Feasibility of Flat Oyster *(Ostrea edulis L.)* restoration in the Dutch part of the North Sea

A.C. Smaal[1], P. Kamermans[1], T.M. van der Have[2] , M. Engelsma[3] & H.J.W.Sas[4]

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[1]Imares, [2]Bureau Waardenburg, [3]CVI-DLO & [4]Sas Consultancy

IMARES Wageningen UR

(IMARES - Institute for Marine Resources & Ecosystem Studies)

Clients:	Ministry of Economic Affairs, Mrs M. Wijnstok POBox 20401, 2500 EK Den Haag Ministry of Infrastructure and Environment Mr F. Zijp, POBox 17, 8200 AA Lelystad
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P.O. Box 68
1970 AB IJmuiden
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 26
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 77
4400 AB Yerseke
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 59
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 57
1780 AB Den Helder
Phone: +31 (0)317 48 09 00
Fax: +31 (0)223 63 06 87
E-Mail: imares@wur.nl
www.imares.wur.nl

P.O. Box 167
1790 AD Den Burg Texel
Phone: +31 (0)317 48 09 00
Fax: +31 (0)317 48 73 62
E-Mail: imares@wur.nl
www.imares.wur.nl

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Summary

The project is carried out under contracts of the Ministry of Infrastructure and Environment and the Ministry of Economic Affairs. Governmental policy aims to include the restoration of shellfish bed communities in the Dutch North Sea, to achieve biodiversity goals, restore ecosystem functions and enhance ecosystem services. For the recovery of flat oyster beds, knowledge is required of the conditions under which the active restoration of this species in the North Sea can be successfully implemented. This is the subject of the current feasibility study. In addition, a plan for the execution of a pilot phase is described, in which restoration of flat oyster beds will be attempted in practice.

The project outcomes can be summarized as follows:

- Fate of the North Sea flat oysters and the possible causes of extinction.

Extensive flat oyster beds have existed in the North Sea and their extinction is predominantly caused by overexploitation and subsequent habitat destruction by intensive bottom trawling.

- Environmental conditions and restoration sites.

Flat oysters require hard a substrate in the form of shell material, other hard substrate or existing flat oyster beds. This can be developed in the soft sediments of the North Sea bed and on existing artificial hard substrates. Potential sites can be found in areas where no bottom trawling occurs. At present this is mainly limited near to offshore platforms and in wind farms. In the near future, protected areas within the Marine Strategy Framework Directive and Natura 2000 network are to be established and may also be suitable.

Living flat oysters have occasionally been found in wind farms. Flat oyster growth has also been demonstrated experimentally in areas where German wind farm are planned. Furthermore, the flat oyster population in the Delta area shows signs of recovery. This all shows that the proper environmental conditions for flat oyster restoration exist in the North Sea. The recent expansion of Pacific oysters should pose no threat to flat oyster restoration since the two species have different habitat requirements.

- Identification of the legal framework for restoration.

Restoration of the flat oyster in the North Sea may be seen as a reintroduction attempt. Therefore, we have investigated the compliance of flat oyster restoration with the Dutch policy for reintroduction of animals. It is concluded that restoration can be organized in such a way that there is indeed full compliance.

- Identification of stakeholder requirements.

Stakeholder consultations have delivered relevant feedback as well as support for the approach. Boundary conditions have been identified, and involvement of various stakeholder groups has been approved.

- Program for pilot experiments.

Prior to carrying out field scale pilot experiments a number of issues have to be addressed in more detail. This includes pre-restoration surveys of biotic and abiotic factors in selected areas, create a habitat suitability index, and develop a model for the connectivity analysis of the populations. Meanwhile, methodological field tests can be carried out on test locations in the Oosterschelde, and specific questions deal with the source population. Oyster spat from the Limfjord, Denmark can be considered, as this is free of the Bonamia infestation.

1 Introduction

The current feasibility study on the restoration of flat oyster beds in the Dutch part of the North Sea has been carried out under contract of the Ministries of Economic Affairs, and Infrastructure and Environment. Several factors motivate a restoration project: (1) flat oyster beds are a threatened species and habitat (OSPAR, EU Habitat Directive, biogenic reefs), (2) they have important ecological functions within the North Sea ecosystem and (3) provide a range of ecosystem services. The project will, among others, contribute to fulfilling Dutch obligations following from the Marine Strategy Framework Directive (MSFD). The recovery of natural hard substrates, including flat oyster beds, is an objective stated in the policy documents Nature Ambition Large Water Bodies (Min EZ, 2014), under the title of shellfish beds in general in the Implementation Agenda Natural Capital (Min EZ 2013) and in recent OSPAR recommendations (OSPAR, 2013).
To achieve the recovery of flat oyster beds, knowledge is required of the conditions under which the restoration of this species in the North Sea can be successfully implemented; this needs to be ascertained through structured pilot experiments in which recovery is attempted.
This feasibility study has the following objectives: analysis of the fate of the North Sea oysters, exploration of conditions and possibilities for recovery, identification of suitable areas, determination of the applicable legal frameworks, identifying substantive success factors, verifying field observations of oysters, consulting stakeholders, and the preparation of a plan for phase two (pilot experiments).

1.1 Background

Until about a century ago, flat oyster *(Ostrea edulis)* reefs constituted an important habitat in the North Sea. The flat oyster was a key species in the North Sea ecosystem that once existed, a fact that has almost disappeared from public memory. According to field surveys conducted in the 19th and early 20th century, the North Sea harboured substantial areas of oyster reefs in that time (over 25,000 km^2, Olsen, 1883; Fischereikarte 1915 in Gercken & Schmidt, 2014; Houziaux, 2008).
In the southern North Sea, the sea floor consists mainly of sand and silt. Rocks are uncommon and the dominant form of natural hard substrate is provided by mollusc shells; in particular flat oysters. Many species of marine flora and fauna are dependent on hard substrate, either directly because they attach themselves to it, or indirectly because the reefs provide shelter, food or spawning grounds. In addition, the oysters filter the water column and thereby improve growth conditions of phytoplankton, deposit organic and inorganic materials and recycle nutrients. Hence, this species once constituted a key element of a rich North Sea ecosystem. Besides, oyster beds provided an important commercial service: a complete shellfish sector was dependent on harvesting flat oysters.
However, by the end of the 19th century the flat oyster fishery became too intensive, which caused the oyster population to decline rapidly (Gercken & Schmidt, 2014; Houziaux, 2008). By the beginning of the 20th century, the oyster beds were already decimated (Fischereikarte 1915 in Gercken & Schmidt, 2014). Later, other types of bottom trawling fishery eliminated the remaining reefs. As a result, the oyster community, including the related species, has vanished from the North Sea.

Recovery of the European flat oyster population and restoration of flat oyster beds in the North Sea is important for:

- Biodiversity: oyster beds function as a habitat for many other species, in particular epibenthic flora and fauna, mobile invertebrates (e.g. crab and lobster, which find food and shelter) and fish (e.g. herring, which needs hard substrates as a spawning ground, whereas many species find shelter, particularly in the juvenile stage).

- Ecosystem functioning: flat oyster beds improve growth conditions of phytoplankton, contribute to nutrient cycling and thereby to primary production.
- Providing ecosystem services, including water quality improvement and oyster harvesting, with the associated cultural values (Coen et al., 2011). Once, a large fishery sector existed on the harvesting of flat oysters.

These functions are key to nature conservation objectives, within the framework of OSPAR, the EU Marine Strategy Framework Directive, the EU Habitat Directive and national policies. The relevance of restoration of flat oyster beds in the North Sea is underlined by the German feasibility study, which was recently carried out by the Bundesamt für Naturschutz (Gercken & Schmidt, 2014).
By raising a broader public awareness of this heritage, support for a forward-oriented North Sea conservation strategy may also be achieved. Flat oysters have a very high market value. If the restoration program becomes a success, in terms of growth, survival and reproduction of oyster reefs, the return of direct or indirect commercial exploitation may become possible.
Current conditions may favour the return of the flat oyster in the North Sea. It has survived in estuaries around the North Sea (e.g. Limfjorden in Denmark, Lake Grevelingen and Oosterschelde in the Netherlands, plus various inlets on the coast of the British Isles and Norway). Recent records of individuals on shipwrecks, buoys and marine wind farms in the North Sea show that it can still survive, reproduce and disperse in the open sea. Newly installed marine protected areas, wind farms and offshore installations could provide shelter areas that are free from bottom trawling fisheries.
Yet, without assistance the oyster reefs may not return on a large scale. Oysters have a limited dispersal range and need hard substrate to settle, but without oysters, very little natural hard substrate has remained on the North Sea bed. So, once the reefs are gone, they will probably not return on their own, even if the conditions are favourable.

1.2 Approach

In order to identify critical success factors for growth, survival and reproduction in the open sea, recovery of the flat oyster has to be preceded by research and monitoring. In line with this, we have developed a three-stage approach:

1. Feasibility study: Desk-based research on ecological conditions, success factors and source populations, consultation of the legal framework, consultation of wind farm and offshore installation owners, further investigation of stakeholder positions and verification of oyster occurrence and status in situ. This results in planning of phase 2 (see annex 1).
2. Pilot phase: Development and execution of small-scale experiments, based on the findings of phase 1. Experiments will have to be executed under a variety of conditions (water depth, distance to shore, type of substrate, nutrient richness), with various age classes and various source populations. This phase will take three to five years
3. Active restoration: This will take place at the most successful sites, with the most successful subpopulations and conditions, as identified in phase 2. The objective is to establish vital and self-reproducing oyster reefs. Monitoring is also required in this phase, which can lead to adaptation of the reintroduction strategy. This phase will take five to eight years.

This report is about phase 1.

1.3 Aims of the feasibility study

In line with the approach described in par. 1.2, the aims of the feasibility study in phase 1 are:

- literature review of the fate of the North Sea oysters and the possible causes of extinction;
- identification of environmental conditions and sites potentially favourable for the reintroduction of flat oysters and restoration of oyster beds in the Dutch part of the North Sea;
- identification of the legal framework for reintroduction and restoration;
- identification of stakeholder interests;
- preparation of a program for pilot experiments (phase 2).

1.4 Acknowledgements

We are grateful to the stakeholders that provided valuable feedback on the approach. We are also grateful to Marnix van Stralen for constructive discussions on the draft plans. We thank Margriet van Asch, Imares, for producing GIS maps and Mark Collier, Bureau Waardenburg, for improving the English text.

2 The North Sea Flat Oysters

2.1 Characteristics and development of natural flat oyster populations

Mature flat oysters can switch between sexes to be male or female (Walne 1970). Generally, flat oysters start as male and become female as they grow older. Older oysters can spawn twice during one season, once as male and once as female. Sperm cells are expelled through the exhalant siphon. Eggs remain in the mantle cavity of the female where they are fertilised and develop into larvae with two shells in a period of one to twe weeks. When they are released, the shell length of the larvae is 170-190 µm. During their free-swimming stage (another 10 – 30 days: Muus and Dahlstrom, 1973) the length increases to 290-360 µm. Metamorphosis from swimming larvae into sessile spat depends on food availability for the larvae. Settlement occurs when a suitable location is detected. A drop of concrete is produced and the left valve is glued to the surface. As a result of the relative short free-swimming stage compared to other bivalve species, the dispersal distance of *O. edulis* is limited: on average 1 km (Jackson, 2007), although longer distances are occasionally possible during favourable conditions, up to 10 km (Berghahn & Ruth, 2005).

Oyster spat settles on hard substrate, such as stones, shell fragments or oyster shells. They adhere or fix themselves to the substrate and do not disperse further. For spat collection, calcified tiles have been employed in many areas and are still in use in Arcachon Bay (FR). Oyster shells in existing oyster beds are a preferred settling substrate for oyster spat. Oyster bed development is therefore a self-reinforcing process due to the positive feedback of existing oysters on successful recruitment and settlement. It implies that oyster beds have a critical mass below which recruitment may fail, due to limited substrate availability in relation to the amount of larvae produced (Berghahn & Ruth, 2005; Kennedy & Roberts, 2006).

The low average dispersal distance of the larvae together with the necessary presence of suitable settling substrate in the form of oyster shells implies that natural recovery of oyster beds will be slow if the natural substrate is lost (Eno et al., 2013). Combined with its vulnerability to bottom disturbance (see below), this makes flat oyster beds one of the most vulnerable habitats in the North Sea area (Eno et al., 2013).

Oysters are key species due to their important contribution to overall ecosystem functioning. They can form dense beds with a three dimensional structure, which consists of living oysters, oyster shells and associated species. The latter include sessile or epibenthic species (e.g., corals, ascidians) as well as mobile species (fish, crabs, lobsters). Fish may also find spawning grounds in oyster beds. All in all, Korringa (1951) counted about 250 species living in association with or on the oyster beds. Hence, restoration would provide opportunities for ecosystem services such as commercial exploitation of fish and mobile invertebrates, as well as flat oysters themselves; provided that exploitation methods are developed that leave the flat oyster beds intact.

Through filtration of particles from the water column, biodeposition and subsequent mineralization of faeces and pseudofaeces, oysters also enhance pelagic-benthic ecosystem coupling, which may stimulate phytoplankton turnover, resulting in an overall increase of primary production (Dame & Prins, 1997). They stabilize the sediment and enrich it by providing substrate for other species (Dame et al 1992; Tyler-Walters 2001).

As a consequence, the loss of oyster beds leads to a less productive and less diverse ecosystem and loss of ecosystem services. In the Wadden Sea, the disappearance of the oyster beds resulted in a less diverse and productive mudflat ecosystem (Reise & Beusekom 2008). Notably, Möbius (1877) first introduced the community (or biocenoese) concept in ecology, based on his studies of flat oyster beds in the German Wadden Sea.

2.2 History of exploitation and disappearance

The European flat oyster *Ostrea edulis* L. has its original habitat along the European coast from Norway to Morocco, across the Mediterranean and the Black Sea. It has been introduced to the USA, Canada and South Africa (Yonge 1960). The flat oyster is native to Europe and has been intensively traded since ancient times because of their culinary appreciation. In the days of Agrippa (63 BC -12 BC), English oysters were brought to Rome. They were harvested at the coast of Kent and were known to the Romans as 'Rutupians' (Horst 1883). The Romans highly appreciated the European oyster. Through time, this appreciation drove the harvesting that led to the disappearance of natural *O. edulis* beds. Stocks disappeared from certain regions of France (Heral 1989), Spain (Figueras 1970), Britain (Laing et al. 2005), the North Sea regions and the Netherlands (Berghahn & Ruth 2005). From the onset of the 18th century stocks were declining nearly everywhere. A few centuries ago the oyster reefs were a substantial part of the ecosystems all along the European and Mediterranean coasts. Now, wild European oyster reefs are barely present and may therefore be considered as one of the most endangered (marine) habitats in Europe. This has been acknowledged in the program "shellfish reefs at risk" of TNC (Beck et al., 2011). For Europe, the review of the status of the flat oyster certainly showed a dramatic overall decline of the populations (Airoldi & Beck, 2007; OSPAR, 2009).

The decline or disappearance is primarily attributed to overexploitation, but other factors such as diseases and abiotic changes have also played a role (Horst 1883; Korringa 1952; Yonge 1960; van Ginkel, 1996; Houziaux et al., 2008). For the North Sea, the maps in Olsen provide an important reference (1883 Fig 2.1.1). One map (Fig 2.1.1.a) gives the composition of the sea floor and shows a huge area with oyster shells between the Dogger Bank, Klaverbank, Friese Front and Helgoland, nowadays known as the Central Oyster Grounds. Another map (Fig 2.1.1.b) shows the distribution of living flat oysters, which also includes coastal areas in Denmark, Germany, the Netherlands, Belgium and Great Britain.

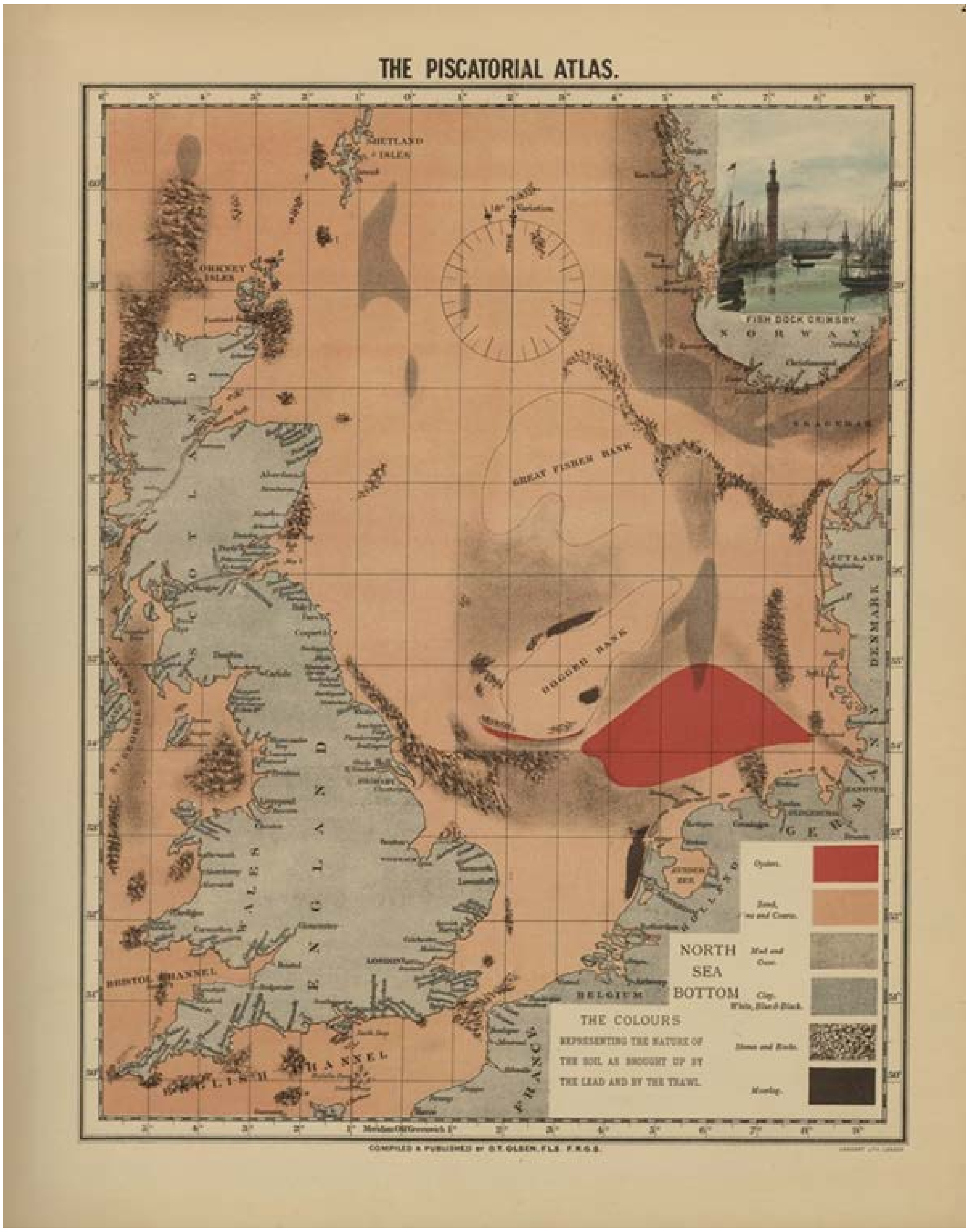


Fig 2.1.1a Sediment characteristics of the North Sea and adjacent areas, according to the Piscatorial Atlas of Olsen (1883).

