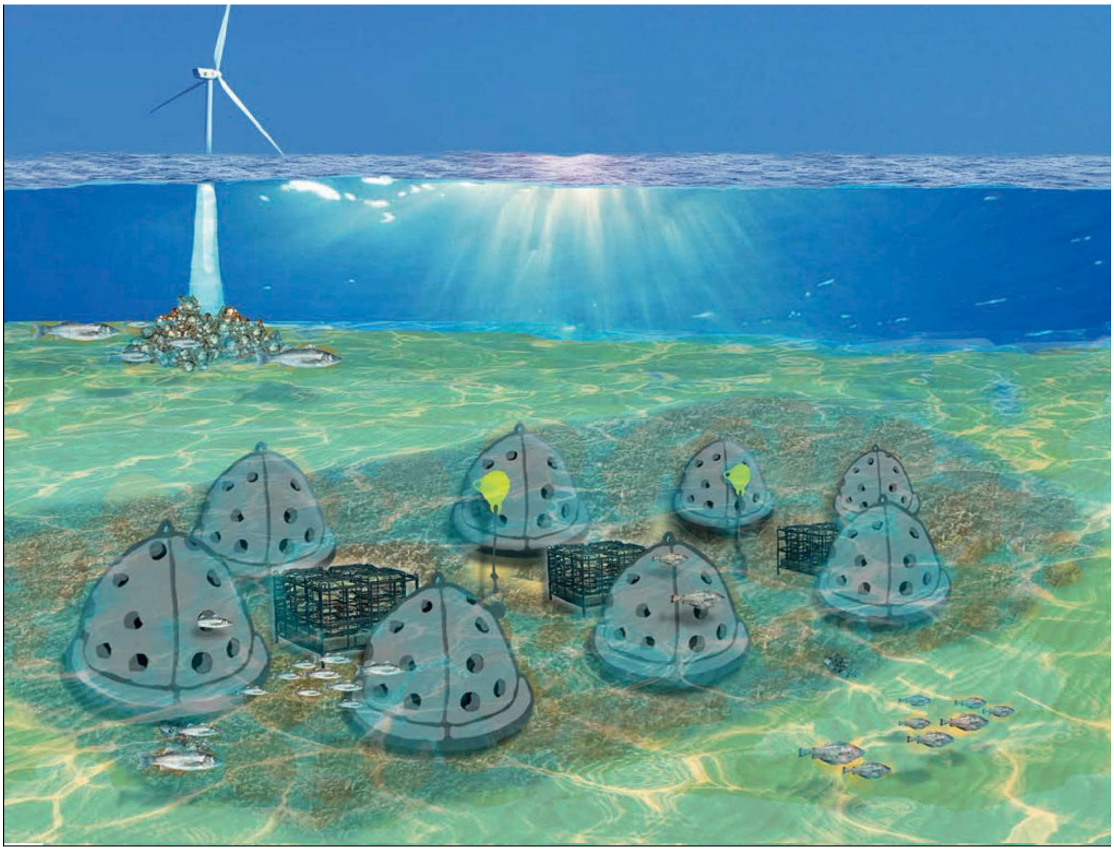
Flat oyster pilot design in North Sea offshore wind farm



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June 27, 2018

Preface

Stichting De Noordzee and Natuur & Milieu assigned the production of this report. It is intended to:

- Provide general guidelines for flat oyster pilot development in offshore wind farms in the Dutch North Sea area
- Provide a cost overview of flat oyster pilots in offshore wind farms in the Dutch North Sea
- Provide recommendations for further research

The authors thank the project principals and the companies involved in the production of this report, in particular Van Oord and Eneco, for information and comments provided. Marije Stokkers, Bureau Waardenburg, prepared the pilot drawings.

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Summary

Motivation flat oyster pilot in wind farms

Flat oyster beds provide natural hard-substrate habitat in a predominantly soft-bottom marine environment. In addition, they change environmental conditions by filtering, nutrient recycling and carbon storage. Hence, North Sea marine life, probably even including fish production, will increase when flat oyster beds are restored.

Since bottom-trawling fishery is excluded in wind farms, an essential condition for flat oyster restoration is fulfilled here. Basic conditions for flat oyster growth and reproduction, such as food availability, sediment composition and sea floor stability, are also met in several wind farms off the Dutch coast. Hence, flat oyster restoration in wind farms constitutes a potential marine biodiversity enrichment opportunity.

The current report provides key information on design, deployment, monitoring and final removal of a flat oyster restoration pilot in a wind farm in the Dutch part of the North Sea.

