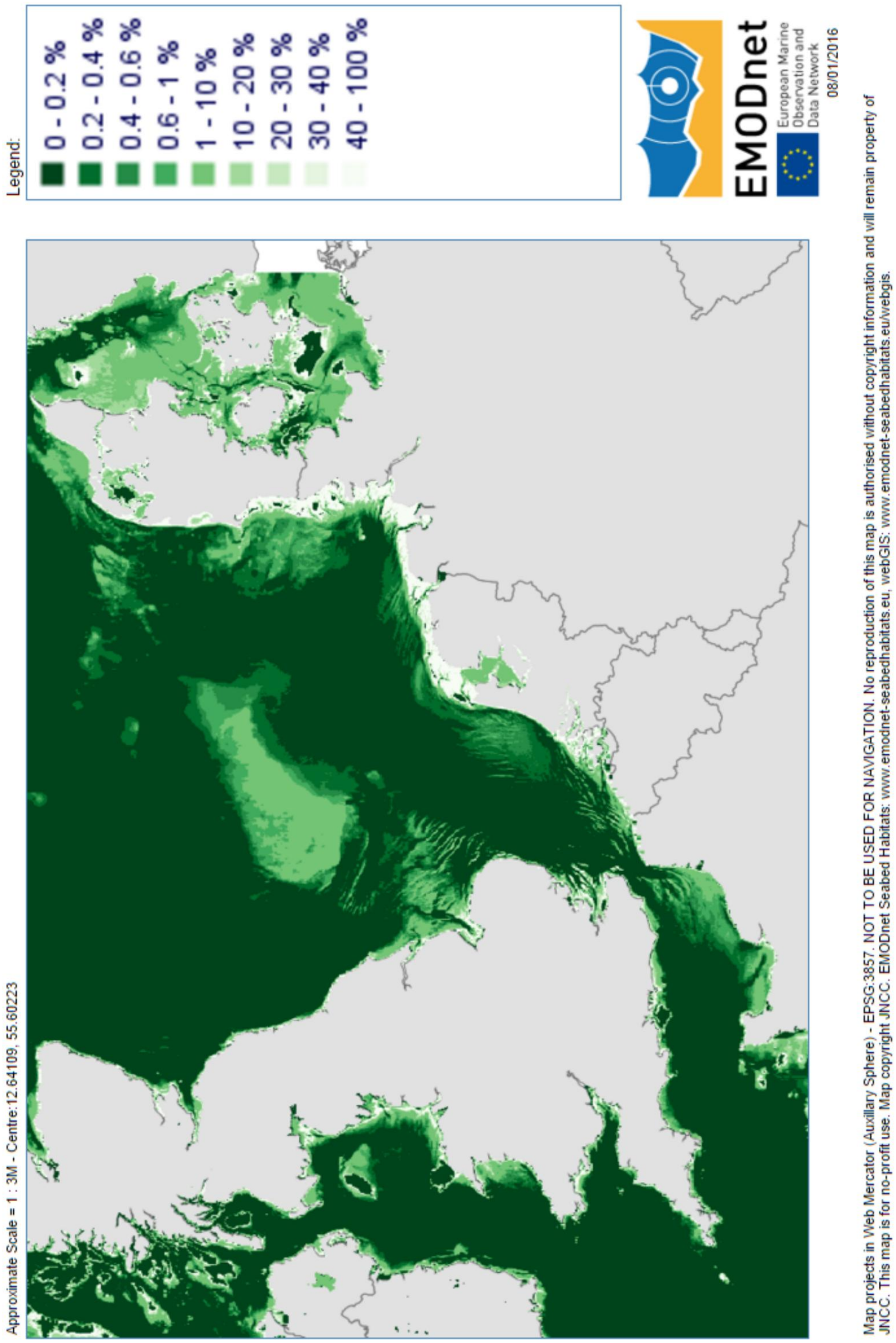


Figure B.4 Light availability at the bed expressed as fraction of the light intensity at the surface. Source: http://www.emodnet-seabedhabitats.eu/default.aspx?page=1974.