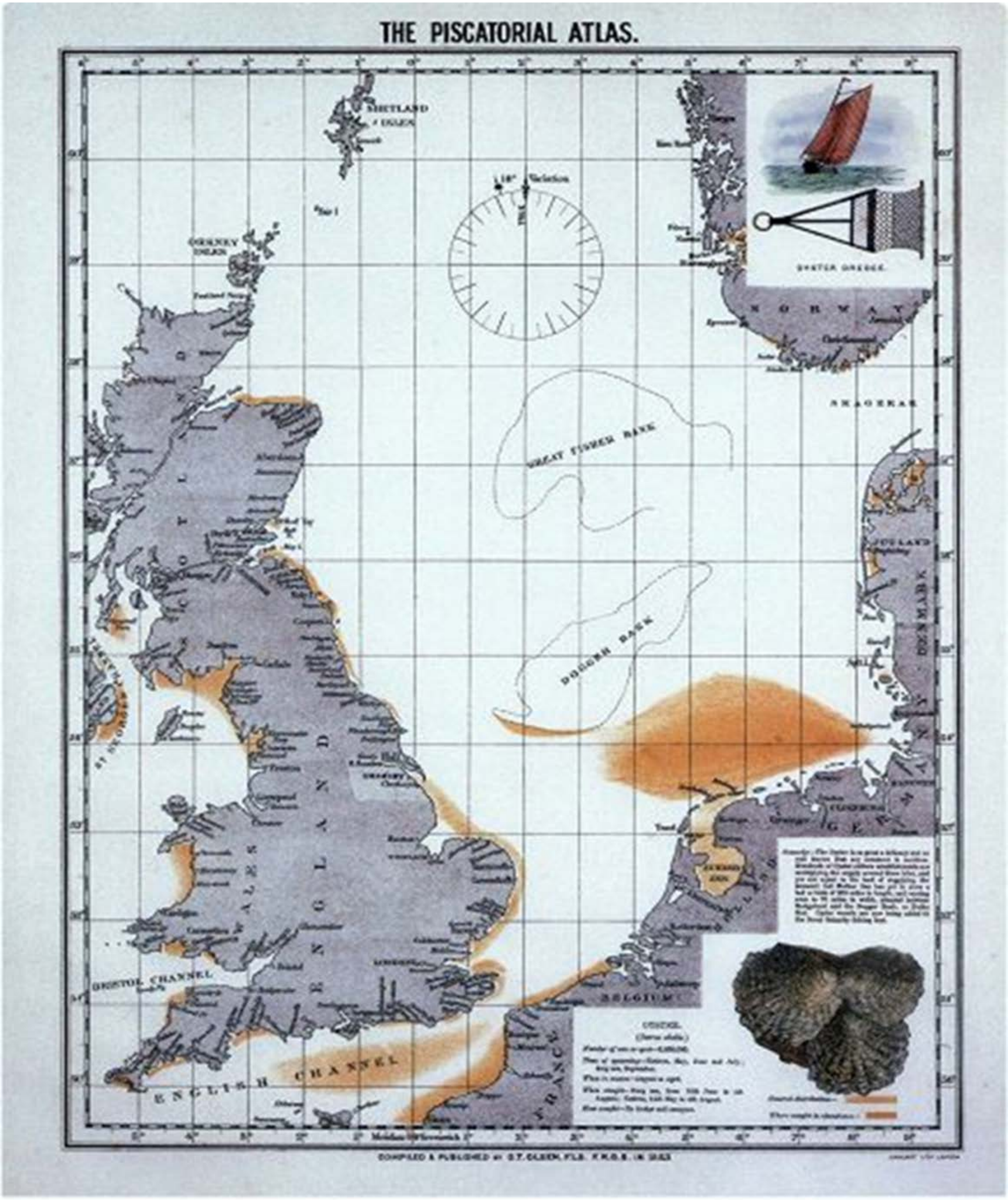


Fig 2.1.1b Occurrence of flat oyster beds in the North Sea and adjacent areas, according to the Piscatorial Atlas of Olsen (1883).

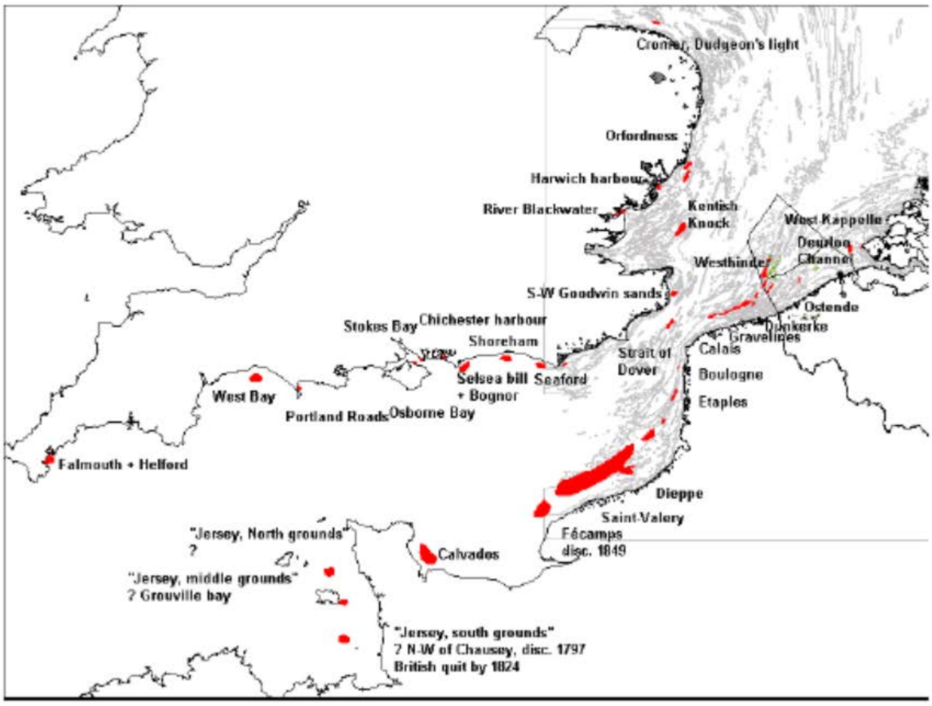


Fig 2.1.2 Preliminary map of the wild "deep-sea" oyster beds visited by M. H. Polley, oysterman from Brightlingsea (UK), between the 1830s and 1876 (Anonymous, 1876).

Prior to the Olsen maps, oyster beds have been documented in the period 1830 – 1876 in the southern part of the North Sea and the English Channel: Fig 2.1.2 from Houziaux et al. (2008). It shows oyster beds along the coast; notably in the mouth of the Western Scheldt (Vlakte van de Raan) an oyster bed was detected.

In addition, an article in a newspaper of 1856 says that fishermen had landed oysters in Scheveningen, on the coast near The Hague; apparently oyster beds have also existed along the Dutch coast.

Quote: "In den laatsten tijd heeft men ook voor Scheveningen een oesterbank ontdekt. Door de visschers worden aldaar van tijd tot tijd oesters aangebracht; maar dewijl zij uit de diepte opgevist worden, zijn zij te zout van smaak." (Dagblad van Zuid-Holland en s Gravenhage, 29-2-1856).

In Berghahn & Ruth (2005) a map with oyster fishery areas is presented, which is based on Lübbert, 1906: Fig 2.1.3. North Sea oyster areas have also been document on a fishery map from 1915, as presented in Gercken & Schmidt (2014) for the German North Sea (Fig 2.1.4). The latter map shows a more contracted and fragmented range compared to the earlier Olsen maps (1883), illustrating the rapid decline in bed surface area occurring around the turn of the century.

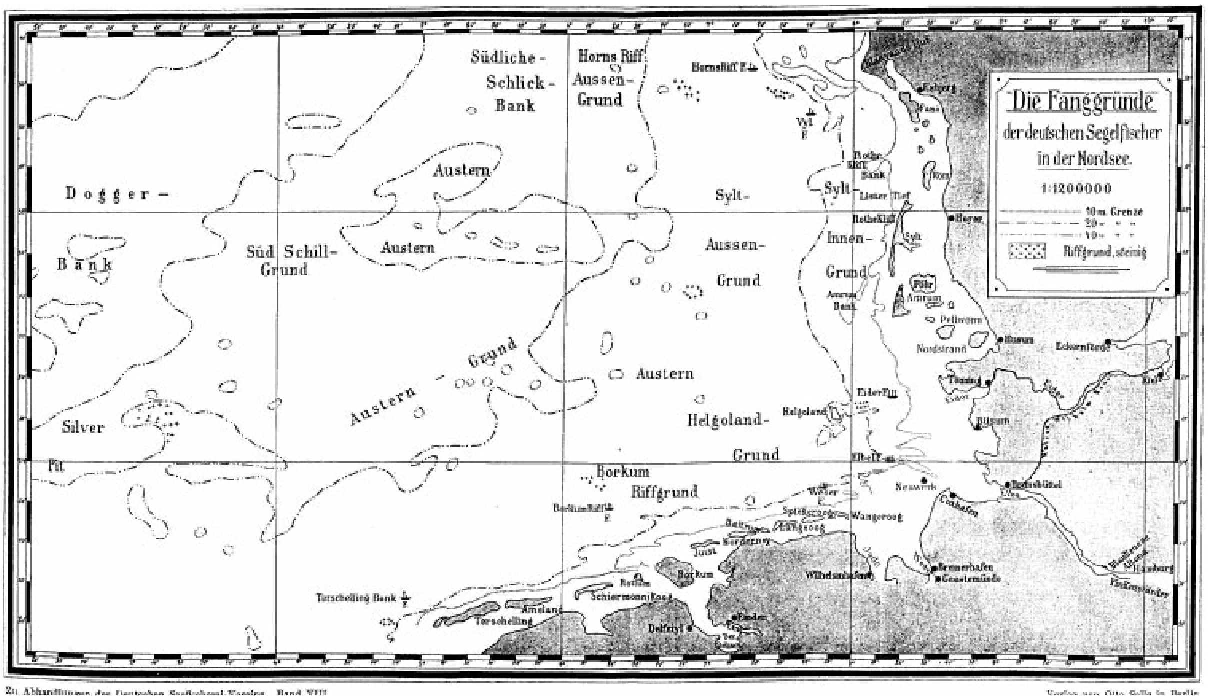


Fig 2.1.3 Fishing grounds of German fishermen with sailing vessels in the North Sea; various Austern (oyster) areas are indicated (after Lübbert (1906)).

Berghahn & Ruth (2005) made a conservative estimate of the historic North Sea stock by the end of the 19th century of 2,650 * 10^6 specimen. This corresponded with a density of 1 oyster per 8 m^2, in an area of 21,202 km^2. Annual yields in the period around 1889 were estimated as 11 – 18 * 10^6 specimens.

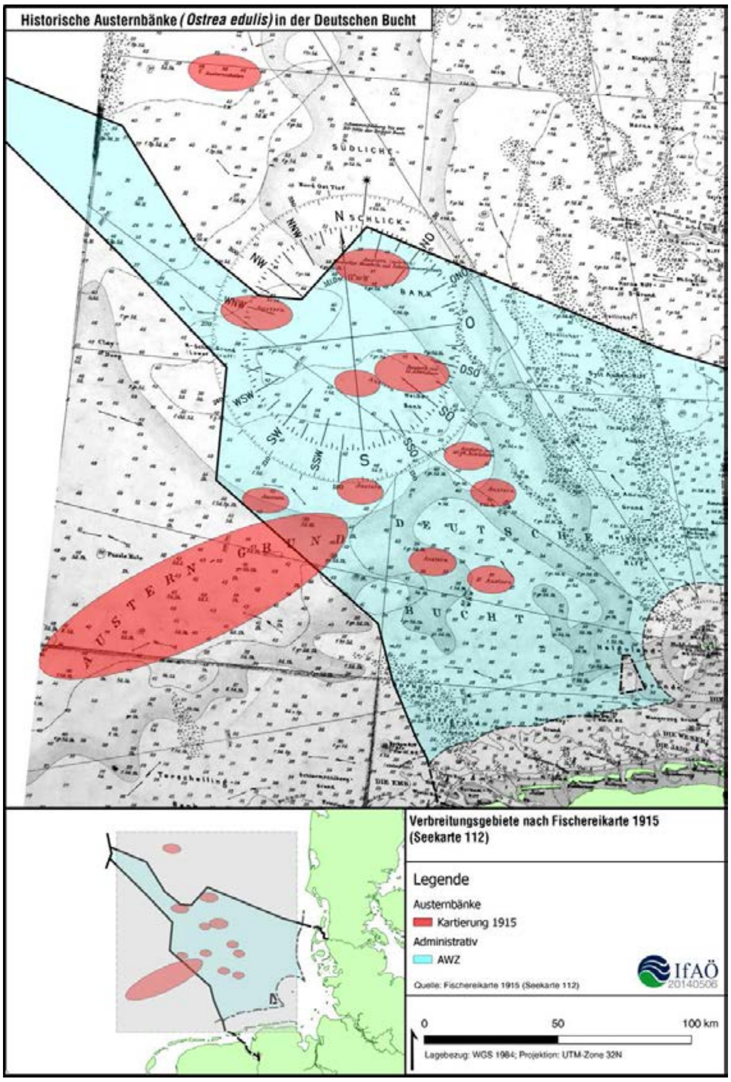


Fig 2.1.4. Fishery map of flat oyster beds, including the oyster grounds and the German section of the North Sea (from Gercken & Schmidt, 2014)

Overexploitation

The maps in Fig 2.1.1 – 2.1.4 show extensive oyster beds in North Sea areas. It is clear that these beds do not exist anymore (see also Chapter 3). Data on oyster landings show an overall decrease during the course of the 19th century: fig 2.1.5 (Neudecker, 1990; van Ginkel, 1996). This is ascribed to the introduction of steam driven oyster dredgers (van Ginkel, 1996; Berghahn & Ruth, 2005).

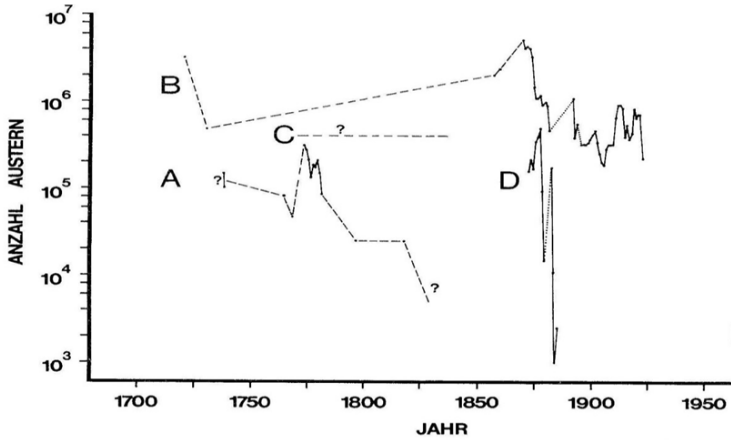


Fig 2.1.5. Reconstruction of flat oyster harvest (log scale) from the German Wadden Sea (A and B), the oyster grounds (C) and near Helgoland (D), after Neudecker, 1990, in Gercken and Schmidt, 2014.

The apparent decrease in catch per unit effort indicates stock depletion as an effect of fisheries. Houziaux et al. (2008) present a reconstruction of the oyster stocks on the Flemish banks, which probably also apply for other areas: Fig 2.1.6. It shows that oyster dredging and the subsequent development of bottom trawling have decimated the flat oyster stocks and also prevented the recovery of the stocks. The timing of the rapid depletion of the relative small area of oyster beds near Helgoland, Germany (Fig 2.1.5) is very similar to the disappearance of the flat oyster beds from the Hinderbanks of Belgium (Fig 2.1.6).

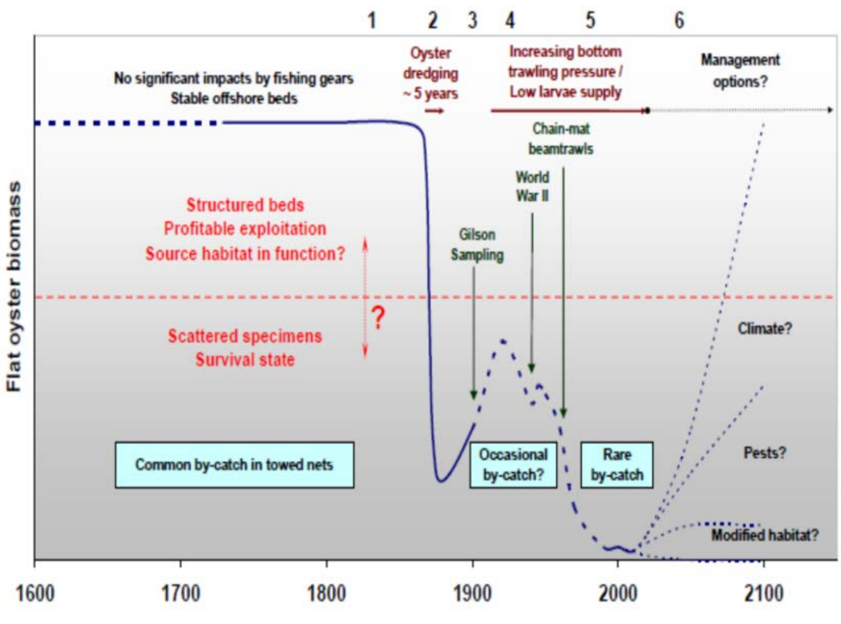


Fig 2.1.6. Reconstruction of flat oyster stocks on the Flemish beds over time, related to fishery activities (Houziaux et al., 2008).

Overfishing includes the removal of habitat on which the oyster larvae might settle; according to Korringa (1951), the clean growth rim of the adult shell is an important settlement habitat for spat. Consequently, when the larger oysters were removed, the younger oysters settled on the remaining shells, which were also removed (Korringa 1952). The removal of settling substrate (or natural spat collectors), the removal of fertile oysters and the variability in recruitment, together with the low growth rate of oysters and limited larval dispersal, makes oyster beds very sensitive to exploitation (cf., Eno et al. 2013). Furthermore, oyster reefs need a certain minimum population to maintain themselves; when this population becomes too low the oyster reefs will completely disappear (Berghahn & Ruth 2005; Korringa 1952).

Diseases

Worldwide, the most serious diseases that have struck *O. edulis* in recent times have been caused by the protozoa *Marteilia refringens* (Berthe et al., 2004) and *Bonamia ostrea* (Engelsma et al. 2014). *Marteilia refringens* caused mortalities of up to 90% in the 1970s in France. At the end of the 1970s, *Bonamia ostrea* appeared and withheld the recovery of the oyster industry of France. After France, the disease appeared in the Netherlands, Spain, Denmark and parts of Ireland. Since the 1970s large mortalities kept occurring throughout Europe, although there are some parts of Europe that remain *Bonamia* free (Approved zones). Hence, these diseases were at a later date than the strong decline of oyster beds in the late 19th century.

To overcome the problem of disease, research has focused on breeding *Bonamia* tolerant oyster strains as the only short-term remedy. A recent EU project (http://oysterecover.cetmar.org/) generated a list of candidate genes that can be important for disease selection. It is believed that the elimination of the parasite, an invasive species of alien origin, is not a realistic option (Culloty & Mulcahy 2001). This research produced promising data but the outcomes can also be discussed with reference to inbreeding problems (Launey et al. 2001) and very large variations under different environmental conditions (Culloty et al. 2004; Naciri-Graven et al. 1999).

Other factors

Environmental changes, severe winters and water pollution have also contributed to the decline of oyster populations and the absence of their recovery. One example is the decline in the *O. edulis* stock from 120 million to 4 million oysters in the Eastern Scheldt estuary in the Netherlands after the severe winter of 1962/1963 (Drinkwaard 1998). Such severe winters did occur during the sharp decline in North Sea oyster beds in the late 19th century and may even have been the cause of a 'regime shift' in the North Sea ecosystem around that time. However, the main body of oyster beds (at the Central Oyster Grounds) were located in the deep North Sea, where temperature decline during cold winters is less dramatic. Hence, incidental die-offs of flat oysters during cold winters have mainly been reported in coastal populations (Gercken & Schmidt, 2014).

The use of TBT compounds in anti-fouling paints on commercial ships and recreational yachts caused declines in several species of molluscs in the North Sea area. Since the ban of TBT-compounds and subsequent decline in the TBT-presence in marine systems, several mollusc species have shown signs of recovery. However, TBT was introduced long after the flat oyster decline of the late 19th century.

Long-term oscillations may also play a role in the dynamics of oyster populations. Berghahn & Ruth (2005) argue that periodic influxes of large densities of oyster larvae from the channel area may have been required for maintaining the North Sea populations. Alheit et al. (2014) point out that regime shifts have occurred in the 1990s in a.o. the North Sea. Drinkwater (1996) argues that also in the 1920s a regime shift may have taken place in the North Sea region. There are indications for a major regime shift around 1890 when fish stocks and fisheries collapsed around the North Sea (pers comm H. Lindeboom).