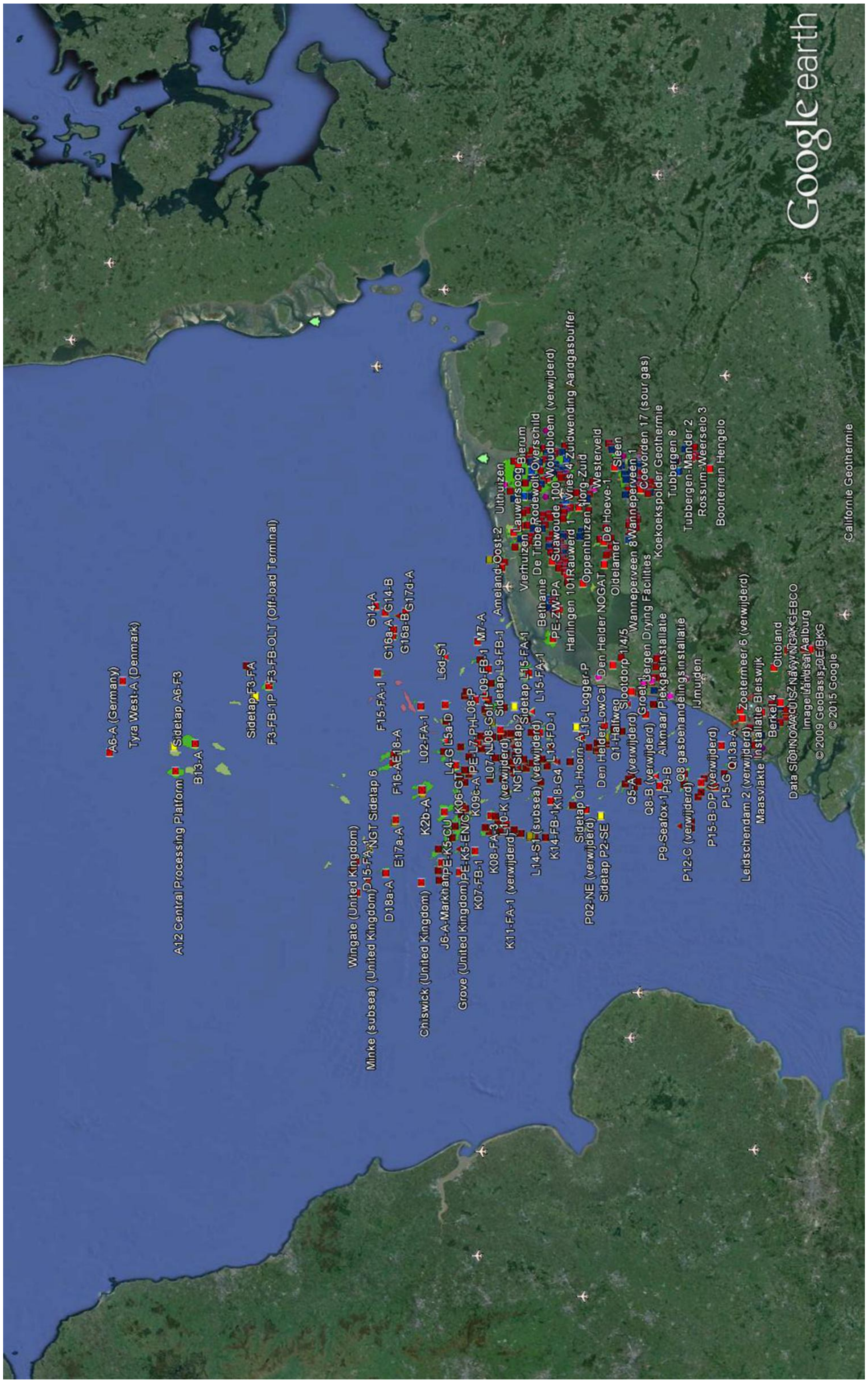


Figure B.5 Locations hard infrastructure oil, gas and mining platforms. Source: NL Olie- en Gasplatform.