Nevertheless, in most papers oyster fishery and subsequent development of bottom trawling are considered to be the most important factors contributing to the decline and cause of the permanent loss of oyster beds in the southern North Sea. This was recently underlined by Gercken & Schmidt (2014), who carried out an extensive analysis of the causes of decline of the flat oyster beds in the German Wadden Sea and North Sea area and came to the same conclusion as presented above.

2.3 Conclusions

Extensive flat oyster beds have occurred in the past in the southern North Sea, not only on the Central Oyster Grounds but also in the German and Dutch Wadden Sea, along the Belgian coast, in the English Channel and along the UK coast. It is these oyster beds that do not exist anymore. Although also other factors are important for oyster dynamics, the decline of the flat oysters in the North Sea area is predominantly due to direct fishing and subsequent habitat destruction by bottom trawling.
As a consequence, restoration of the oyster stocks and beds might be achieved in such a way that the oyster beds themselves act as a suitable habitat for further development of a sustainable oyster community, provided that the reintroduction area is free from bottom disturbance (i.e. trawling).

3 Current flat oyster distribution in coastal and offshore waters of The Netherlands

3.1 Recent reports and field surveys

3.1.1 Introduction

Information about the current distribution of flat oysters is important for several reasons. Observations of live oysters would suggest that water quality meets requirements for reproduction and survival. If areas with substantial numbers of oysters were found, these populations could function as a source and/or target population for re-stocking. Furthermore, these occurrences can give up to date information on the critical needs of the species, such as habitat preference, local adaptations, food requirements, predators and diseases.
The focal area of this feasibility study is the Dutch part of the North Sea (*Nederlands Continentaal Plat*, NCP) and the adjacent coastal zone. Additional information will be given on the presence of flat oysters in the Delta area and Wadden Sea. Oysters prefer to settle on various types of hard substrate including oyster shells and by doing so they can form biogenic reefs in otherwise soft sediment substrates. Oyster larvae can also settle on natural or artificial hard substrates. For this reason we look for records in surveys of both soft sediment and hard substrates.
Given the apparent scarcity of flat oysters in the Dutch part of the North Sea, systematic surveys are important to confirm the presence or absence of flat oysters in most of the area. These surveys of soft sediments started in the 1960s whilst hard substrate surveys followed much later in the 1980s.

Habitats
Soft sediments dominate the southern North Sea, which range from soft mud (Central Oyster Grounds) to fine and coarse sand (Doggersbank, Friese Front, Coastal Zone). Gravel and small rocks are the only naturally occurring hard substrates (Klaverbank, Borkumse Stenen in German part of the North Sea, figure 3.1.1.1). Depth range is shown in Fig 3.1.1.2.

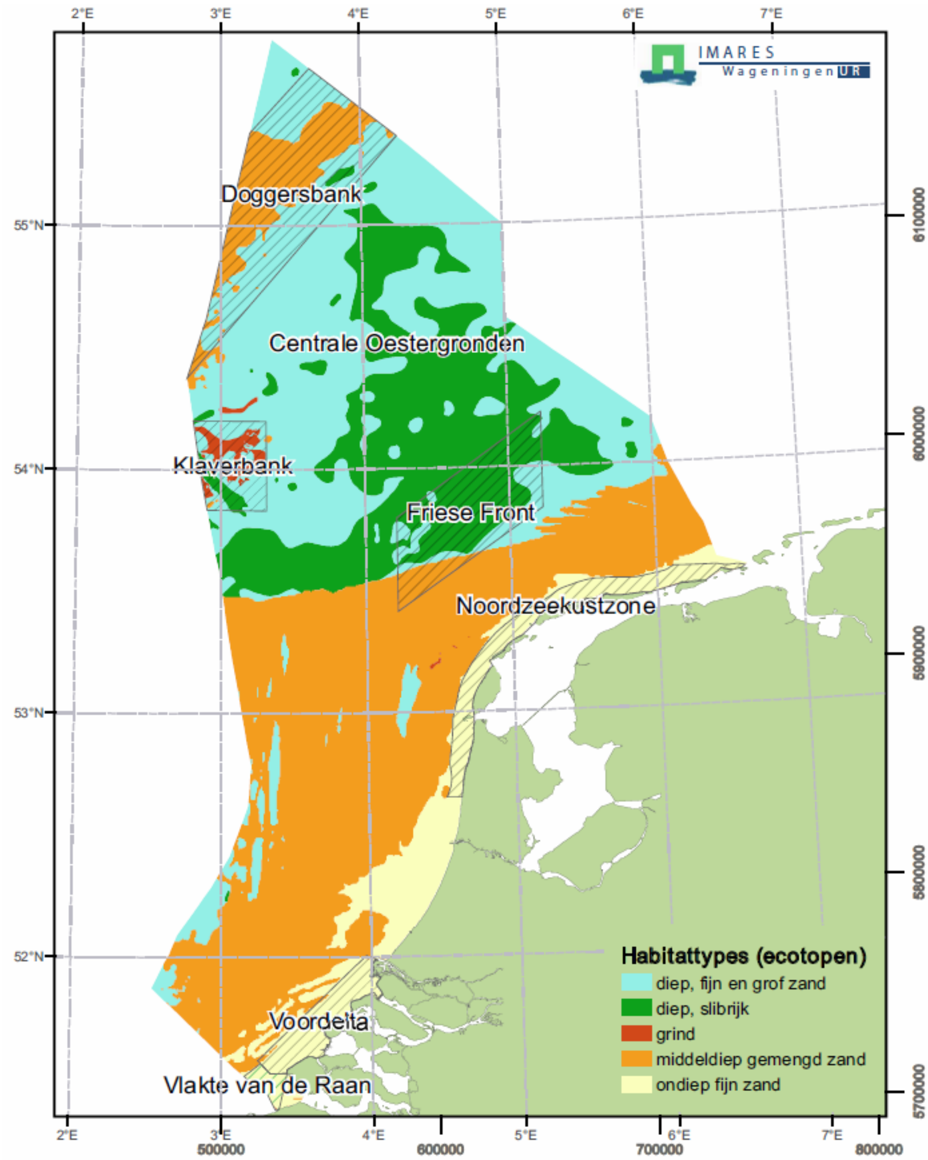


Figure 3.1.1.1. Habitat types in the NCP: deep, fine and course sand (blue); deep, fine silt (thick mud layer, green); gravel with stones (red), middle deep, mixed sand (orange); shallow, fine sand (yellow). Natura 2000 –areas are indicated with shaded grey (Lindeboom, 2008).

Artificial hard substrates consist of shipwrecks and energy platforms, and are increasing both in surface area and geographical spread. They have changed from incidental (shipwrecks) to large-scale constructions from 20 km from the shore (wind farms) to over 100 km offshore (mining platforms). This has created an extensive network of artificial hard substrate in the NCP down to 35 m depth. Shipwrecks have been accumulating over the centuries and, in particular since the construction of steel ships, are degrading only slowly. Approximately 2000 objects have been identified in the NCP of which 100 – 200 are thought to be real shipwrecks (Didderen et al., 2013).

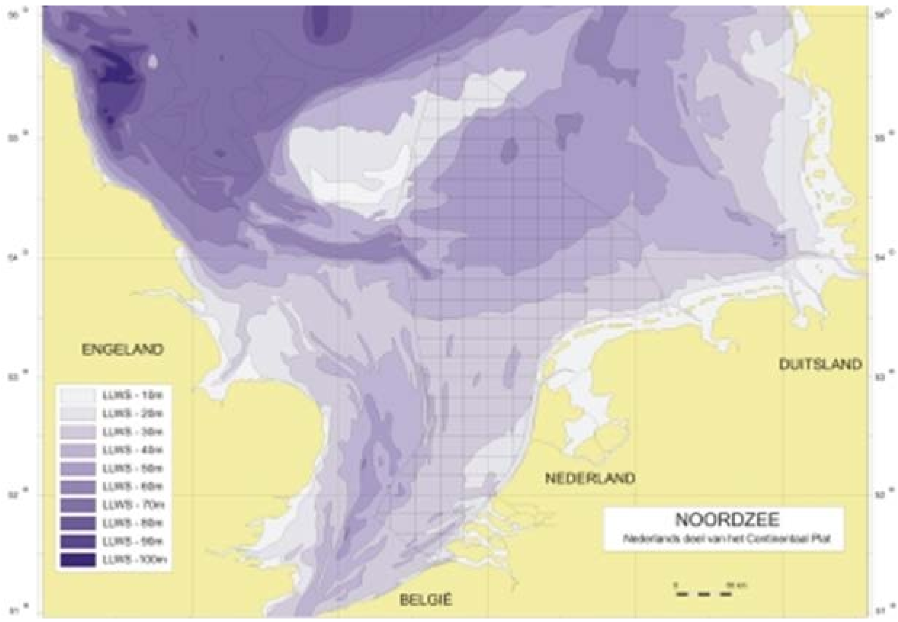


Figure 3.1.1.2. Depth zones in the NCP of the North Sea. (RWS Noordzee atlas).

3.1.2 Results of monitoring and surveys

North Sea

Soft sediments
Surveys of the soft sediment in the NCP have been reviewed in de Bruyn et al. (2013). Regular surveys started in the 1960s and Van Veen Grabs were used for sampling (Cadée, 1984). In 1986 the first systematic survey was carried out and other sampling methods were used including box corer and bottom dredge (De Wilde & Duineveld, 1988). Oyster banks, like other biogenic reefs, have a clustered distribution and are better sampled with a bottom dredge than with a corer. The BIOMON and MWTL programs, started in 1990 and continued annually up to 2011, sampled the soft sediment macrozoobenthos community in North Sea and coastal zone of the North Sea with box corers (e.g., Holtmann et al, 1998). No flat oysters were found. IMARES conducts fish and shellfish surveys, which includes the WOT shellfish survey that has been carried out annually since 1991 in the Coastal Zone. A trawled dredge ('bodemschaaf') is used, and ~850 locations are sampled each year. This sampling gear is constructed for the collection of shallow living buried bivalves and is not particularly suited for oyster sampling. However, a relatively large area is sampled (typically about 10-15 square meters per sample). The only observations of oysters in the Coastal Zone are in the 'Voordelta', close to the Schelde estuaries and these are Pacific oysters rather than flat oysters (see fig. 3.1.2.1 and 3.1.2.2.). In the Wadden Sea and Oosterschelde, different sampling gears are used, including an 'Oystergrab' in the last few years, which is specifically suited for estimating oyster densities. Pacific oysters are very regularly encountered there. Only two observations of flat oysters have been made: one in the Wadden Sea and one in the Voordelta, just outside Lake Grevelingen. Fish surveys such as the Demersal Fish Survey (DFS) are carried out since 1965, using a beam trawl. Occasionally a flat oyster is found, however, all but one of these are outside the NCP area. One flat oyster was observed to the west of Texel in 1981 during the Sole Net Survey (SNS) survey.

Figure 3.1.2.2 shows that the natural habitat of Pacific oysters consists of shallow waters, i.e. the (shallow parts of) Wadden Sea and Delta area. Even though there are large populations in these areas, occurrence in the deeper North Sea is very rare indeed. This may demonstrate the differences in habitat requirements of these species, from which it can be inferred that Pacific oysters will not interfere with restoration attempts for flat oysters. This is underlined by the fact that both species co-exist in Lake Grevelingen.

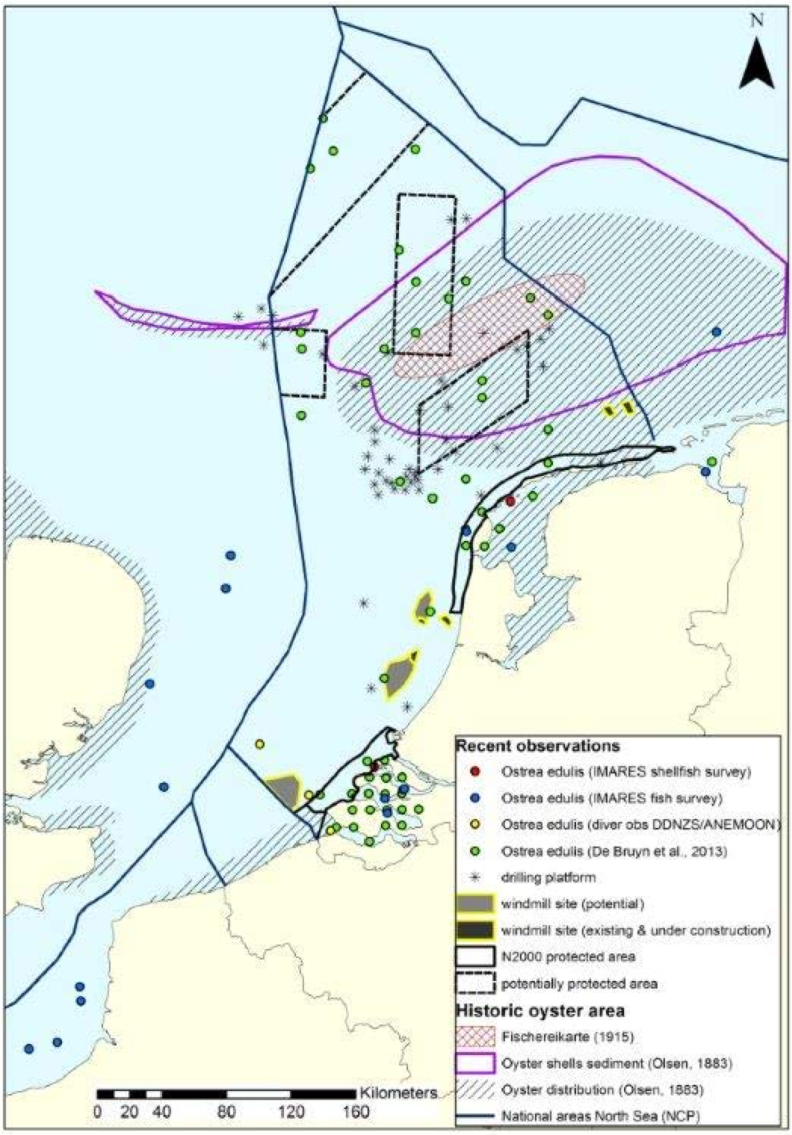


Figure 3.1.2.1. Observations of flat oysters in the North Sea, are based on IMARES fish (1965-2013) and shellfish (1991-2013) survey data, ANEMOON 'Schelpdierenatlas' (1960-2012, De Bruyn et al., 2013) and by divers from 'Duik de Noordzee Schoon'/ ANEMOON. The Fischereikarte 1915 (red hatched area, Gercken & Schmidt, 2014) outlines the distribution in 1915, when the oyster beds were already severely degraded and the range contracted. The Piscatorial Atlas outlines the oyster distribution in 1883 (Olsen, 1883).

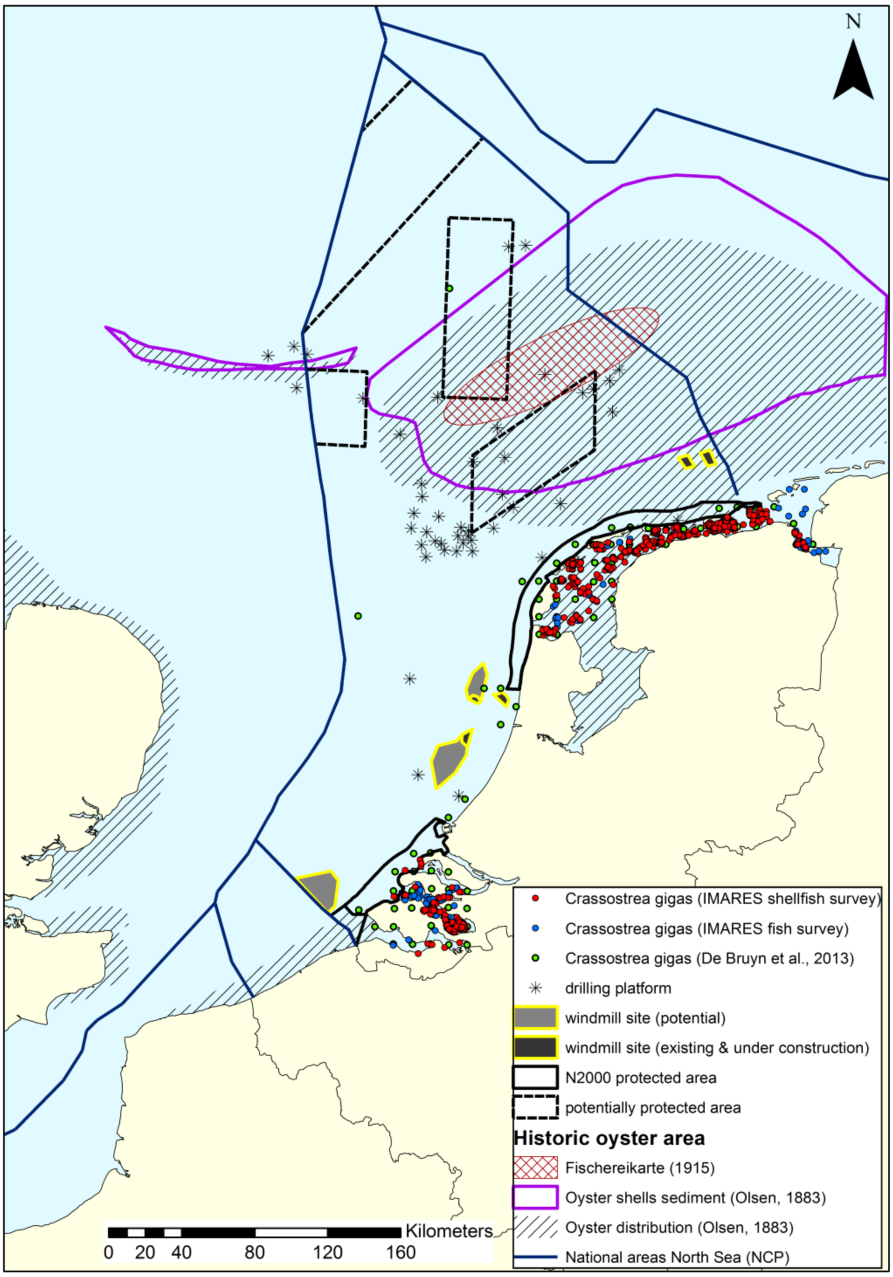


Figure 3.1.2.2. Observations of Pacific oysters (Crassostrea gigas) in the North Sea, based on IMARES fish (1965-2013) and shellfish (1991-2013) survey data, ANEMOON 'Schelpdierenatlas' (1960-2012, De Bruyn et al., 2013). See Fig 3.1.3 for full legend.

Hard substrates

Occasional surveys of artificial hard substrates, including shipwrecks, mining platforms, artificial reefs and wind turbines, have been carried out in addition to the soft-sediment monitoring programs (reviewed by de Bruyn et al., 2013). Naturally occurring hard substrates are relatively rare within the NCP and are mainly found in the Klaverbank (van Moorsel, 1993). The surveys have been done by visual inspection by divers, who take pictures and video footage and collect samples by hand (e.g., Bouma & Lengkeek, 2012).

After 1985, only some tens of individual flat oysters have been found throughout the NCP (figure 3.1.2.1) and roughly half of them were found within the historical range indicated by the North Sea bottom chart of Olsen (1883).

Shipwrecks

Approximately 22 shipwrecks were surveyed in the period 1986 – 1990 of which half were located approximately 15 km offshore (van Moorsel et al., 1991). Flat oysters were found only once on one of the seven shipwrecks that were surveyed annually in the period 1986 – 1990 (van Moorsel & Waardenburg, 1991). Recently in 2013, ten shipwrecks were surveyed in the Dutch part of the North Sea and no flat oysters were found (Lengkeek et al., 2014). Zintzen et al. (2008) surveyed ten shipwrecks along the Belgian coast at different distances from the shore, but no flat oysters were found. In August 2014, circa 20 flat oyster shells were found on the shipwreck of the Delft (1790) with intact ligaments. Ligaments degrade within 1.5 – 2 years (Merrill & Posgay 1964) and this suggests that these oysters died only a few years ago. In September 2014, the North Sea Expedition 2014 of Stichting Duik de Noordzee Schoon visited nearly twenty locations, including ten different shipwrecks, in the North Sea coastal zone, Friese Front, Doggersbank and Centrale Oestergronden, but no living flat oysters were found.

Mining platforms

Substantial numbers of platforms for gas and oil exploration and production have been constructed in the North Sea in the last decades, starting in 1974. Most of these are situated at relatively large distances offshore. Several platforms have been surveyed for hard substrate communities in the Dutch part of the North Sea, but with negative results. Similar surveys of platforms in the British part of the North Sea also had negative results for flat oysters. Jager (2013) reports the occurrence of flat oysters on platforms in the UK, but this refers to platforms in the English Channel and Keltic Sea where natural oyster beds still occur.

Artificial reefs

An artificial reef was constructed relatively close to the shore close to Noordwijk in 1992. This reef was monitored annually for a period of several years yet no flat oysters were observed (Leewis et al., 1997).

Wind farms

The construction of wind turbines in wind farms in the southern North Sea is a very recent development that started in Denmark (Horns Rev in 2002), followed by OWEZ (2006) and Princess Amalia (2008) in the Netherlands, Thorntonbank (2008) and Bligh Bank (2009) in Belgium and Alpha Ventus (2009) in Germany. Suitable habitats for flat oysters are the lower parts of the monopiles and the rocks of the scour protection layer (e.g., Bouma & Lengkeek, 2012). The recently constructed wind farms are mainly situated within 10 to 25 km offshore. Individual flat oysters were found on monopiles or the scour protection layer in three wind farms (Horns Rev, Denmark, and OWEZ and Princess Amalia wind farms, the Netherlands) (Table 3.1.2.1). These three wind farms are the earliest constructed. These results show that flat oysters are able to settle on near-shore artificial hard substrates. The source population of these new settlements is unknown.

Table 3.1.2.1. Overview of monitoring programs in wind farms which include surveys of hard substrate communities.

Location	Country	Flat oyster	Built	Survey	Depth	Source
Horns Rev	Denmark	yes	2002	2003-2004	13.5	Leonhard & Pedersen, 2006
OWEZ	Netherlands	yes (2011)	2006	2008, 2011	15	Bouma & Lengkeek, 2012
Princess Amalia	Netherlands	yes	2008	2011	?	Vanagt et al., 2013
Thorntonbank	Belgium	no	2008	2005-2012	18 – 24	Kerckhof et al., 2012
Bligh bank	Belgium	no	2009	2005-2012	15-40	Kerckhof et al., 2012
Alpha Ventus	Germany	?	2009	2007-2014	50	?

Delta area

The Grevelingen estuary was closed off from the sea in 1971, which resulted in a stagnant saltwater lake. Flat oysters were already found shortly afterwards (Waardenburg, 1973). The development of this population and the hard substrate community was monitored in subsequent years (Waardenburg et al., 1990; de Kluijver, 1995). After its discovery a regulated oyster culture developed, which continues to this day. Mussel shells are used for oyster spat collection. Recently, a flat oyster reef with a three-dimensional structure was found in a non-fished area in Lake Grevelingen (Smaal pers comm, 2014).

Hard substrate communities, including macrozoobenthos, of Grevelingen, Oosterschelde and Westerschelde were monitored in the period 1989 – 1998 as part of the BIOMON (MWTL) program (van Moorsel & Waardenburg, 1999). Flat oysters were found most commonly in the Grevelingen, with small numbers throughout the Oosterschelde and only in the saline, western part of the Westerschelde estuary (Fig 3.1.2.3).

The population of flat oysters in the Delta area was generally in decline since the early 1960s (figures 3.1.2.4 & 3.1.2.5). The very severe winter of 1962/1963 decimated the flat oyster population on the culture plots in the Oosterschelde. To restore the culture, oyster farmers imported flat oysters as well as Pacific oysters from different areas. After the introduction of Bonamia in the Oosterschelde in 1979 and in Lake Grevelingen in 1988, flat oyster production further declined (figure 3.1.2.5) and many oyster farmers changed to Pacific oysters. Oyster production now mainly consists of Pacific oysters. However, as figure 3.1.2.5 also shows, the population in the Delta area has stabilized and may even show signs of modest expansion, notwithstanding annual harvests of about 0.5 million individuals per year. This is in agreement with the observation that the Grevelingen population is coping with the Bonamia disease (see par. 3.2).

In August 2014, a small flat oyster bed was found in the northern branch of the Oosterschelde and in the eastern part flat oysters seem to expand since 2012 (pers. com. A. Cornelisse). In August 2014 a small number of flat oysters was found inshore at the low-low tidal level on a dyke in the Voordelta (W. Lengkeek, pers. comm.).

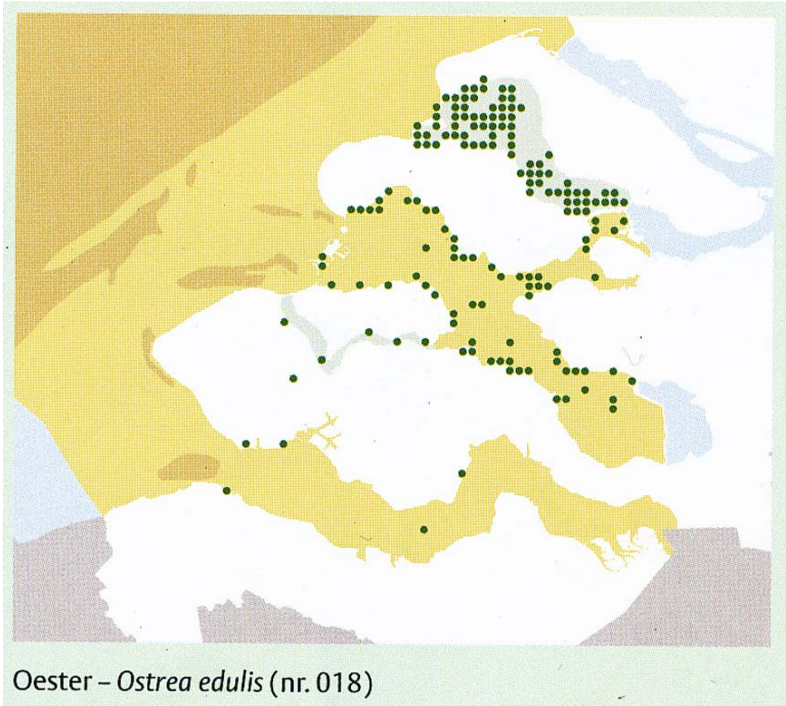


Figure 3.1.2.3. Distribution of flat oyster in the Delta area: common in the salt water lake Grevelingen (grey), scarce in the half open sea arm Oosterschelde (yellow, center), Lake Veere (blue), also found in the "Kanaal door Walcheren" (white); rare in the open estuary Westerschelde; (yellow, lower part, source: Schelpdieratlas, de Bruyn et al., 2013).

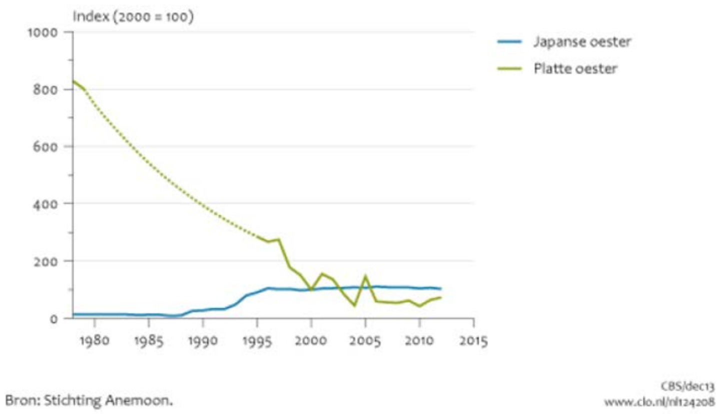


Figure 3.1.2.4. Reconstructed population trend of flat oyster with yr 2000 as reference point (green line) and Pacific Oyster (blue line) on hard substrates in the Delta area (source: Stichting Anemoon).

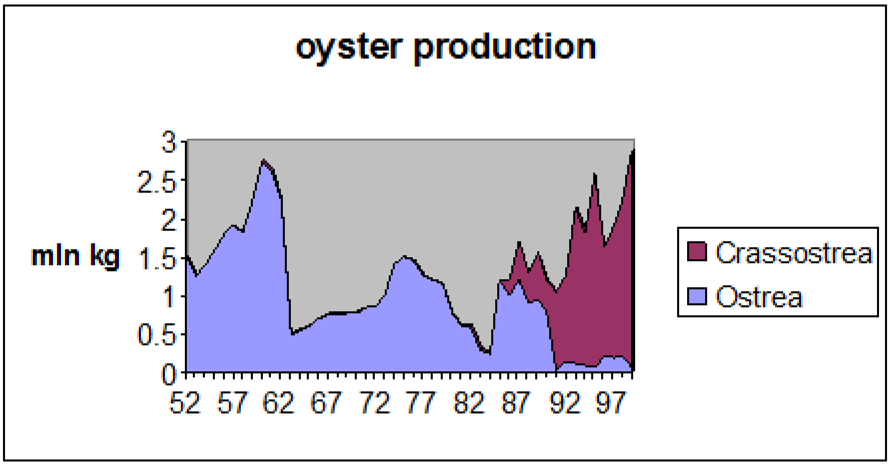


Figure 3.1.2.5. Production of flat oysters (blue) and Pacific oysters (red) in the Delta area (source: Productschap Vis).

Wadden Sea
After 1985, very few flat oysters have been found in the Wadden Sea (one near Texel, de Bruyn et al., 2013). No flat oysters were sampled in the monitoring program of soft sediment (MWTL) and several surveys of hard substrates (Gittenberger et al., 2009) in the Wadden Sea. Recently, several individuals have been found near Texel (K. Phillipart, pers. comm 2014; L. Westbroek, pers. comm. 2014.) and one on mussel culture plots (A. Dijkstra, pers. comm. 2014).

3.1.3 Conclusions

Flat oysters still occur within the former distribution range in the North Sea, which suggests that growth, reproduction and dispersal in the North Sea area is still possible. However, they are rare and do not exist anymore in the form of beds and have been found almost exclusively on artificial hard substrates (shipwrecks, wind farms). The absence of flat oyster beds in most of the North Sea and Wadden Sea is confirmed by surveys of soft sediments and hard substrates with considerable geographical spread within the NCP. This confirms the conclusion by OSPAR (2008) that flat oyster beds as a habitat are functionally extinct in the NCP.
Extensive oyster beds still occur in the Delta area in the Grevelingen, a former estuary where they are exploited, and only locally in the Oosterschelde. Flat oysters are rare in the Westerschelde (western part), Voordelta (artificial hard substrate) and Wadden Sea (near Texel). In most of these areas bottom trawling is not allowed or impossible. The flat oyster population in the Delta area is stable, and shows recent signs of modest expansion.
By comparing the distribution patterns of flat oysters and Pacific oysters, it may be concluded that these species have different habitat requirements. Therefore, it is not expected that Pacific oysters will interfere with flat oyster restoration attempts in the North Sea or deeper parts of the Delta estuaries. In addition, it is acknowledged that both species co-exist in Lake Grevelingen, without apparent adverse effects; there is concerted culture of both species in this area.

3.2 Bonamia prevalence and distribution

Bonamia ostreae is an intracellular parasite of oysters with as natural host species the European flat oyster. The parasite was first observed in Europe in 1979 (Pichot et al. 1980). With transfers of flat oysters to other culture areas in Europe the parasite quickly spread to all major flat oyster culture areas within Europe. The presence or absence of *Bonamia ostreae* is mainly known from the areas with commercial oyster fisheries or farms. From wild populations the information is mostly restricted to the populations in close proximity with farmed or fished stocks, especially for the North Sea the information is very limited.
In the countries around the North Sea *B. ostreae* is currently present in oyster stocks in England and the Netherlands (Engelsma et al. 2014). Furthermore, the parasite has been incidentally detected in flat oysters from Norway (WAHID-Interface 2009) and Belgium (WAHID-Interface 2008).

The Netherlands
In the Netherlands, the parasite was first observed in oysters from the Yerseke Bank area in the Oosterschelde in 1980 (Van Banning 1982), presumably introduced with a shipment of flat oysters originating from Brittany, France. Strict hygiene measures for shellfish farmers prevented outbreak of bonamiosis in Lake Grevelingen until 1988. In that year *B. ostreae* was recorded in Lake Grevelingen (Van Banning 1991) and the parasite quickly spread through the commercial oyster beds and wild oyster stocks with mortality of flat oysters up to 80% in some locations (Van Banning 1991). The parasite has established itself in both areas. The prevalence of *B. ostreae* in the flat oyster stocks of Lake Grevelingen ranges between 10% and 20% in spring (Engelsma et al. 2010). *Bonamia ostreae* can be observed in flat oysters throughout the year with a seasonal peak in prevalence in early spring. The decrease in prevalence is coinciding with the spawning of the flat oyster, especially in the larger specimens. This suggests that the conditional toll of spawning results in a relatively higher mortality rate in the infected oysters compared to non-infected oysters. In the Oosterschelde area the population of flat oysters has diminished. Occasionally flat oysters are found during the annual monitoring for shellfish diseases and *B. ostreae* still seems to be present in this area with the last positive case detected in 2005.
Despite the high prevalence of *B. ostreae* in flat oysters from Lake Grevelingen the population seems to cope with the parasite. In a study that compared the sensitivity to *B. ostreae* between flat oysters from different origins, the Lake Grevelingen population did not perform well in terms of prevalence and intensity of infection, but performed well in terms of overall survival (Culloty et al. 2004). In the recent EU project OYSTERECOVER (http://oysterecover.cetmar.org/) spat produced from parents originating from the Limfjord in Denmark, the Oosterschelde estuary and Lake Grevelingen were tested in Lake Grevelingen. Results showed that the best growth and survival for the spat were produced from the Grevelingen stock. Together with the current stable biomass of the flat oyster population in Lake Grevelingen these results indicate that since introduction of the parasite the flat oyster population has acquired a reduced susceptibility to *B. ostreae*. Natural resistance to *B. ostreae* is only acquired slowly by the oyster population, as the more susceptible (the older) oysters have already reproduced before infection develops (Engelsma et al. 2010)., Recent observations by oyster farmers show a revival of the flat oyster in the Oosterschelde area (pers. com. A. Cornelisse).

UK
Recently, an overview has been published on the spread of *Bonamia* in the UK by Laing et al. (2014). The first confirmed case of *B. ostreae* in the UK was in *O. edulis* from the river Fal, Cornwall in 1982. In subsequent years the parasite spread further, mainly along the south and southeast coast of England. A number of *Bonamia*-infected zones are recognized along the UK

coast. Two of them are bordering the English Channel: one containing the Fal and Helford estuaries and Plymouth harbour, the other containing the area between Chichester harbour and Portland harbour including the Solent. On the North Sea coast of southeast England, the *Bonamia*-infected area is ranging from Walton Black to the Thames estuary. The oyster industry is concentrating here in the Blackwater Estuary and river. Over the period 1993 to 2007, the prevalence of *B. ostreae* in this area was on average 22.2% at the cultivation sites and 9.7% in the wild fisheries (Laing et al. 2014).

Belgium

The detection of *B. ostrea*e in flat oysters in Belgium (Oostende) in 2008 was not linked to a disease outbreak but instead limited to detections of the parasite during routine surveys for disease control.

Norway

Similar to Belgium, *B. ostrea*e was detected in flat oysters from Norway (Langestrand) in 2009. Also here this was not linked to a disease outbreak.

Denmark

The Limfjord is the only area in Denmark with a remaining flat oyster population. The population has grown substantially over the last decades (Madsen et al. 2013). In the past *B. ostreae* has been observed in imported French oysters in 1980, after which these sites were fallowed till 2004. In a subsequent surveillance program the parasite was no longer observed (Madsen et al. 2013) and in 2004 the area gained approved EU status as being free from *Bonamia ostreae* and *Marteilia refringens*. Considering the absence of both pathogens in this area the Limfjord population would potentially be a suitable candidate as *Bonamia*-free source population for reintroduction. Furthermore, preliminary data on the genetic background of flat oyster populations in Europe suggest that oyster populations from the North Sea basin have a similar genetic background (unpublished data IFREMER, personal communication Sylvie Lapègue). This is confirmed by results of the recent EU project OYSTERECOVER (http://oysterecover.cetmar.org/) that indicate the existence of three sub-groups within the populations that were studied: (1) Galicia in Spain, (2) Brittany in France, south coast UK and west coast Ireland and (3) Grevelingen in the Netherlands and Limfjord in Denmark.

France

Disease outbreaks caused by two protozoan parasites have marginalised the commercial culture of flat oysters in France over the past decades. At the end of the 1960s *Marteilia refringens* caused large mortalities and a crash of the flat oyster stocks (Grizel et al. 1974). Subsequently, in 1979 the first outbreaks were observed in flat oysters in Brittany caused by *Bonamia ostreae* (Pichot et al. 1980), further diminishing the flat oyster stocks. The total production in France dropped from an annual 20,000 tonnes to 2,000 tonnes and remains low despite efforts to assist recovery (Buestel et al. 2009). A number of attempts have been made to improve resistance to *B. ostreae* by selective breeding, either by mass spawning (Naciri-Graven et al. 1998) or by selectively breeding oyster families. The results show enhanced survival of the progeny although inbreeding and population bottlenecks remain an issue (Launey et al. 2001).

3.3 Overview of oyster introductions, reintroductions and restorations

The introduction or reintroduction of flat oysters has occurred in most cases for commercial exploitation only. Transplantations have been carried out at a large scale since the Roman times (Günther 1897). Attempts to improve native *O. edulis* fisheries date back to the 18th century. These have taken the form of both scientific studies and the introduction of legislation to support the industry by allowing protection and management of the remaining beds (Korringa 1946). According to the review of Laing et al. (2006), pond culture was the method that was originally developed in early attempts to stimulate production following the decline of native oyster stocks in the late 19th century. Ponds were built near to high water spring tides, filled with seawater and then isolated for the period of time during which the oysters are breeding naturally. Collectors were put into the ponds to encourage and collect the settlement of juvenile oysters. There is an inherent limited amount of control over the process and success is highly variable. In France, where spat collectors were also deployed in the natural environment, it was relatively successful and became an established method for a time. In the UK, spat production from ponds built at that time was insufficiently regular to provide a reliable supply of seed to the industry and the method was largely abandoned (e.g. see Knight-Jones 1952). In the 1960s and 1970s, hatchery techniques were developed for *O. edulis* (Walne 1974). According to Laing et al. (2006) it has a limited application in the restoration of oyster beds due to the large numbers of seed oysters that would be required.

More recently, restoration efforts and associated studies in disease-free areas have shown the potential for success of native oyster stock regeneration. Such efforts in Strangford Lough in Northern Ireland (Kennedy and Roberts 1999), Spain (Figueras, 1970;Guerra 1998) and in Limfjord in Denmark (Dolmer and Hoffmann 2004) are of particular note. Various attempts have been made in the German and Dutch Wadden Sea (Hagmeier, 1943; Jan Bol, pers com), but with no success.

In the UK, flat oyster restoration projects for nature management purposes are being developed. In their review, Laing et al. (2006) describe the issues that need to be taken into account when these projects are being developed. An important aspect is legislation, as restored beds need protection and proper management. They also address aspects like prevention of pests and diseases, and appropriate water quality, including control of TBT levels. In the UK, the flat oyster is a Biodiversity Action Plan species, so it is expected that more attention will be given to restoration. Indeed, Shelmerdine et al. (2010) address the decline and the options for restoration of flat oyster stocks in various lochs for the Shetlands. They have identified habitats for the flat oyster that would allow restoration. Yet, further studies are needed to prepare a pilot project.
For other oyster species extensive restoration programs are in execution in the USA. This has been reviewed by Coen et al. (2012) and is updated annually at the International Conference on Shellfish Restoration (ICSR http://www.scseagrant.org/content/?cid=297).

In the framework of a program for coastal defence innovation, called Building with Nature (BwN, **Fout! De hyperlinkverwijzing is ongeldig.**; Temmerman et al., 2013) efforts have been made to use oyster reefs as eco-engineers (Walles et al., 2014). Artificial reefs of the Pacific oyster *Crassostrea gigas* have been created in the Oosterschelde (southwest Netherlands) by using oyster shells packed in gabions to prevent the flushing of the shells, with natural recruitment, growth and survival being monitored. In fact, various aspects of these artificial reefs are being studied in detail, including their impact on the environment and their self-sustaining capacities (Walles et al., in prep). This programs delivers practical knowledge on oyster bed development that might be useful in pilots for flat oyster reintroduction.