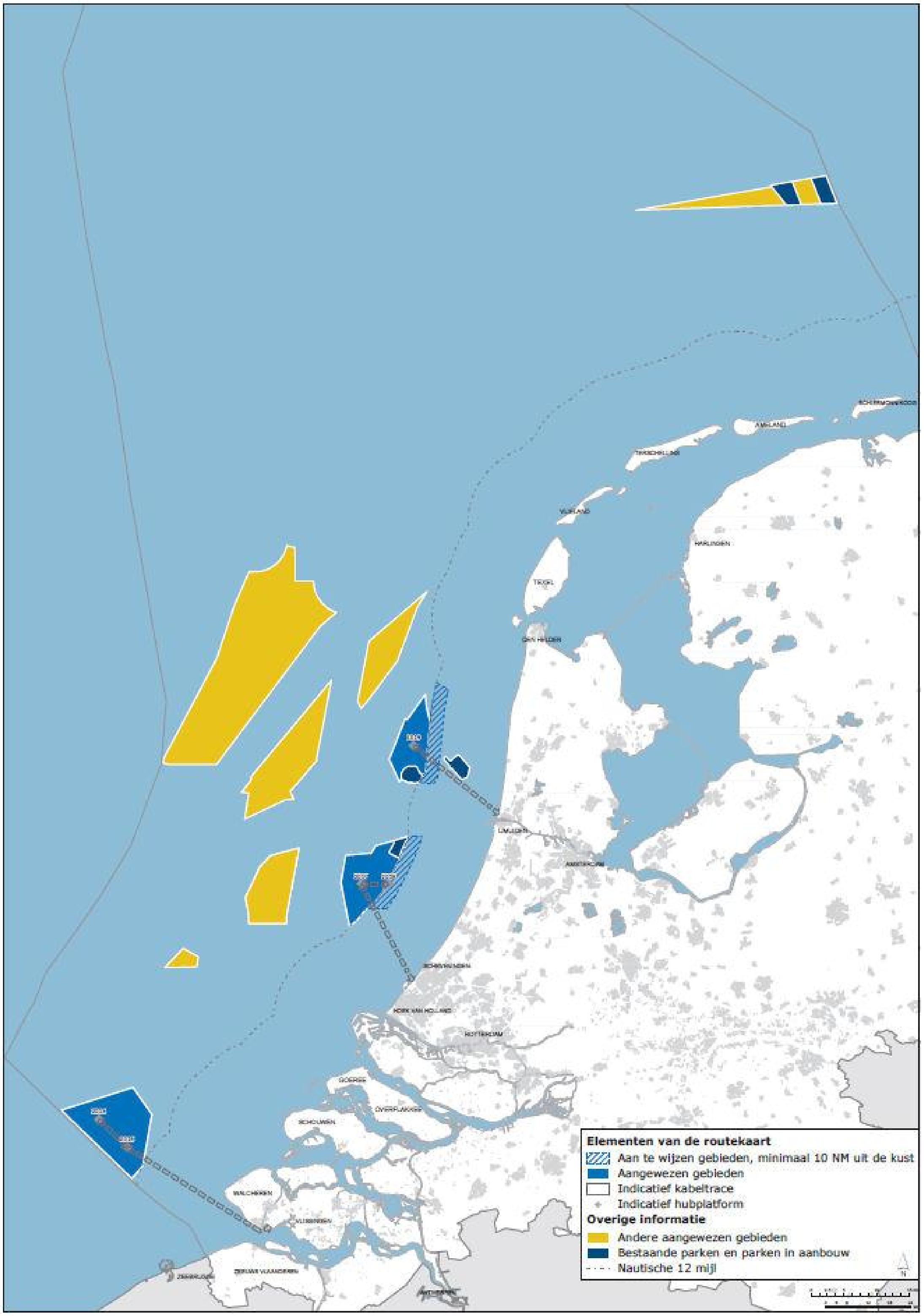


Figure B.6 Existing, designated and future areas for offshore wind farms. Source: Noordzeeloket