4 Identification of restoration opportunities

4.1 Requirements

For shellfish restoration, a number of items for a protocol have been developed (Brumbaugh, 2006; Lipcius et al., 2008). The approach as mentioned in Table 4.1.1. is not a fixed protocol, rather a set of guidelines to be addressed. It includes site-specific information on the pre-restoration conditions with respect to the target populations as well as existing other populations. It is also relevant to know the local sediment conditions as an important factor for evaluating the suitability of the habitat. Pollack et al., 2012 published a restoration suitability index for a specific area, as an integration of the various criteria that need to be met.

Table 4.1.1. Items of a protocol for restoration projects.

protocol for restoration projects		reference
1	history of the populations	Brumbaugh et al, 2006
2	pre-restoration population survey	Brumbaugh et al, 2006
3	pre-restoration bottom survey	Brumbaugh et al, 2006
4	habitat quality and environmental conditions	Pollack et al, 2012
5	habitat suitability index	Soniat et al, 2013
6	metapopulation connectivity analysis	Lipcius et al, 2008
7	population dynamics	
8	ecosystem services and exploitation rate	Coen et al, 2012
9	reef design and scale	La Peyre et al, 2014
10	regulations	Brumbaugh et al, 2006
11	accountability and monitoring; BACI approach	
12	adaptive management	Allen & Stankley, 2009

To predict the required critical mass the approach of Lipcius et al., 2008 can be used, consisting of a meta population analysis of the connectivity between different populations. This includes an analysis of population characteristics (fecundity, spawning requirements) with larval transport and hydrodynamic parameters.

The other items, such as the ecosystem services, are a basis for an analysis of the functionality of a reef in the given environment. Some authors address the filtration capacity of a restored oyster population as a criterion for setting targets: it could be decided to restore the population to a size where filtration capacity (expressed as clearance time) equals water renewal time (Hancock et al., 2014). Others aim at increasing demersal fish stocks with oyster bed restoration (Coen et al., 2012, Grabowski et al., 2012). It needs to be stressed that the realization of a restoration project needs to be accompanied by a monitoring program that follows the before-after-control-impact (BACI) approach, in order to evaluate the real effects on ecosystem services of the restoration efforts. This should deliver a basis for adaptive management.

4.2 Habitat suitability: Site selection

Suitable sites for flat oyster restoration will be evaluated with our knowledge of the environmental factors, which determine the optimal or suboptimal habitats for flat oyster in the North Sea. Ultimately, the goal of the restoration is the re-establishment of the oyster beds within the former range of occurrence, which is in areas with silt in the calm, deeper parts of the North Sea, currently known as the Centrale Oestergronden in the central NCP. The Dogger Bank is the northern border of this area, Klaverbank constitutes its western border, the German Exclusive Economic Zone (EEZ) its eastern border and the Friese Front forms the southern border. Frequent surveys of the soft sediment habitat have failed to find flat oysters in this area in the last three decades (see par. 3.1). It is generally believed that bottom trawling precludes establishment of flat oysters beds by removing all remaining natural hard substrate, so the primary requirement of any restoration location is that bottom trawling is excluded there.

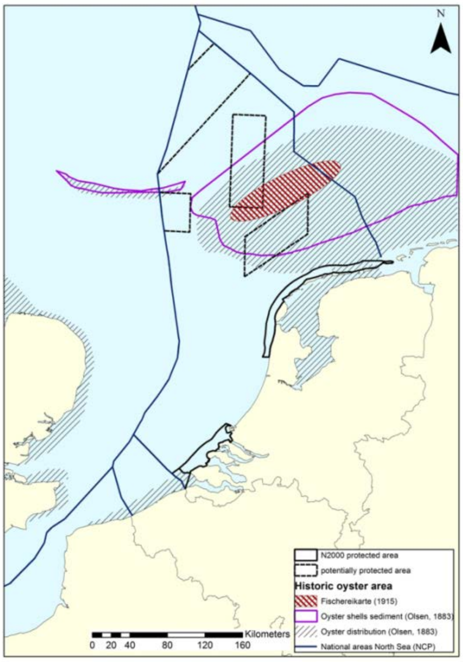


Fig 4.2.1 Historic oyster areas and projected no take zones.

NCP

This area includes the Natura 2000 areas "Friese Front", "Noordzeekustzone', "Voordelta" and "Vlakte van de Raan" (figure 4.2.1) and the Marine Strategy Framework Directive area "Centrale Oestergronden". Currently, almost the entire area is open for bottom trawling, except for parts of the Noordzeekustzone, Voordelta and Vlakte van de Raan. The Dutch government has decided to designate "no-take" zones (VIBEG areas) within the Natura 2000 and MFSD areas and has started stakeholder consultation. This process will be finalised in 2016. In addition, any pilot experiment within a Natura 2000 area will have to be evaluated in the light of the conservation goals of that area. Flat oyster beds are not included in the conservation goals of any North Sea Natura 2000 area within the NCP, because the species was absent at the time of designation. The status of the flat oyster in the MSFD area is still a subject of discussion.

The near shore areas "Noordzeekustzone', "Voordelta" and "Vlakte van de Raan" are relatively shallow, sandy and dynamic, which do not constitute a good settling habitat for flat oysters. There may be possibilities on the lee side of sand banks for test sites; yet more detailed information on local conditions would be needed.

Fig 4.2.2 shows areas with different hydrodynamic conditions. In some areas there are gyres with extended residence times of the water body. This is also the case in the deeper Central Oyster Grounds. It is assumed that deep water, protected by the Dogger Bank (Fig 3.1.1.2), with an extended water residence time, makes the area suitable for oyster bed development.

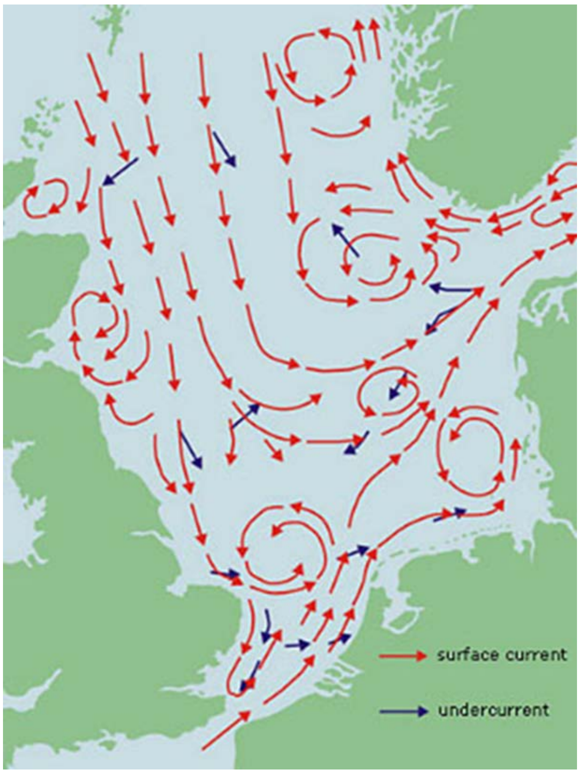


Fig 4.2.2. Water current patterns in the North Sea.

Areas within wind farms

Since all fisheries are prohibited in wind farms in the Dutch NCP, the soft sediment habitats within these areas are protected against any type of fishery. Because the first wind farms in the southern North Sea were constructed after 2002 (Horns Rev, Denmark) and considering the long recovery time of oyster beds, no spontaneous recovery is expected to occur with several decades to come. In the NCP most wind farms are situated or planned relatively close (20-40 km) to the shore. Only the Gemini wind farm, which is now under construction north of Ameland and Schiermonnikoog, is situated further offshore, but in less optimal habitat (high current speed, fine sand, no silt). Flat oysters were found in wind farms within a few years after construction (see section 3.1). Pogoda et al., (2011) showed the presence of good oyster growth in an area where offshore wind farms are planned in the German part of the North Sea. This suggests that wind farms are suitable sites for pilot experiments for restoration and test sites for larval collectors, substrates and growth conditions. However, no wind farms are planned within the central NCP (figure 4.1).

Areas near mining platforms

No flat oysters have yet been found on or around mining platforms within the NCP (Joop Coolen, pers. comm. 2014). This is probably due to the fact that biological surveys on North Sea mining platforms are very rare (Joop Coolen, pers. comm. 2014). Several platforms in the central NCP, however, are situated within the former range of occurrence of flat oysters, with soft sediment (silt) on the sea floor and low current speed. Fishery in a zone of 500 meters around platforms is prohibited and is enforced through continuous ship movement monitoring, which should make these areas suitable for flat oyster reintroduction pilots. In the long term, artificial reefs constructed from abandoned platforms could create new opportunities for hard substrate communities (rigs-to-reefs, such as the Living North Sea Initiative; IMSA, 2014). Safety regulations around such reefs will probably be less restrictive than around operating platforms and fisheries will need to be absent close to these artificial reefs.

Shipwrecks
Several hundreds of shipwrecks are situated throughout the NCP and flat oysters have been found alive (or recently alive) on several of them. However, they are not protected against bottom trawling and are also freely accessible for divers. This makes them less suitable for pilot experiments.

Artificial reefs
No artificial reefs are currently situated or planned in the NCP. In the long term, multi-functional and multi-user artificial reefs might be suitable for flat oyster restoration and by that adding a number of unique ecosystem services.

Delta area
Flat oysters have been found in the deepest parts (40 m) of the Northern branch of the Oosterschelde where bottom trawling is prohibited. These conditions are somewhat similar to the deeper parts of the NCP and can be used as test site.

4.3 Further steps

Once suitable sites have been identified, specific information on local conditions is needed. This includes abiotic and biotic factors that are relevant for the oysters, such as hydrodynamics, sediment, water quality, other biota including predators and food availability. This can be integrated in a restoration suitability index. Based on this index specific sites can be selected for trials; through meta-populations modelling the design can be refined. If artificial substrates are required, which shall be the case in most areas, design and dimensions are to be decided. As part of the process, regulations that are relevant for the selected areas have to be integrated in the project program.

5 Analysis of regulatory conditions for restoration

5.1 Compliance check with Policy Reintroduction of Animals

Background

Since flat oysters still exist in the North Sea, as was demonstrated in Chapter 3, it can be argued that the prospective restoration attempt is not a reintroduction of the species. However, to check in how far the prospective flat oyster restoration complies with the regulations that apply for reintroductions we have evaluated the project as if it concerns a reintroduction.
In the Netherlands, an exemption is needed for the reintroduction of protected animals (Flora & Fauna Law, art. 75a, see also section 5.2), which is assessed for compliance with the Policy Reintroduction of Animals (Ministry of Economic Affairs, 2008). This section presents the compliance check and the main results are summarised in table 5.1.1.
In addition, the policy document recommends following the IUCN Guidelines for reintroductions (IUCN, 1995), which includes information on how to set up a feasibility study, preparations for implementation and monitoring after completion. This feasibility study follows closely the IUCN Guidelines.

Assessment for the Policy Reintroduction of Animals

5.1.1 Other considerations than ecological

a. Contribution to conservation of threatened species.
The flat oyster and flat oyster beds are considered a threatened species and habitat respectively, within the OSPAR region (OSPAR, 2008, 2009). Flat oyster beds on soft sediments have disappeared completely from the Dutch part of the North Sea and only scattered individuals, predominantly on artificial hard substrate, have been found in the NCP (section 3.1).

b. Contribution to ecosystem functioning
Flat oyster beds are biogenic reefs (Natura 2000 habitat: biogenic reefs H1170), which have a number of contributions to the functioning of the wider North Sea ecosystem (Jackson, 2007). They provide a natural hard substrate for a rich epibenthic fauna in a region dominated by soft sediments. Their large filtration capacity improves water clarity by removing suspended silt leading to better growth conditions for phytoplankton. They further increase primary production by enhancement of nutrient cycling. The epibenthic fauna and three-dimensional-structure provides food and shelter against predators for mobile fish and large invertebrates.

c. Contribution to completeness of the ecosystem
Flat oyster beds typically support a natural assemblage of 100 – 150 species of epibenthic fauna (animals fixed to hard substrate) on live and dead oyster shells, including special species like *Alcyonium digitatum*, one of the few cold water corals in the North Sea (Möbius, 1877; Thurstan et al., 2013). They occur mainly on flat oyster beds or on artificial hard substrates (Houziaux 2011; Lengkeek et al., 2011). The North Sea ecosystem can be considered incomplete without flat oyster beds.

d. Contribution to public awareness of nature
For centuries oysters have had a reputation of being exclusive, both as food and as a source of valuable commodities like pearls and mother-of-pearl. Flat oysters are considered as a tasty and relative expensive natural product. It is likely that flat oyster beds as a restored habitat will be considered valuable and of high natural value, in particular in relation to the ecosystem services

(Grabowski et al., 2012; Jackson, 2007) and the occurrence of special species like cold water corals. The general image of the North Sea is an exploitation area for fisheries, shipping, mining and recreation. The attention for flat oysters and the aim to restore oyster beds in the North Sea ecosystem will contribute to the awareness that this rich habitat has completely disappeared through overexploitation and will not recover in areas with bottom trawling. This can contribute to the public awareness that the environmental quality in certain areas has substantially improved to make recovery possible.

e. Contribution to increase of knowledge
Flat oyster beds disappeared from the southern North Sea well over a century before the development of modern ecological research. The return and recovery of this habitat will provide the opportunity to acquire new knowledge about the functioning of flat oyster beds in the soft sediments ecosystem of the North Sea. This knowledge can be applied to other initiatives and restoration projects of flat oysters around the North Sea and related species worldwide (e.g., the Olympia oyster *Ostrea lurida* on the Pacific coast of the U.S.A. and the New Zealand oyster *O. chilensis* in New Zealand).

5.1.2 Urgency

a. Probability of spontaneous recovery
The dispersal capacity of flat oysters is low because a large part of the early larval development occurs within the shell of the females (c. 1 km, Jackson, 2007). This differs, for example, from the Pacific oyster in which the complete larval development occurs during the planktonic phase. Furthermore, the nearest substantial populations are in the Limfjord, Denmark and in Ireland, which are too distant to function as a source population with natural dispersal. The Lake Grevelingen population is not directly connected with the North Sea.

b. Urgency of action
All remaining populations in the wider North Sea area (including Irish and Celtic Seas) are relatively small, isolated and under pressure from pollution, diseases and exploitation (OSPAR, 2008, 2009). The creation of a large, continuous population is considered to be an important condition for the long-term survival of the flat oyster in the North Sea area (Lallias et al., 2010).

5.1.3 Ecological considerations

a. Originality (nativeness) of the species
The flat oyster is a native species in the Netherlands and has recently been found in only a few localities in the NCP (see section 3.1). Until the mid-19th century, flat oyster beds dominated the sea floor of the southern North Sea over an area of approximately 25,000 square kilometres (Olsen, 1883). A genetic analysis of the remaining populations around the North Sea showed it to be relatively uniform and different from populations in other areas, such as the French and Spanish coastal zones and the Mediterranean Sea (Lallias et al., 2010).

b. Impact of reintroduction
The activities for flat oyster reintroduction and settlement in the North Sea might have an impact on the soft sediment ecosystems, which nowadays virtually dominate the whole southern North Sea. These habitats cover such huge areas that local changes will have insignificant impacts on the total habitat. The large-scale recovery of flat oyster beds will have a substantial impact, but mainly positive, which is related to the restoration of the biodiversity associated with the natural hard substrate of flat oysters. The potential source areas for the translocation of oysters (e.g., Limfjord, Denmark or Strangeford Lough and Tralee Bay Ireland) are so large that these populations will not

be affected by taking stock material for reintroduction in the North Sea (Gercken & Schmidt, 2014).

c. Probability of independent, sustainable population
The success of reintroduction depends highly on the quality of information on habitat requirements and whether the causes of extinction are known and taken away. Recently, a substantial number of studies of the distribution, ecology and genetic variation have been carried out in the remaining flat oyster populations in North Sea area (Jackson, 2007; Lallias et al., 2010, see also section 4.1). These studies are sufficient to identify suitable areas for reintroduction in the Dutch part of the North Sea (section 4.2).
The factors that have caused local extinction and absence of recovery of flat oyster beds in the North Sea have been identified and removed or mitigated locally. These causes are mainly: (1) direct fishery and (2) bottom trawling. Fishery, including bottom trawling, is not allowed in several areas and these will be further extended as a result of Natura 2000 and the Marine Strategy Framework Directive (see Chapter 4). Besides, the water quality of the North Sea has improved, in particular since the ban on TBT compounds in anti-fouling paints. These compounds have a negative impact on the reproduction of molluscs. Several regulations have been implemented to prevent the spread infectious diseases, in particular the invasieve alien species Bonamia and Marteilla. A surveillance program is carried out by the Central Veterinary Institute, Lelystad (see also section 5.3). Bonamia occurs in Lake Grevelingen and this population has become to some extent tolerant for Bonamiosis (Engelsma et al., 2010). The Netherlands is designated as a Marteilla free area. The growth of flat oysters in offshore areas of the North Sea is very good, as has been shown in growing experiments on offshore mining platforms in the German part of the North Sea (Pogoda et al., 2011).

5.1.4 Other considerations than ecological

a. Probability of damage
The probability that the activities needed for reintroduction will damage economic activity or infrastructure is low, provided that all obligatory security measures for working close to mining platforms and wind farms in the North Sea are implemented.
b. Veterinary risks
The veterinary risks are generally well known and manageable (Arzul et al., 2009, Culloty & Mulcahy, 2007; Engelsma et al., 2010; Peeler et al., 2011, see section 5.2). The Central Veterinary Institute will be consulted and involved in the careful screening of the source populations and the areas where flat oysters will be introduced.

5.1.5 Organisation

a. Clear and realistic ambition
The aim of the reintroduction project is to establish at least one independent and sustainable population of flat oysters in the North Sea. This feasibility study will further assess this ambition and the plan for phase 2 will propose milestones and success criteria for the relevant steps and alternative strategies for contingencies. Oyster restoration projects were successful in the United States, including the west coast Olympia oyster *O. lurida* and the east coast Eastern oyster *Crassostrea virginica.*
b. Monitoring and research
Monitoring is part of the reintroduction project and will be detailed in phases 2 and 3. The aim is to include the monitoring in current or future monitoring programs for the MSFD.
c. Mandate and strength of organisation
The reintroduction project is a co-operation of three consortium partners, each of which have considerable experience in marine research and monitoring and process management and

expertise in marine ecology, shellfish ecology, macrofauna of hard substrates, infectious diseases and process management. The project has acquired considerable support in the relevant ministries and stakeholder organisations (see also section 5.3).

Table 5.1.1. Assessment for compliance with the Policy for Reintroduction of Animals.

	impact	**Remarks**
1.Considerations		
a. Contribution to conservation of threatened species.	large	Species and habitat has threatened status (OSPAR, EU Habitat Directive H1170, biogenic reefs)
b. Contribution to ecosystem functioning	large	Oyster beds have various contributions to ecosystem functioning: biodiversity, improving water quality, enhancing primary production and nutrient cycling, food and shelter for mobile fish and invertebrates.
c. Contribution to completeness of ecosystem	large	Oyster beds provide natural hard substrate which is scarce in the North Sea, which is dominated by soft sediments
d. Contribution to public awareness of nature	large	Oysters are generally considered a valuable asset. Current image of North Sea is an exploitation area. Restoration of biodiversity with oyster beds will add to a greener image.
e. Contribution to increase of knowledge	large	A complete ecosystem has disappeared before it could properly studies and understood. Oyster bed restoration provides opportunities for new knowledge.
2. Urgency		
a. Probability of spontaneous recovery	very low	Dispersal capacity is low, larvae develop partly in mother shell, substantial and nearby source population are lacking in North Sea.
b. Urgency of action	high	All remaining flat oyster populations are threatened in the OSPAR area.
3. Ecological considerations		
a. Nativeness of the species	high	Flat oyster is a native species that dominated a large part of the southern North Sea.
b. Impact of reintroduction	broad	Restoration of biodiversity, provision of new ecosystem services, enhancement of genetic variation in current populations, improving conservation status flat oysters, impact on current soft sediment communities very low.
c. Probability of independent, sustainable population	high	Habitat requirements are well known, most causes of local extinction and lack of recovery have been mitigated (no direct fishery, no bottom trawling in wind farms, management of veterinary risks, reproduction and dispersal still occurs in North Sea.
4. Other considerations than ecological		
a. Probability of damage	low	Reintroduction activities similar to fishery activities in Lake Grevelingen
b. Veterinary risks	present, managable	Surveillance for Bonamia and Marteilla is present in Delta area. Central Veterinary Institute will screen source populations and minimise veterinary risks.

	impact	Remarks
5. Organisation		
a. Clear and realistic ambition	present	The aim is at least one independent and sustainable population in the North Sea.
b. Monitoring and research	plan	Will be included in phase 2 and phase 3. After completion of project monitoring will be integrated in current monitoring programs.
c. Mandate and strength of organisation	good	The current consortium has extensive experience and expertise in monitoring and research of shellfish in the North Sea area, including project management.

5.2 General and site-specific legal requirements and licenses

The legal requirements depend on the location that will be selected for reintroduction. In general, there are three types of locations: (1) areas selected and protected for nature conservation purposes (Natura 2000 and MSFD), (2) areas set aside for offshore wind farms, (3) other areas that are restricted because of specific uses (e.g. shipping lanes, anchorage areas, pipelines, cables, oil and gas platforms, locations for sand extraction, etc.). Fig. 3.1.3 in par 3.1 shows closed areas and wind farm areas. Restricted areas are indicated in Fig. 5.2.1.

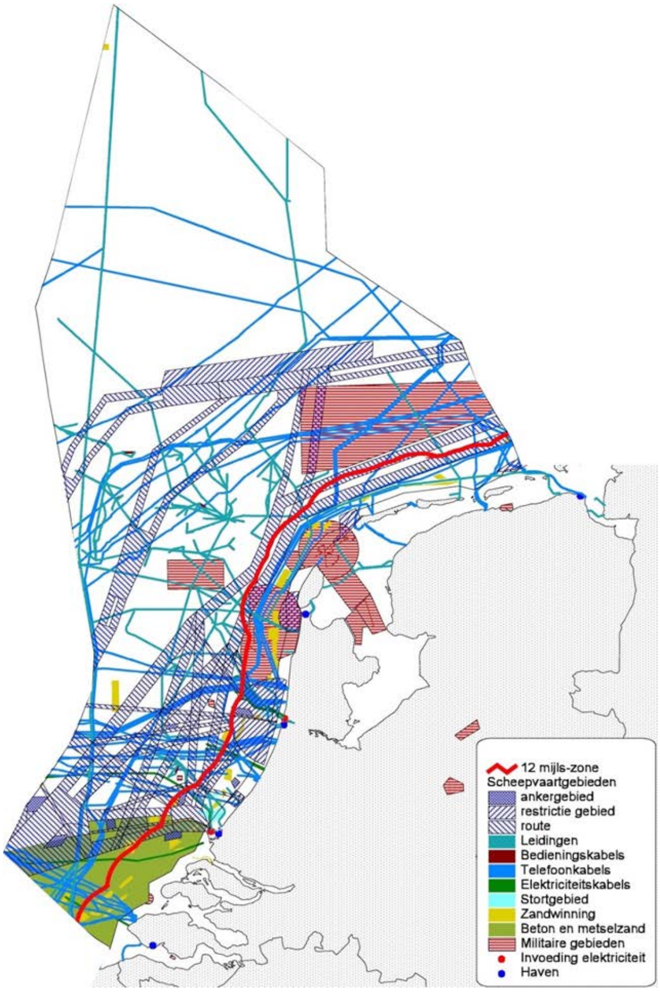


Fig. 5.2.1. Restricted areas. Source: RWS

The Nature Protection Law 1998 is the implementation of the European Council Directive 92/43/EEC on the conservation of natural habitats and Directive 2009/147/EC on the Conservation of wild birds (referred to as the Habitats and Birds Directives respectively). These were developed with the aims of protecting habitats and species considered to be of European importance and are intended to help maintain biodiversity in the Member States. This is achieved through member states designating sites of Special areas of Conservation (SAC) for the protection of habitats (as listed in Annex I of the habitats directive) and species (as listed in Annex II of the habitats directive) and Special Protection Areas (SPA) for the protection of wild birds and the habitats of listed species. SAC and SPA designated sites form the European Natura 2000 network. The network is given coherence by other activities involving monitoring and surveillance, reintroduction of native species, introduction of non-native species, research and education. Flat oyster beds are included in the habitat type "biogenic reefs" (H1170). This ensures protection under the EU Habitat Directive if they are present in the North Sea.
Member States must take all necessary measures to guarantee the conservation of habitats in special areas of conservation and to avoid their deterioration and the significant disturbance of species. Protected species should not be killed, captured or disturbed and plants not picked, uprooted or collected. In addition, everybody should take care of wild plants and animals and not disturb or destroy their direct environment. A new activity must apply for a permit within the Nature Protection Law at the Ministry of Economic Affairs. The application must be accompanied by an Appropriate Assessment.
When an area is not a Natura 2000 area, an Appropriate Assessment is not needed, but a Pre- or Scoping Consultation (Voortoets) will be sufficient to show that nearby Natura 2000 areas will not be negatively impacted.
Flat oyster pilot experiments to be undertaken in Nature 2000 sites are subject to a permit and Appropriate Assessment procedure. The experiments are of course intended to improve the habitat quality and biodiversity of these sites. However, flat oysters are not registered as a designated species for these sites, so the outcome of the assessment is not directly clear.

The Marine Strategy Framework Directive (MSFD) aims to achieve Good Environmental Status (GES) of the EU's marine waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. It is the first EU legislative instrument related to the protection of marine biodiversity, as it contains the explicit regulatory objective that "biodiversity is maintained by 2020", as the cornerstone for achieving GES. The Directive applies the ecosystem approach to the management of human activities having an impact on the marine environment, integrating the concepts of environmental protection and sustainable use. In order to achieve its goal, the Directive establishes European marine regions and sub-regions on the basis of geographical and environmental criteria. The Directive lists four European marine regions – the Baltic Sea, the North-east Atlantic Ocean, the Mediterranean Sea and the Black Sea – located within the geographical boundaries of the existing Regional Sea Conventions. Cooperation between the Member States of one marine region and with neighbouring countries that share the same marine waters, is already taking place through these Regional Sea Conventions. In order to achieve GES by 2020, each Member State is required to develop a strategy for its marine waters (or Marine Strategy). In addition, because the Directive follows an adaptive management approach, the Marine Strategies must be kept up-to-date and reviewed every six years.

The EU Water Directive aims at the improvement of water quality of fresh and coastal waters according to EU Directive 2000/60/EC and reach Good Environmental Status (GES). Water management is coordinated per river catchment area. The Voordelta is part of catchment area of the rivers Scheldt and Meuse. In the national policy, nature conservation in these areas is the primary goal, but human use is also allowed.

The Water Law submits all plans to place constructions in the water to permit application. The Ministry of Infrastructure and the Environment issues this permit. The law manages some procedures concerning the Water Directive too.

The Flora & Fauna Law protects a wide scope of species and an exemption can be given for specific activities. The FFL forbids releasing protected species. The potential negative impact and importance of every activity within the NCP and coastal zone has to be assessed before an exemption can be issued.

EU Regulation 95/70 aims to prevent introduction of infectious diseases of shellfish. Imports of flat oysters are, therefore, subjected to this regulation.

The Fishery Law aims to regulate the fishery of oysters and includes flat oysters, Portuguese oysters and Pacific oysters. This does not apply to this project because no fisheries are included.

The National Policy on Reintroduction of Animals includes a set of conditions for reintroduction projects of animals and reference to the IUCN Guidelines (IUCN, 2013). The compliance with this policy has been assessed in section 5.1.

5.3 Area management and stakeholders consultation

Chapter 4 describes the sites on the NCP where, according to current information, flat oysters could be successfully reintroduced. As mentioned in Chapter 1, the reintroduction procedure will entail two phases:

- Pilot phase: Development and execution of small-scale experiments (planned to start in 2015 and to continue to 2018-2019)
- Reintroduction: This will take place at the most successful sites, with the most successful subpopulations and conditions, as identified in the pilot phase (to start in 2018 or later).

The primary criteria for site selection are identical for both phases, since flat oysters need to survive, reproduce and settle (in order to form beds) in either phase. The dominant criterion is the absence of bottom disturbance, since this would preclude oyster bed formation. In practice it means that restoration areas need to be closed for bottom disturbing fisheries.
As chapter 4 has shown, there are four types of candidate areas where this is, or may become, the case:

A. *Wind farms*: no fishery at all is allowed here (within the NCP) and trespassing is not reported to occur (except around the extreme edges). Hence, bottom trawling is indeed absent here.
B. *Safety zones around oil and gas exploration platforms* (500 m): no fishery is allowed in these areas and this is enforced, although trespassing seems still to occur occasionally. Hence, disturbance-free sites can possibly be identified here.
C. Robust artificial structures, such as abandoned oil and gas platforms. These structures may be suitable, if sufficiently marked, so that fishing trawlers can indeed avoid them. OSPAR regulation prescribes removal of platforms after production has ceased, but there are exceptions (for instance, concrete platform need not be totally removed) and there is discussion about 'rigs-to-reefs' opportunities in the North Sea.
D. *Protected areas within the Natura 2000 and Marine Strategy Framework Directive*. The main historical flat oyster areas, such as the Central Oyster Grounds and Friese Front, overlap with the Marine Strategy Framework Directive areas, but they will not be free from bottom trawling fishery before 2016. Besides, some 'no take areas', which are already defined within the Natura 2000 framework (in the North Sea coastal area and the Voordelta), may include locations that are suited for flat oyster restoration. Since flat oysters are no designated species for Dutch Natura 2000, a permit procedure may be required.

Since pilot experiments are planned to start in 2015, the straightforward choice of pilot phase locations would seem to be within categories A and B. This was actually the hypothesis under which the investigations of phase 1 started. However, it has appeared that health, safety & environment (HSE) regulations imposed on visits to wind farms and oil & gas platform safety zones are extremely strict. Such visits are, obviously, required to construct the pilot experiments in situ and to perform regular monitoring on and around them.
Therefore, discussions with wind farm and platform managers have been started in order to further explore conditions and opportunities.
In order to explore the opportunities within category C, we are currently consulting the same parties as category B, together with consultancy agency IMSA, which has initiated a - roughly described - 'rigs-to-reef' program for the North Sea (The Living North Sea Initiative).
Given the uncertainties in category A, B and C, and because some of the protected areas within Nature 2000 and MSFD are historical flat oyster grounds, we have also decided to explore the opportunities in category D. As indicated above, the selection process of 'no take zones' within these frameworks is still continuing. We have taken up contact with the project management in order to gain insight in planning and procedure.

The other parties that are involved in the stakeholder consultation process are:

- Fishery organisations
    - Trawling associations (VisNed and De Visserbond)
    - The oyster farmers, united in the Netherlands Oyster Association
- Nature conservation organisations (Stichting de Noordzee, World Wildlife Fund, Natuurmonumenten, Greenpeace, Stichting De Ark)
- Science (NIOZ, MarinX, Grontmij, Ecosub, eCoast, CVI, Stichting Anemoon/Duik de Noordzee Schoon)

We have consulted the fishery and nature conservation organisations in order to gain insight in the conditions for their cooperation and explore the possibilities of their active support (including sponsorship). There appears to be broad support for the project. The question is raised whether it will indeed be possible to restore viable oyster beds on the North Sea bottom, but the three-step approach adopted in this project is seen as the best way forward to answer this question in practice. In the annex, a report of the stakeholder workshop of Dec 2, 2014, is included.

6 Summary of projects outcomes

The project outcomes can be summarized as follows:

Fate of the North Sea oysters and the possible causes of extinction
Extensive oyster beds have existed in the North Sea and their extinction is predominantly caused by overexploitation and subsequent habitat destruction by intensive bottom trawling. Additional causes include possible changes in currents and climate, although this is considered less likely.

Environmental conditions and restoration sites
Oysters require hard substrate, in the form of shell material, other hard substrate, or existing oyster beds. This can be developed in the soft sediment environment of the North Sea bottom and on existing artificial hard substrates. Potential sites can be found in areas where no bottom trawling occurs. At present this is the case near offshore platforms and in wind farms. In the near future, protected areas within the Marine Framework Directive and Natura 2000 are also to be installed and may also be suitable.
Living flat oysters have occasionally been found in wind farms. Besides, flat oyster growth was experimentally demonstrated in areas where German wind farms are planned. Furthermore, the flat oyster population in the Delta area shows signs of recovery. This all shows that there are proper environmental conditions for flat oyster restoration in the North Sea. The recent expansion of Pacific oysters should pose no threat to flat oyster restoration since the two species have different habitat requirements.

Identification of the legal framework for restoration
Restoration of the flat oyster in the North Sea may be seen as a reintroduction attempt. Therefore, we have investigated the compliance of flat oyster restoration with the Dutch policy for reintroduction of animals. It appears that restoration can be organized in such a way that it complies fully.

Identification of stakeholder requirements
Stakeholder consultations have delivered relevant feedback as well as support for the approach. Boundary conditions have been identified and involvement of various stakeholder groups has been approved.

Program for pilot experiments
A program for the next steps is in preparation. Use will be made of the protocol of Table 4.1.1. Prior to carrying out field scale pilot experiments a number of issues have to be addressed in more detail. This includes pre-restoration surveys of biotic and abiotic factors in selected areas, assess a habitat suitability index, and develop a model for the connectivity analysis of the populations. Meanwhile methodological tests can be carried out on test locations in the Oosterschelde. A specific question deals with the source population. It can be considered to use oyster spat from the Limfjord, Denmark as this is free of Bonamia infestation.

7 References

Airoldi L, Beck MW. 2007. Loss, status and trends for coastal marine habitats of Europe. Oceanography and Marine Biology: An Annual Review 45: 345–405.

Alheit J, Priscilla Licandro, Steve Coombs, Alberto Garcia, Ana Giráldez, Maria Teresa Garcia Santamaría, Aril Slotte, Athanassios C. Tsikliras, 2014. Atlantic Multidecadal Oscillation (AMO) modulates dynamics of small pelagic fishes and ecosystem regime shifts in the eastern North and Central Atlantic. Journal of Marine Systems 131 (2014) 21–35.

Arzul I, Béatrice Gagnaire, Céline Bond, Bruno Chollet, Benjamin Morga, Sylvie Ferrand, Maeva Robert, Tristan Renault, 2009. Effects of temperature and salinity on the survival of *Bonamia ostreae*, a parasite infecting flat oysters *Ostrea edulis.* Diseases of aquatic organisms 85: 67-75.

Beck MW, Brumbaugh RD, Airoldi L, Carranza A, Coen LD,Crawford C, Defeo O, Edgar GJ, Hancock B, Kay M,Lenihan HS, Luckenbach MW, Toropova CL, Zhang G,Guo X (2011) Oyster reefs at risk and recommendations forconservation, restoration and management. Bioscience61:107–116

Berghahn, R., and M. Ruth. 2005. The disappearance of oysters from the Wadden Sea: A cautionary tale for no-take zones. Aquatic Conservation: Marine and Freshwater Ecosystems 15:91-104.

Berthe, F.C.J., Le Roux, F., Adlard, R.D. & Figueras, A. (2004) Marteiliosis in molluscs: A review. Aquat Living Res, 17, 433-448.

Bont de, Cordes , Smidt van Gelder. 1871. Aanmoediging ter kunstmatige oesterteelt door de Nederlandse Maatschappij ter bevordering van de Nijverheid. Pages 197-201. Tweede jaarverslag van de Heeren, de Bont, Cordes en Smidt van Gelder, wegens proefnemingen gedaan in 1870-1871.

Bouma, S. & W. Lengkeek. 2012. Benthic communities on hard substrates of the offshore wind farm Egmond aan Zee (OWEZ). Bureau Waardenburg Reportnr. 11-205, Bureau Waardenburg, Culemborg

Bruyne, RH de, SJ van Leeuwen, AW Gmelig Meyling & R Daan (red.), 2013. Schelpdieren van het Noordzeegebied. Ecologische atlas van de mariene weekdieren (Mollusca). Uitgeverij Tirion, Utrecht & Stichting Anemoon, Lisse.

Buestel, D., Ropert, M., Prou, J. & Goulletquer, P. (2009) History, Status, and Future of Oyster Culture in France. *J Shellfish Res,* **28,** 813-820.

Cadée, G.C. 1984. Macrobenthos and macrobenthic remains on the oyster ground, North Sea (Review). JSR Volume 18, Issue 1-2, Pages 160-178

Coen LD, Brett R. Dumbauld and Michael L. Judge, 2011. Expanding Shellfish Aquaculture: A Review of the Ecological Services Provided by and Impacts of Native and Cultured Bivalves in Shellfish-Dominated Ecosystems. In: Shumway (ed)**:** Shellfish Aquaculture and the Environment. Wiley & sons.

Culloty, S. C. 2007. Bonamia Ostreae in the Native Oyster Ostrea Edulis: A Review. Marine Institute, Oranmore, Galway.

Culloty, S. C., M. A. Cronin, and M. F. Mulcahy. 2001. An investigation into the relative resistance of Irish flat oysters *Ostrea edulis* L. to the parasite *Bonamia ostreae* (Pichot et al., 1980). Aquaculture 199:229-244.

Culloty, S. C., M. A. Cronin, and M. F. Mulcahy. 2004. Potential resistance of a number of populations of the oyster Ostrea edulis to the parasite *Bonamia ostreae*. Aquaculture 237:41-58.

Culloty, S. C., and M. F. Mulcahy. 1996. Season-, age-, and sex-related variation in the prevalence of bonamiasis in flat oysters (*Ostrea edulis* L.) on the south coast of Ireland. Aquaculture 144:53-63.

Culloty, S. C., and M. F. Mulcahy. 2001. Living with bonamiasis: Irish research since 1987. Hydrobiologia 465:181-186.

Culloty, S. C., B. Novoa, M. Pernas, M. Longshaw, M. F. Mulcahy, S. W. Feist, and A. Figueras. 1999. Susceptibility of a number of bivalve species to the protozoan parasite *Bonamia ostreae* and their ability to act as vectors for this parasite. Diseases of Aquatic Organisms 37:73-80.

Dame RF, JD Spurrier & RG Zingmark,1992. In situ metabolism of an oyster reef. JEMBE 164,4, 147- 159.

DameRF & T. Prins, 1997. Bivalve carrying capacity in coastal ecosystems. Aquat Ecol. 31-4,409-421

Didderen, K., W. Lengkeek, J.W.P. Coolen, H.W. Waardenburg (2013). Harde substraten en biodiversiteit Vooronderzoek naar kunstmatige objecten in de Noordzee (NCP). BuWa Rapport 12-181.

Drinkwaard, A. C. 1998. Introductions and developments of oysters in the North Sea area: A review. Helgolander Meeresuntersuchungen Volume 52, Issue 3-4, Pages 301-308

Engelsma, M. Y., Haenen, O.L.M. 2008. Jaarverslag Schelpdierziekten 2007. Centaal veterinair instituut van Wageningen UR.

Engelsma, M.Y., Kerkhoff, S., Roozenburg, I., Haenen, O.L.M., Van Gool, A., Sistermans, W., Wijnhoven, S. & Hummel, H. (2010) Epidemiology of *Bonamia ostreae* infecting European flat oysters *Ostrea edulis* from Lake Grevelingen, The Netherlands. *Mar Ecol Prog Ser,* **409,** 131-142.

Engelsma, M.Y., Culloty, S.C., Lynch, S.A., Arzul, I. & Carnegie, R.B. (2014) *Bonamia* parasites: a rapidly changing perspective on a genus of important mollusc pathogens. *Diseases of Aquatic Organisms,* **110,** 5-23.

Eno C C. L. J. Frid, K. Hall, K. Ramsay, R. A. M. Sharp, D. P. Brazier, S. Hearn, K. M. Dernie, K. A. Robinson, O. A. L. Paramor and L. A. Robinson, 2013. Assessing the sensitivity of habitats to fishing: from seabed maps to sensitivity maps. Journal of Fish Biology Volume 83, Issue 4, pages 826–846.

Figueras, A. 1970. Flat oyster cultivation in galicia. Helgolander Wissenschaftliche Meeresuntersuchungen 20:480-485.