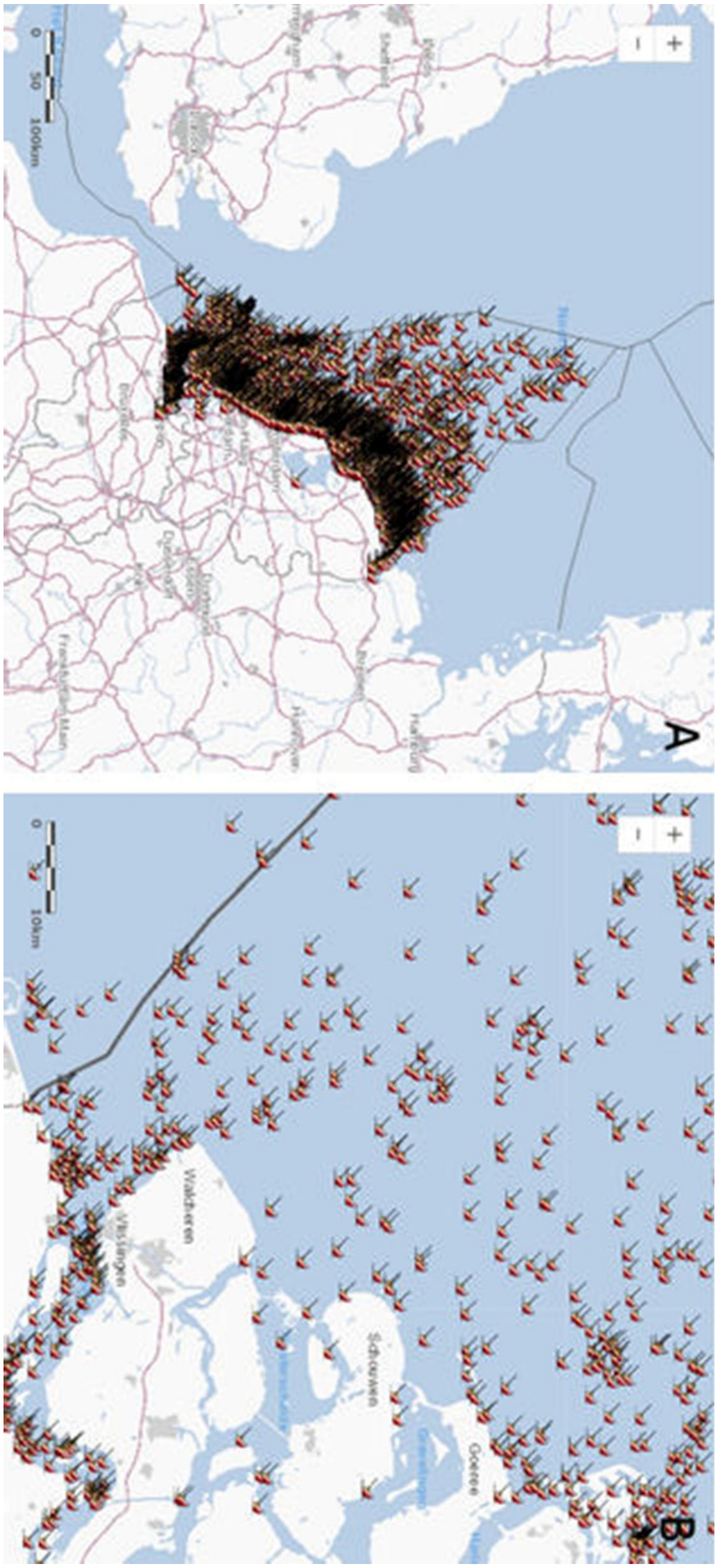


Figure B.7 Wrecks on the Dutch continental shelf (A) full data set (B) Detail from the Voordelta Source: (www.beschermeenwrak.nl).