Grabowski et al., 2012. Economic Valuation of Ecosystem Services Provided by Oyster Reefs. Bioscience *Vol. 62 No. 10*

Grizel, H., Comps, M., Bonami, J.R., Cousserans, F., Duthoit, J.-L. & Le Pennec, M.A. (1974) Recherche sur l'agent de la maladie de la glande digestive de *Ostrea edulis* Linne. *Science et Pêche, Bull Inst Pêches marit,* **240,** 7-30.

Guerra A., 1998, La ostricultura en Galicia: Situación estudios y perspectives. Marisqueo en Galicia, Estudios do Castro, pp. 77-88.

Günther, R. T. 1897. The oyster culture of the ancient Romans. Journal of the Marine Biological Association of the United Kingdom 4:360-365.

Hagmeier, A. 1943. Die intensive Nutzung des nordfrieschen Wattenmeeres durch Austern- und Muschelkultur. Z. Fisch 39:105-165.

Hancock B, BM DeAngelis & J Greene, 2014. How much is enough? Tools te help set goals for oyster restoration based on the ecosystem service returned. TNC; ICSR presentation.

Havinga, B. 1932. Austern- und Muschelkultur. Handbuch der Seefischerei Nordeuropas 7:64.

Heral, M. 1989. Traditional oyster culture in France. Aquaculture 1:295-336.

Hoek, P. P. C. 1902. Rapport over de oorzaken van den achteruitgang in hoedanigheid van de Zeeuwsche

Holtmann, S.E., G.C.A. Duineveld, M.Mulder & P.A.W.J. de Wilde, 1998. The macrobenthic fauna in the Dutch sector of the North Sea in 1997 and in comparison with previous data. - NIOZ-rapport 1998-5: 1-103

Horst, R. 1883. Verslag omtrent onderzoekingen op de oester en de oestercultuur betrekking hebbende, uitgebracht door de Commisie van het Zoologisch Station. Tijdschrift Ned. Dierkundige Ver. Suppl. 1.

Houziaux,J.-S., Kerckhof,F., Degrendele, K.,Roche, M. Norro A.,2008. The Hinder Banks Yet an important region for the Belgian marine biodiversity? Final report HINDERS project, Belgian Science Policy Office,pp.249. AvailableonlineatURL: /http://www.belspo.be/belspo/home/publ/pub_ostc/EV/rappEV45_en.pdfS.

Jackson, A. 2007. *Ostrea edulis*. Native oyster. Marine Life Information Network: Biology and Sensitivity Key Information Sub-programmem [on-line]. Marine Biological Association of the United Kingdom., Plymouth.

Jager, Z. 2013. Biodiversiteit kunstmatig hard substraat in de Noordzee (NCP) ZiltWater – rapport ZW 2013-04.

de Kluijver, M.J. 1995. De sublitorale hard-substraat levensgemeenschap in het Grevelingenmeer. Rapport 95.0683. Rijksinstituut voor Kust en Zee.

de Kluijver, M.J. Sublitoral communities of North Sea hard substrata. PhD thesis, University of Amsterdam

de Vooys CGN. 2001. Oestervisserij in Noordzee ruim honderd jaar geleden. Visserij Nieuws 28 (39): 33.

de Wilde, P. A. W. J. and G. C. A. Duineveld. 1988. Macrobenthos van het Nederlands Continentaal Plat verzameld tijdens de ICES 'North Sea Benthos Survey' april 1986.

Kennedy RJ and D. Roberts, 2006. Commercial oyster stocks as a potential source of larvae in the regeneration of *Ostrea edulis* in Strangford Lough, Northern Ireland. JMBA 86: 153 - 159

Korringa P. 1946, A revival of natural oyster beds? Nature 158,586-587.

Korringa, P. 1951. The shell of Ostrea edulis as a habitat. Arch. Neerl. Zool. 10:32-152.

Korringa, P. 1952. Recent advances in oyster biology. Q. Rev. Biol. 27:266-308.

Korringa, P. 1980. Management of marine species. HelgolaÌˆnder Meeresuntersuchungen 33:641-661.

Kröyer, H. 1839. Die dänische Austernbänke (mitgetheilt von Wiegmann). Archiv. f. Naturg. 5:358-363.

Laing, I., P. Walker, and F. Areal. 2005. A feasibility study of native oyster (*Ostrea edulis*) stock regeneration in the United Kingdom. CARD Project Report FC1016.

Laing, I., P. Walker, and F. Areal. 2006. Return of the native - Is European oyster (Ostrea edulis) stock restoration in the UK feasible? Aquatic Living Resources 19:283-287.

Laing, I., Dunn, P., Peeler, E.J., Feist, S.W. & Longshaw, M. (2014) Epidemiology of *Bonamia* in the UK, 1982 to 2012. *Diseases of Aquatic Organisms,* **110,** 101-111.

Lallias D., N. TARIS, P. BOUDRY, F. BONHOMME and S. LAPÈGUE, 2010. Variance in the reproductive success of flat oyster *Ostrea edulis* L. assessed by parentage analyses in natural and experimental conditions Genetics Research / Volume 92 / Issue 03 / 2010, pp 175-187

La Peyre M, Jessica Furlong, Laura A. Brown, Bryan P. Piazza, Ken Brown, 2014. Oyster reef restoration in the northern Gulf of Mexico: Extent,methods and outcomes. Ocean & Coastal Management 89 (2014) 20-28

Launey, S., M. Barre, A. Gerard, and Y. Naciri-Graven. 2001. Population bottleneck and effective size in Bonamia ostreae-resistant populations of *Ostrea edulis* as inferred by microsatellite markers. Genetical Research 78:259-270.

Launey, S., C. Ledu, P. Boudry, F. Bonhomme, and Y. Naciri-Graven. 2002. Geographic structure in the European flat oyster (Ostrea edulis L.) as revealed by microsatellite polymorphism. Journal of Heredity 93:331-338.

Leewis, R.J., de Vries, I., Busschbach, H.C., de Kluijver, M. & G.W.N.M. van Moorsel. 1997. Kunstriffen in
Nederland. Eindrapportage project Kunstrif, Rijkswaterstaat DIrectie Noordzee.

Lindeboom H, EM Dijkman, OG Bos, EH Meesters, JSM Creemer, I de Raad, R van Hal & A Bosma, 2008. Ecologische atlas Noordzee, ten behoeve van gebiedsbescherming. Imares.

Lipcius RN , David B. Eggleston , Sebastian J. Schreiber , Rochelle D. Seitz , Jian Shen , Mac Sisson , William T. Stockhausen & Harry V. Wang (2008) Importance of Metapopulation Connectivity to Restocking and Restoration of Marine Species, Reviews in Fisheries Science, 16:1-3, 101-110

Lübbert HO. 1906. Die Einf .uhrung von Motor und Schernetz in die Deutsche Segelfischerei. Abhandlungen des
Deutschen Seefischerei-Vereins 8.

Madsen, L., Kamp, J. & Mellergaard, S. (2013) What can the Limfjord tell us about limiting factors for *Bonamia ostreae* in northern Europe? *Bull Eur Ass Fish Pathol,* **33,** 165 - 169.

Mann, R., and E. N. Powell. 2007. Why oyster restoration goals in the Chesapeake Bay are not and probably cannot be achieved. Journal of Shellfish Research 26:905-917.

Marteil, L. 1979. La conchyliculture francaise. L'ostreiculture et la mytiliculture. Rev. Trav. Inst. PeÌ‚ches Marit. 43:5-130.

Merrill AS, Posgay JA (1964) Estimating the natural mortality rate of sea scallop (*Placopecten magellanicus*). ICNAF Res Bull 1:88–106

Metzger, A. 1873. Physik. und Faunist. Untersuchungen in der Nordsee wahrend des Sommers 1871. Anhang zu dem Bericht uber die Expedition auf S.M. Avisodampfer Pommerania., Kiel.

Ministry of Economic Affairs, 2008

Ministry of Economic Affairs , 2013 Implementation Agenda Natural Capital. www.minez.nl

Ministry of Economic Affairs, 2014 Nature Ambition Large Water Bodies. www.minez.nl

Mobius, K. 1877. Die Auster und die Austerwirtschaft. Report of the U.S. Commission of Fisheres:683-751.

Muus BJ, Dahlstr.om P. 1973. Meeresfische. BLV: Munchen.

Naciri-Graven, Y., J. Haure, A. Gerard, and J. P. Baud. 1999. Comparative growth of *Bonamia ostreae* resistant and wild flat oyster *Ostrea edulis* in an intensive system II. Second year of the experiment. Aquaculture 171:195-208.

Naciri-Graven, Y., A. G. Martin, J. P. Baud, T. Renault, and A. GeÌ□rard. 1998. Selecting the flat oyster *Ostrea edulis* (L.) for survival when infected with the parasite *Bonamia ostreae*. Journal of Experimental Marine Biology and Ecology 224:91-107.

NEUDECKER, T. (1990): The history of the former German oyster fishery and mariculture: 400 years of crown law on oysters (4.2.1587). Dt. hydrogr. Z., Erg.-H. B 22: 518-525

Odmann, J. 1744. Naschrichten von Austern. Abhandlgn. d. Schwed. Akad. Bd. 4:118-125.

Olsen, O. T. 1883. The piscatorial atlas of te North Sea, English and St. George's Channels. Grimsby, London.

Orton, J. H. 1937. Oyster Biology and Oyster Culture. Being the Buckland Lectures for 1935. Edward Arnold & Co., London.

OSPAR (2009): Background document for *Ostrea edulis* and *Ostrea edulis* beds. Biodiversity series, OSPAR Kommission, 21 S.

OSPAR (2013): OSPAR recommendation 2013/4 on furthering the protection and conservation of *Ostrea edulis* in region II of the OSPAR maritime area and *Ostrea edulis* beds in regions II, III, IV of the OSPAR maritime area. OSPAR Kommission, OSPAR Recommendation 2013/4.

Peeler EJ, RA Reese & MA Trush, 2013. Animal Disease Import Risk Analysis – a Review of Current Methods and Practice. Transboundary and Emerging Diseases

Pichot, Y., Comps, M., Tigé, G., Grizel, H. & Rabouin, M.A. (1980) Recherches sur *Bonamia ostreae* gen. n., sp. n., parasiste nouveau de l'huître plate *Ostrea edulis* L. *Rev Trav Inst Pêches Marit,* **43,** 131-140.

Pogoda, B. BH Buck & W. Hagen, 2011. Growth performance and condition of oysters (*Crassostrea gigas* and *Ostrea edulis*) farmed in an offshore environment (North Sea, Germany). Aquaculture 319:3-4: 484-492

Reise, K. 1998. Pacific oysters invade mussel beds in the European Wadden Sea. Senckenbergiana Maritima 28:167-175.

Reise, K., and J. E. E. Beusekom. 2008. Interactive effects of global and regional change on a coastal ecosystem. Helgoland Marine Research 62:85-91.

Riesen, W., and K. Reise. 1982. Macrobenthos of the subtidal Wadden Sea: revisited after 55 years. Helgolander Meeresuntersuchungen 35:409-423.

Shelmerdine, R. L. and Leslie, B. (2009). Restocking of the native oyster, *Ostrea edulis*, in Shetland: habitat identification study. Scottish Natural Heritage Commissioned Report No. 396.

Soniat, Tom, Craig P. Conzelmann, Jason D. Byrd, Dustin P. Roszell, Joshua L. Bridevaux, Kevin J. Suir and Susan B. Colley, 2013. Predicting the Effects of Proposed Mississippi River Diversions on Oyster Habitat Quality; Application of an Oyster Habitat Suitability Index Model. Journal of Shellfish Research 32(3):629-638.

Temmerman, S., Meire, P., Bouma, T.J., Herman, P.M.J., Ysebaert, T., De Vriend, H.J., 2013. Ecosystem-based coastal defence in the face of global change. Nature 504, 79-83.

THURSTAN, R.H., HAWKINS, J.P., RABY, L. & ROBERTS, C.M. (2013): Oyster (*Ostrea edulis*) extirpation and ecosystem transformation in the Firth of Forth, Scotland. J. Nature Conserv. 21 (5): 253-261

Tyler-Walters, H. 2001. *Ostrea edulis* beds on shallow sublittoral muddy sediment. Marine Life Information Network: Biology and Sensitivity Key Information Subprogramme [on-line].

Van Banning, P. (1982) Some aspects of the occurrence, importance and control of the oyster pathogen *Bonamia ostreae* in the Dutch oyster culture. In: *Proceedings XVth Annual Meeting of the Society for Invertebrate Pathology* (ed. by H.D. Burges & C.C. Payne), pp. 261-265, University of Sussex, Brighton, UK.

Van Banning, P. 1987. Further results of the *Bonamia ostreae* challenge tests in Dutch oyster culture. Aquaculture 67:191-194.

Van Banning, P. (1991) Observations on bonamiasis in the stock of the European flat oyster, *Ostrea edulis*, in the Netherlands, with special reference to the recent developments in Lake Grevelingen. *Aquaculture,* **93,** 205-211.

Wahid-Interface (2008) Infection with *Bonamia ostreae*, Belgium 21/11/2008. In: *OIE World Animal Health Information Database*. OIE.

Wahid-Interface (2009) Infection with *Bonamia ostreae*, Norway 05/06/2009. In: *OIE World Animal Health Information Database*. OIE.

Van Ginkel, R. 1996. The abundant sea and her fates: Texelian oystermen and the marine commons, 1700 to 1932. Comparative Studies in Society and History 38:218-242.

Vanagt, T., van de Moortel, L. & M. Faasse. 2013. Development of hard substrate fauna in the Princess Amalia Wind Farm. Monitoring 3.5 years after construction. eCOAST report 2011036.

van Moorsel, G.W.N.M. & H.W. Waardenburg. 1999. Biomonitoring van levensgemeenschappen op sublitorale harde substraten in Grevelingenmeer, Oosterschelde, Veerse Meer en Westerschelde. Rapport Bureau Waardenburg, Culemborg.

van Moorsel, G.W.N.M. 1993. Long-term recovery of geomorphology and population development of large molluscs after gravel extraction at the Klaverbank (North Sea). Bureau Waardenburg, Culemborg. *(no Ostrea edulis)*

van Moorsel, G.W.N.M. & H.W. Waardenburg. 1991. Het leven op en rond scheepswrakken en andere harde substraten in de Noordzee (1986 tot en met 1990) – een synthese-. Rapport Bureau Waardenburg, Culemborg.

van Moorsel, G.W.N.M. & H.W. Waardenburg. 1992. De fauna op wrakken in de Noordzee in 1991. Rapport Bureau Waardenburg, Culemborg

Waardenburg, H.W. (1973) Sociologisch onderzoek en vergelijk van de macrobenthische flora en fauna op en tussen het harde substraat in Oosterschelde, Grevelingen, Veerse Meer en Brielse meer. Doctoraal rapport, Wageningen Universiteit.

Waardenburg, H.W., van Beek, A.C. & A.J.M. Meijer. 1990. Monitoringsonderzoek onderwaterflora en – fauna op harde substraten in het Grevelingenmeer, resultaten periode 1979 – 1988. Rapport Bureau Waardenburg, Culemborg.

Walles, B, João Salvador de Paiva, Bram C. van Prooijen, Tom Ysebaert, Aad C. Smaal, 2014. The Ecosystem Engineer *Crassostrea gigas* Affects Tidal Flat Morphology Beyond the Boundary of Their Reef Structures. ECSSxx

Walne, P. R. 1956. Observations on the Oyster (*Ostrea edulis*) Breeding Experiments at Conway 1939-1953. Rapp. et Proc.-Verb. 140:10-13.

Walne, P. R. 1958. Growth of oysters (*Ostrea edulis* L.). J. Mar. Biol. Assoc. U. K. 37:591-602.

Walne, P. R. 1970. The seasonal variation of meat and glycogen content of seven populations of oysters Ostrea edulis L. and a review of the literature. Fish. Invest. 26:1-35.

Walne, P. R. 1974. Culture of Bivalve Molluscs: Fifty Years Experience at Conwy:189.

Yonge, C. M. 1960. Oysters. Collins, London.

Zintzen, V., A Norro, C Massin & J Mallefet, 2008. Spatial variability of epifaunal communities from artificial habitat: Shipwrecks in the Southern Bight of the North Sea. Estuarine, Coastal and Shelf Science Volume 76, Issue 2, Pages 327–344 [a]

8 Quality Assurance

IMARES utilises an ISO 9001:2008 certified quality management system (certificate number: 124296-2012-AQ-NLD-RvA). This certificate is valid until 15 December 2015. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. Furthermore, the chemical laboratory of the Fish Division has NEN-EN-ISO/IEC 17025:2005 accreditation for test laboratories with number L097. This accreditation is valid until 1th of April 2017 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation.

Bureau Waardenburg has an ISO 9001: 2008 certified quality management system (certificate number 634033.2). This certificate is valid until 11 May 2016. Bureau Waardenburg has been certified since 11 May 1998. The certification was conducted by Certiked.

9 Justification

Report number: C028/15
Project number: 4303107501

The scientific quality of this report has been peer reviewed by the a colleague scientist and the head of the department of IMARES.

Approved: Prof dr H. Lindeboom

Signature:

Date: February 12, 2015

Approved: dr R. Trouwborst
Head of department Delta

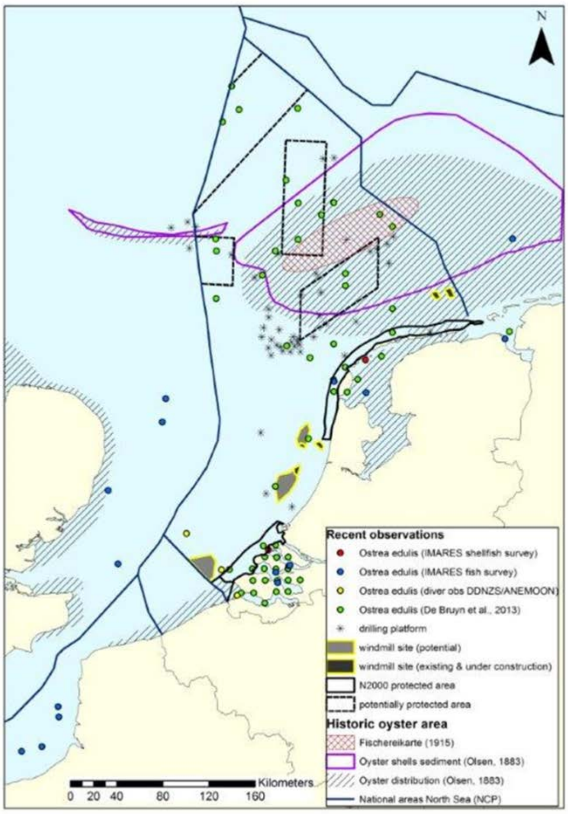
Signature:

Date: February 19, 2015

Annex 1 Approach of pilot-experiments for development of flat oyster beds in the North Sea

A closed or complete lifecycle is a prerequisite for a viable flat oyster population in the North Sea. This implies that survival, growth, maturation, reproduction and settlement take place successfully. The absence of bottom disturbance will be a prerequisite for survival; the absence of diseases (*Bonamia*) and low predation pressure will enhance the chances of survival. Sufficient food will ensure growth and the development of reproduction organs (‘gonads’). For successful reproduction, the number of males and females present should not be a limiting factor, which implies that several year classes should be present (cf. par. 2.1). For settlement the presence of suitable substrate at the location and time of availability of larvae that are ready to settle is crucial.

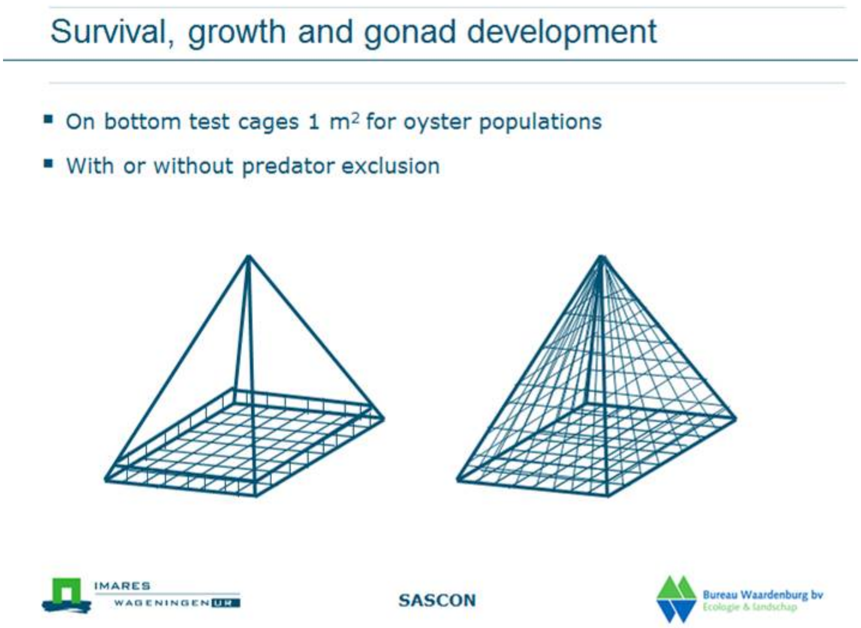
In order to study the possibilities for recovery of flat oysters in the North Sea, pilot experiments at different scales are needed. Survival, growth and maturation can be studied in small groups of oysters at a scale of a number of m^2. For reproduction and settlement a larger scale of several hectares is needed. This is mainly because current will tend to carry spat away from the oysters already present; a large oyster surface area will lower the chance of spat being carried away beyond its limits. As our inventory of historical data shows, a full size oyster bed has an even larger scale, of the order of km^2.



Potential test sites in areas without bottom disturbance, such as windfarms, mining platforms and and no-take zones within conservation areas (Natura 2000 network and MSFD, to be identified).

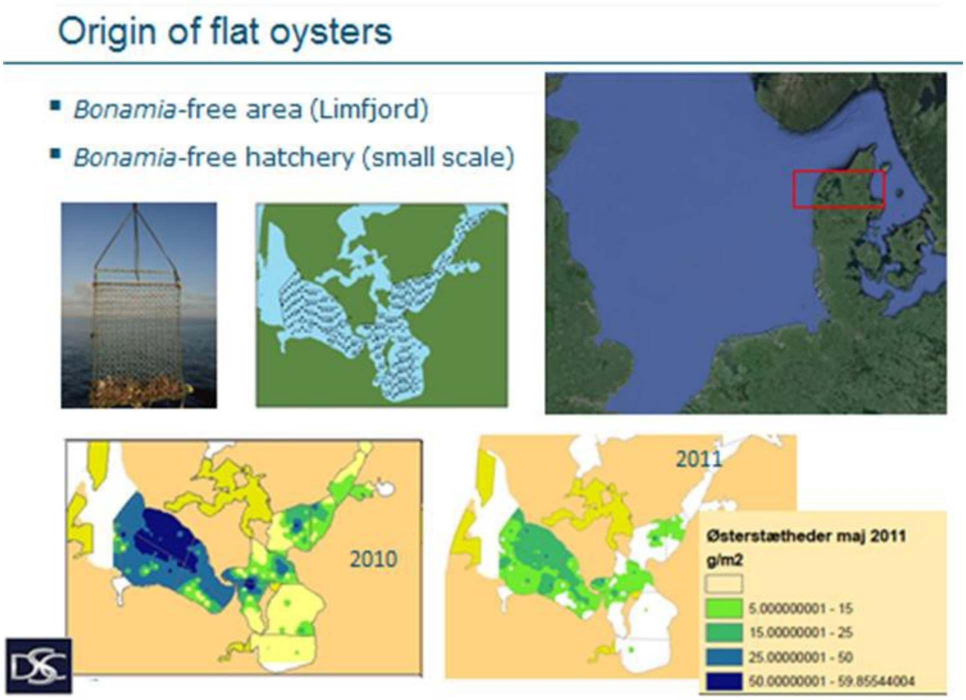
Survival, growth and maturation

To study survival, growth and maturation of flat oysters, experimental bottom cages of several m^2 will be used (see picture below). These cages have a mesh bottom and will be placed on the sea floor at locations where the sediment is firm enough to support the construction. The advantage of these cages is that they can be easily maintained on the sea floor and that they can be hoisted up for inspection and maintenance.
The sides of the cages will have different mesh sizes in order to prevent or allow predators such as starfish and crabs to enter the cage. In this way survival with and without predator types/sizes can be monitored. Flat oysters of different ages will be introduced into the cages, since a complete flat oyster bed requires survival, growth and maturation of several generations of oysters.
The functionality of the set-up will be tested at a deep location with low currents. Ideally, this is located close to the Imares Yerseke laboratory in the Oosterschelde. The flat oysters employed for this experiment will have to originate from the Grevelingen or Oosterschelde itself, since Limfjord oysters have shown a low chance of survival in the Delta area (probably because of Bonamia incidence). When successful, the cages can be deployed at a number of potential sites in the North Sea (10-15). In this way, survival, growth and maturation can be tested under a variety of conditions. The most successful sites will be selected for the second pilot stage, in which reproduction and settlement will be tested.



Reproduction and settlement

The absence of a substantial population of flat oysters in the North Sea is a bottleneck for studying reproduction and settlement. Therefore, we plan to initially circumvent reproduction and settlement in the North Sea by using spat collectors in an area with an abundance of flat oyster larvae. In this way a population can be built up that will eventually sustain itself. As long as it is unknown whether *Bonamia* disease is present or absent in the North Sea, spat collection needs to take place in a *Bonamia*-free area. The Limfjord in Denmark is such an area. Dutch oyster growers use empty mussel shells to collect oyster spat. This method, and the use of oyster shells and other substrates, such as reef balls, can be tested.
Important factors to study are the moment of exposure of the collectors relative to the larval abundance and the size of the spat for which transport to the North Sea is most successful. In addition, ways to introduce the collectors with spat into the North Sea need to be tested. The desired scale for plots seeded with the collected spat is 5 ha. As larval production occurs once a year, a back-up spat settlement on collectors in a hatchery is envisioned to ensure the availability of collectors with spat for small-scale testing of the method. These substrates with spat can be introduced in the bottom cages to study growth and survival. Collectors without oyster spat can also be introduced in the cages to study potential natural spat fall.



Development of a flat oyster bed in the North Sea

Results of the oysters in the bottom cages at a number of sites in the North Sea will give information on the best location for survival, growth and gonad development. Since the transition of the youngest stages, that reproduce as males, into reproducing females will take several years, a three-year trial is planned. Parallel to the bottom cage experiments, larval dispersal by currents is modelled to find the best location for larval retention. Based on the information on survival, growth, gonad development and larval retention the two best locations will be selected. At these locations the sediment grain size, bathymetry and fauna will be studied in detail to select the best area for introduction of substrates with oyster spat. Next, introduction of substrates with oyster spat on 5 ha plots will be carried out. As stated above, this is carried out during a three-year trial period, in order to allow maturation of the spat. After three years, the flat oyster bed can be expanded by introducing more substrate with flat oysters. Table 1 presents the time schedule for development of a flat oyster bed in the North Sea.

Table 1. The time schedule for development of a flat oyster bed in the North Sea.

Year	1	2	3	4	5	>5
Test of bottom cage set-up in Oosterschelde	X					
Monitoring oysters in bottom cages at 10-15 locations in the North Sea	X	X	X			
Spat collection in the field	X	X	X	X	X	X
Larval production for collectors in hatchery	X	X				
Tests of transport of substrate with spat to the North Sea	X	X				
Model larval dispersal		X	X			
Study sediment grain size, bathymetry and fauna		X	X			
Introduction of substrates with oyster spat at two locations (5 ha plots)			X	X	X	
Monitor substrates with oyster spat at two locations			X	X	X	
Expand best location and monitor development of oyster bed						X

Annex 2 Verslag van de workshop "Herstel Platte oester op de Noordzee" Den Haag, 02-12-2014

1. Opening

De workshop wordt geopend door voorzitter Jan Paul van Soest, die de basisregel voor de discussies en de verslaglegging benadrukt. De Chatham House Rule is van toepassing, wat wil zeggen: uitspraken, anders dan gedaan in presentaties, mogen door niemand van de aanwezigen[1] geciteerd worden, maar de algemene inzichten kunnen in eigen kring vrijelijk worden gebruikt.

2. Inleiding opdrachtgevers

Marleen Wijnstok licht toe dat het Platte oester herstelproject onder diverse beleidslijnen valt, onder verantwoordelijkheid van twee ministeries: Economische Zaken en Infrastructuur & Milieu. De beleidslijnen zijn:

- De Kader Richtlijn Mariene Strategie (I&M, EZ)
- De Uitvoeringsagenda Natuurlijk Kapitaal (EZ)
- De Natuurambitie Grote Wateren (EZ).

Vandaar dat de beide ministeries samen fase 1 van het Platte oester herstelproject ondersteunen.

Tom van der Have vult aan dat Stichting De Ark eveneens aan fase 1 heeft bijgedragen, voor het uitvoeren van duikacties naar Platte oesters op de Noordzee.

3. Presentaties, vragen en opmerkingen

Achtereenvolgens Aad Smaal, Tom van der Have en Pauline Kamermans presenteren de bevindingen en conclusies van fase 1. De hoofdconclusies zijn:

- Platte oester herstel op de Noordzee is nuttig vanuit diverse gezichtspunten tegelijk: biodiversiteit, ecosysteemdiensten (waterfiltratie, nutriënt recycling e.d.) en - op de lange termijn - mogelijk ook oogst (van de oesters zelf en van soorten die van oesterbanken profiteren, zoals vissen, kreeften, garnalen e.d.).
- Zelfs bij het aanbieden van geschikte ('harde') ondergrond, gaat het herstel maar heel langzaam. Het kan versneld kan worden door op geschikte plekken zowel de oesters zelf als de benodigde ondergrond aan te bieden. Geschikte plekken daarvoor zijn, in beginsel:
    - Harde ondergrond (eventueel eerst aan te brengen)
    - Rustig en diep water, met weinig zeestroming
    - Voldoende voedsel (algen)
    - Geen bodemberoering
- De volgende gebieden komen het meest in aanmerking: Centrale Oestergronden, Friese Front, Voordelta/Vlakte van de Raan en de Zeeuwse Delta (de laatste vooral als controle - locatie, omdat daar Platte oesters al gedijen).
- Om het herstel in de praktijk te bewerkstelligen is een stapsgewijze strategie nodig, waarbij per stap zoveel mogelijk wordt geleerd over groei-, overleving- en voortplantingscondities van Platte oesters. De stappen zijn:

[1] Zie de appendix bij dit verslag voor de lijst van deelnemers.

- Eerst geschikte locaties identificeren, met een omvang van enige hectares, op basis van gegevens als zeestroming, bodemreliëf en bodemsamenstelling (vooral: slibgehalte).
- Vervolgens, met behulp van kleine populaties uit te zetten Platte oesters, op een flink aantal (ca. 10) locaties, groei, overleving en reproductie ter plaatse bepalen.
- Daarna op de 2 à 3 beste plekken proberen om grotere banken aan te leggen, met een methodiek die is afgeleid van de manier waarop commerciële oestertelers dat doen (schelpmateriaal uitzaaien in het brongebied opdat daar jonge oesters op settelen; dit materiaal vervolgens ter plaatse brengen).

Vragen en opmerkingen in de discussie hierna:

- Probeer ook de invloed van 'regime shifts' (met name die van rond 1890) op het verdwijnen van de Platte oesterbanken op de Noordzee te achterhalen. Aan de dominante invloed van de visserij bij het wegraken van de banken hoeft niet getwijfeld te worden, maar hoe meer je van eventuele co-factoren weet, des te groter de kans op succesvol herstel.
- Gebruik de ervaringen met Platte oester herstel in USA en Nieuw Zeeland. De uitgangssituatie is enigszins anders (ander subtype oesters, grotere populaties nog aanwezig), maar er zijn mogelijk bruikbare ervaringen.
- Is er iets bekend over de mechanismen achter de oorspronkelijke vestiging van de oesterbanken op de Noordzee, of in andere wateren? Dat kan je ook helpen bij het inrichten van succesvol herstel.
- Onderbouw duidelijker dat de Japanse en de Platte oester andere habitat-eisen hebben en dat ze dus niet met elkaar concurreren.
- Onderscheid bij het achterhalen van patronen in zeestromingen de invloed van het getij en de 'reststroom'. Bij het onderzoeken van het wegstromen van oesterlarven is de reststroom van meer belang dan de getijstroom. Kijk daarbij specifiek naar de stroming langs de bodem, want daar moeten de oesters zich vestigen.
- Probeer herstel-instrumenten als broedcollectoren en beschermingsconstructies (kooien, rifballen) eerst op beperkte schaal uit, liefst op makkelijk bereikbare plekken, zoals de Zeeuwse Delta. Reden: de open zee stelt je steeds weer voor verrassingen (invloed stormen, dichtgroeien openingen, onverwachte predatoren e.d.).
- Op broedcollectoren kunnen zich ook andere soorten vestigen. Wat daar mee te doen als broed uit bijv. de Limfjord wordt gehaald?

4. Resultaten deelsessies

In twee deelsessies werd parallel gesproken over A) mogelijke locaties, en B) mogelijkheden tot financiering en andere vormen van support.

A. Mogelijke locaties

Deze sessie ging over het vinden van geschikte locaties voor Platte oester herstelpogingen. Er werden 5 categorieën locaties geïdentificeerd die in beginsel geschikt zijn, met daarbij de volgende kanttekeningen:

- KRM gebieden, zodra de beschermingszones (waar bodemberoerende visserij is uitgesloten) zijn ingesteld. Dat is naar verwachting vanaf 2016.
- Natura 2000 gebieden, zodra daar de beschermingszones zijn ingesteld (eveneens 2016+), met als extra complicatie dat de Platte oester geen aangewezen soort is voor Natura 2000; misschien is een passende Beoordeling nodig t.b.v. vergunningverlening.
- De vrijwaringszone rondom olie- en gasinstallaties. In beginsel zijn deze geschikt, aangezien (boomkor)visserij er tegenwoordig effectief uit wordt geweerd. Bovendien staan er veel in de

Centrale oestergronden. Een probleem is dat de geldende veiligheidsregelgeving heel zwaar is; dat bemoeilijkt bezoeken t.b.v. onderhoud en monitoring.

- Windparken. In beginsel zijn deze eveneens geschikt, zij het dat de bestaande parken niet in gebieden staan die optimaal zijn voor vorming van Platte oesterbanken. Bovendien is de veiligheidsregelgeving hier is eveneens zwaar. EZ en I&M ontwikkelen momenteel beleid om medegebruik van windparken mogelijk te maken en om de veiligheidsregelgeving minder strak te maken.
- Rigs-to-reefs e.d. (bijvoorbeeld via het Living North Sea Initiative); dat project heeft echter nog veel uitwerkingstijd nodig.

Het projectteam geeft aan reeds met alle betrokken partijen over de mogelijkheden te overleggen. De grootste kans op korte termijn lijken de vrijwaringzones rondom olie- en gaswinninginstallaties in de Centrale Oestergronden en Friese Front. Helaas is er - door de gecompliceerde situatie rondom de platforms - geen vertegenwoordiging uit die sector bij de workshop aanwezig, maar het projectteam is wel in gesprek met de ogenschijnlijk meest bereidwillige bedrijven, zoals GdF-Suez.

B. Financiën/support

In deze sessie werden de mogelijkheden onderzocht om uitvoering van Platte oester herstelpogingen te financieren. Participatie vanuit de maatschappij is een voorwaarde van de overheid. In de groep ontstond snel consensus dat het daarbij ook gaat om andere vormen van ondersteuning dan geld alleen. Als relevante en kansrijke vormen van ondersteuning in geld en in natura werden aangemerkt:

- Meedenken met de vormgeving van de herstelpogingen en duurzame oogstmethoden, bijvoorbeeld vanuit de oestersector. Deze is daartoe bereid.
- Het ter beschikking stellen van middelen die onderhoud en monitoring van herstelexperimenten mogelijk maken, zoals boottijd naar olie- en gaswinninglocaties en windparken. Met deze sectoren voert het projectteam reeds overleg, zoals hierboven gemeld.
- Samenwerking met reeds geplande projecten, zoals de aanleg van schelpdierbanken in de Voordelta en de Vlakte van de Raan (project van WNF; er is al samenwerking tussen WNF en projectteam bij de voorbereiding van dit project) en in het Droomfondsproject 'Met de stroom mee' (als dit wordt toegekend, de beslissing valt in februari 2015). Maar ook een donateursactie t.b.v. fondsenwerving vanuit WNF behoort tot de mogelijkheden.
- Mobilisatie van publiek en politiek draagvlak voor het project. Hieraan kunnen partijen als Greenpeace en WNF bijdragen. Suggestie voor een pakkende slogan: **Koester de oester.**
- Fondsvorming door kosten uit te sparen bij afdanking van olie- en gasplatforms (slechts ten dele ontmantelen). Dit is een (lange termijn) optie in het eerder genoemde 'Living North Sea Initiative' (IMSA).

Het is duidelijk dat er op korte termijn geen economisch verdienmodel is; daarvoor is het Platte oesterherstel een project met te lange termijn en teveel onzekerheid. Op directe financiering vanuit economische partijen kunnen we de komende jaren dus niet rekenen.

Het is zaak om de hierboven genoemde vormen van ondersteuning op korte termijn concreet te maken en tot een samenhangend plan te vormen. Het projectteam pakt dit op.

5. Slotwoorden

Jan Paul van Soest stelt als volgende stap voor om een beeld te creëren van het beoogde eindresultaat (hoeveel km^2 oesterbank, qua orde van grootte, willen we terugkrijgen?) en daarbij alle daardoor gerealiseerde maatschappelijke waarden en meewerkende factoren den brede te betrekken. Niet vergeten bijvoorbeeld: de CO2 vastlegging door schelpdierbanken. Het is ook van belang de bereidheid tot medewerking van de ons omringende landen te onderzoeken. Te denken valt daarbij vooral aan Duitsland, waar - ook in opdracht van de overheid - recent een haalbaarheidsstudie naar Platte oesterherstel uitgevoerd (met analoge conclusies als de onderhavige).

Namens het projectteam laat Hein Sas weten deze handschoen graag op te pakken en een plan te gaan ontwikkelen, waarbij de adviezen en kansen die op de workshop zijn geopperd - uiteraard - worden meegenomen. Het projectteam komt daartoe graag bij de workshopdeelnemers en andere geraadpleegde partijen terug voor nader overleg. Dit zal op afzienbare tijd gebeuren: begin 2015. Hij zegt tevens toe dat alle aanwezigen het rapport van fase 1 toegestuurd zullen krijgen, nadat dit door de opdrachtgevers is goedgekeurd. Dat zal naar verwachting eveneens begin 2015 zijn.

Deelnemers aan de workshop 'Herstel Platte oester op de Noordzee', Den Haag, 02-12-2014

Voorzitter: Jan Paul van Soest, De Gemeynt

Deelnemers:

- Janne van den Akker, IMSA/Living North Sea Initiative
- Wouter van Broekhoven, VisNed
- Waldo Broeksma, Rijkswaterstaat, Zee & Delta
- Tom Grijsen, Greenpeace
- Ingvild Harkes, Wereldnatuurfonds, Oceans & Coasts Programme
- Ton IJlstra, Ministerie van Economische Zaken, Directie Natuur & Biodiversiteit
- Anne-Mette Jorgensen, IMSA/Living North Sea Initiatieve
- Wouter Lengkeek, Bureau Waardenburg/Stichting Duik de Noordzee Schoon
- Han Lindeboom, IMARES
- Carolien van der Mark, Ark Natuurontwikkeling
- Vincent van der Meij, Ministerie van Economische Zaken, Directie Natuur & Biodiversiteit
- Godfried van Moorsel, Ecosub
- Anne Paijmans, Ministerie van Economische Zaken, Directie Natuur & Biodiversiteit
- Jaap de Rooij, Nederlandse Oestervereniging
- Edwin Verduin, Grontmij
- Jeroen Vis, Ministerie van Economische Zaken, Directie Natuur & Biodiversiteit
- Monique van de Water, Delagua Consultancy
- Bas Weenink, Ministerie van Infrastructuur & Milieu, Directie Noordzee
- Marleen Wijnstok, Ministerie van Economische Zaken, Directie Natuur & Biodiversiteit
- Gijs van Zonneveld, Wereldnatuurfonds/Ark Natuurontwikkeling

Projectteam:

- Aad Smaal, IMARES (projectleider)
- Tom van der Have, Bureau Waardenburg
- Pauline Kamermans, IMARES
- Hein Sas, Sas Consultancy