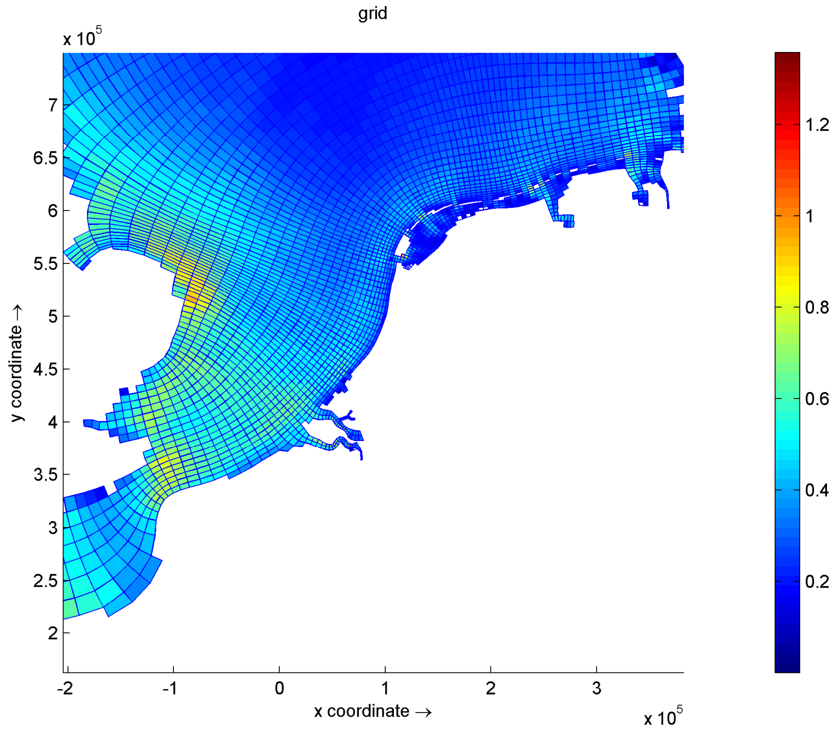
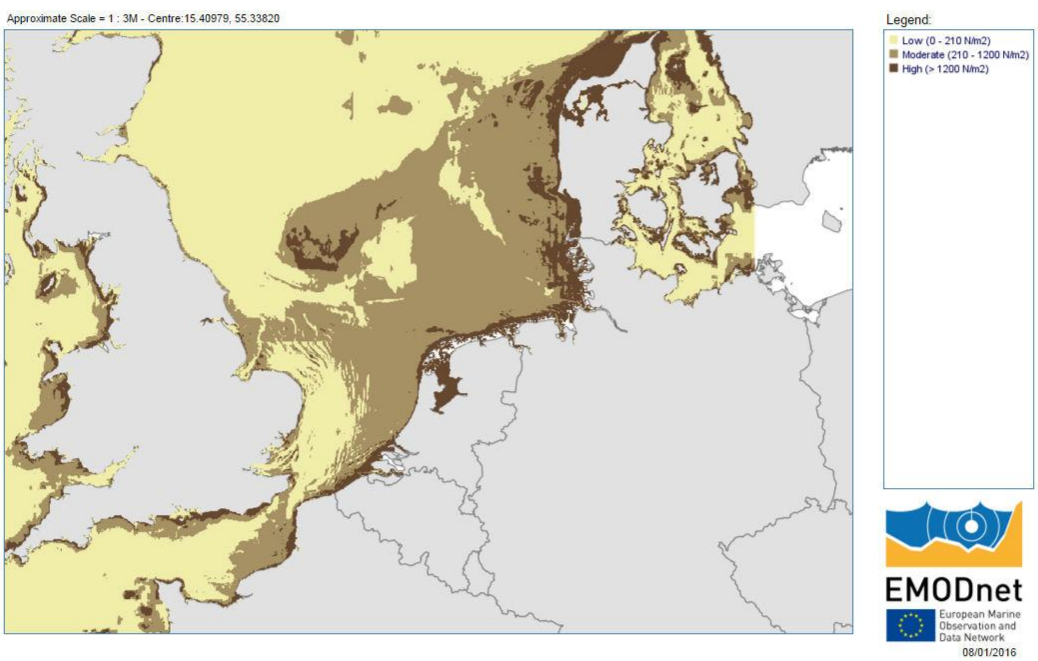


Figure B.8   Average current velocities in the North Sea (Source: ZUNO DD model Deltares)



Map projects in Web Mercator (Auxillary Sphere) - EPSG:3857. NOT TO BE USED FOR NAVIGATION. No reproduction of this map is authorised without copyright information and will remain property of JNCC. This map is for no-profit use. Map copyright JNCC. EMODnet Seabed Habitats: www.emodnet-seabedhabitats.eu, webGIS: www.emodnet-seabedhabitats.eu/webgis.

Figure B.9   Spatial distribution of wave action on the sea bed (data http://www.emodnet-seabedhabitats.eu/).

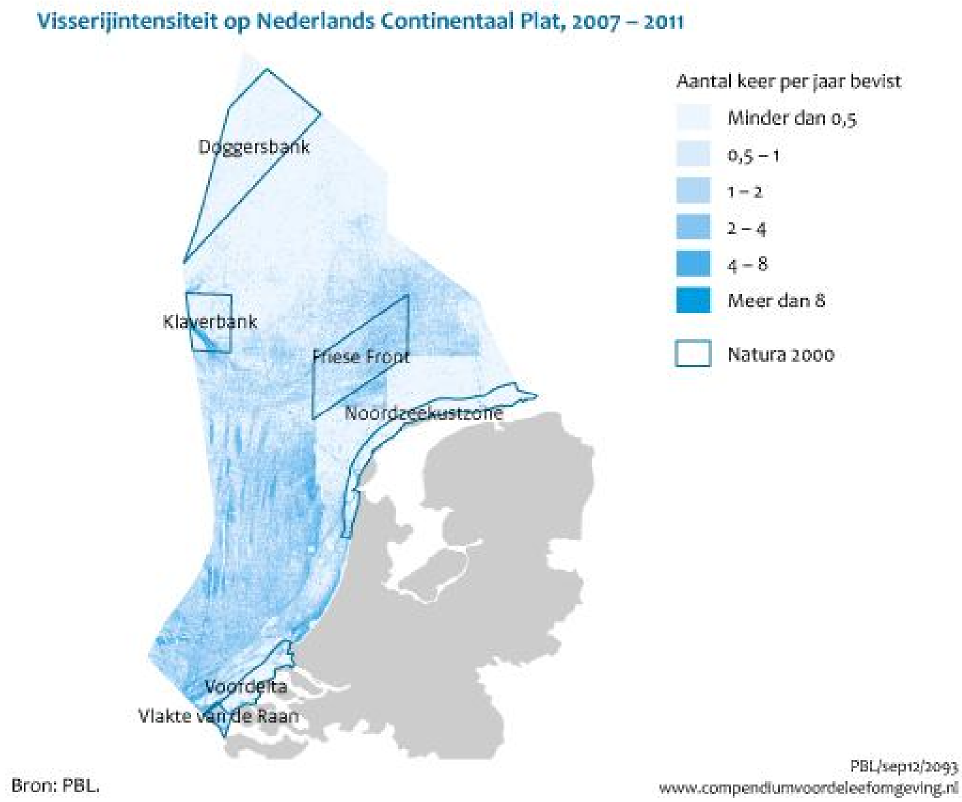


Figure B.10 Fishing intensity expressed as the number of times the sea bed is disturbed on average per year (Source Planbureau voor de leefomgeving)

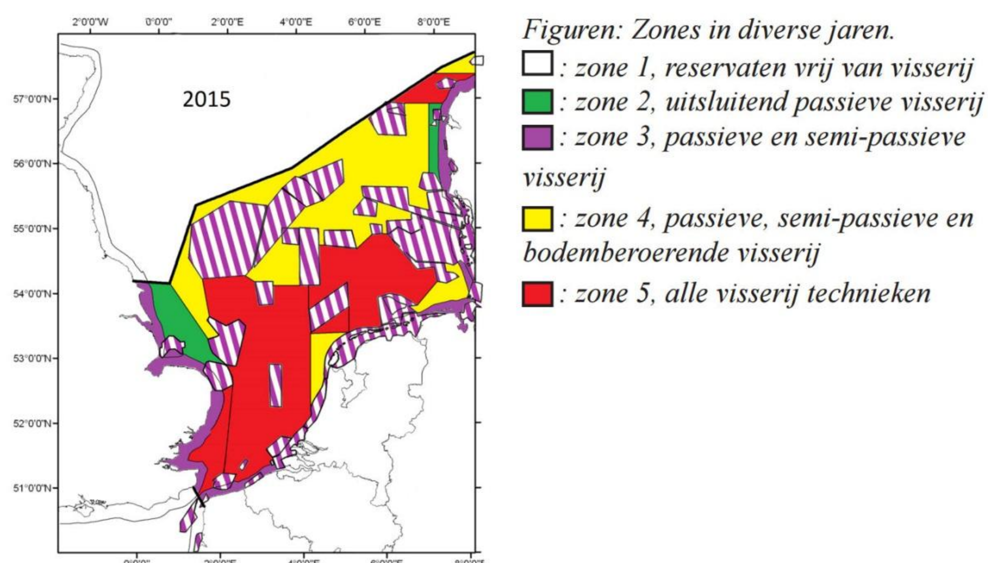


Figure B.11 Allowed fishing in the North Sea (Factsheet Visserij, Stichting de Noordzee). White (Reserve, no fishing allowed), green: only passive gears, purple: passive and semi passive gears, yellow: passive, semi-passive and bottom trawling, red: all techniques allowed