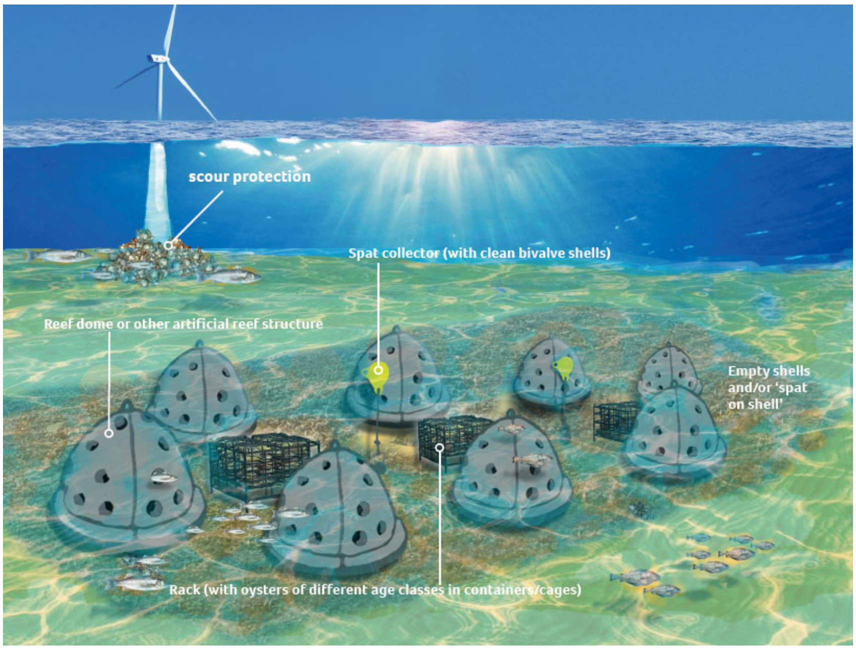

Figure S1: Layout for a typical offshore flat oyster pilot. Spat collectors will be positioned between reef domes and cages. The drawing is not according to scale. The total area with shells will be ca. 100 x 300 m.

General components

The primary objective of a flat oyster restoration pilot is to test the feasibility of active restoration of offshore flat oyster beds[1], in particular in a wind farm. The secondary objective is monitoring the success factors of oyster restoration ('learning by doing'). The feasibility test starts with a small initial or test population (300 adult and 300 young oysters) and monitors its survival, growth, reproduction and recruitment (settlement of young oysters) for 5 years.

We recommend using flat oysters, which originate from a natural population, free of Bonamia and with a low risk of presence of alien invasive species. In addition, the oysters are preferably

[1] The term 'reef' is often employed internationally to indicate an aggregate of flat oysters. However, 'bed' is more common in the European context, as oysters can also be found within the sediment in high densities.

harvested carefully and manually, without destruction of their habitat. The oysters need to be treated to strongly reduce all risks by eliminating all alien invasive species that are attached.

If these biological conditions are met, the resulting oyster reef can generate healthy and self-supporting reefs. Population extension may be stimulated through deployment of substrate and young oysters settled on shell material ('spat-on-shell').

The test population of flat oysters should be well defined and retraceable, therefore it should be contained in racks, designed to remain stable on the North Sea floor. In order to allow monitoring survival, growth and reproduction of the oysters, these racks have to be hoisted up every year. This implies that they should be placed at a well-defined location on the seabed, by means of a vessel equipped with a crane, dynamic positioning instruments on GPS and a Remotely Operated under water Vehicle (ROV) with camera. This type of vessel is also required to avoid risks to wind farm equipment. Hoisting the racks allows regular maintenance too. In particular, attached marine growth should be regularly removed (at least once a year), since this will tend to block the water flow through the cages in which the oysters are contained, resulting in risk of suffocation.

Basic legal requirements for this type of pilot are:
- A Nature Conservation Act (Wet natuurbescherming) permit.
- A Water Act (Waterwet) permit.

General pilot components and layout are shown in figure S1.

During the project lifetime (5 years minimum), the following activities are recommended:
1. Year 1. To survey the pilot area for physical suitability and biodiversity ('T_0 monitoring') in April – May of year 1 and to deploy the oysters before the start of the summer period, i.e. ultimately by 15 May. By doing so, the population will probably be productive that same year. If deployment previous to 15 May is not possible, deployment should be postponed to October or later in the year.
2. Years 1-5. To deploy new, clean substrate (empty bivalve shells) in June – July of each year, i.e. when oyster larvae are in the water. Deployment of the substrate at this time ensures it is clean of fouling organisms and hence promotes flat oyster larvae settlement. We recommend developing an effective method to deploy the substrate on the seabed in a controlled way to facilitate monitoring.
3. Year 2. To inspect the pilot components in the subsequent autumn to spring, when also oysters are to be measured for survival and growth and substrate is to be investigated for young oyster settlement.
4. Years 1-2. To monitor settlement of juvenile oysters ('spat') by employing spat collectors, in the first 2 pilot years (after that period, the spat settlement pattern should be clear).
5. Years 3-5. Optional extension. If the oysters appear to survive, grow and reproduce well: to deploy new oysters in large amounts, to extend the bed. Probably, the most cost-effective method to do this is by deploying spat-on-shell.
6. Years 3-5. Biodiversity monitoring is recommended from year 3 onwards, since the flat oyster bed may start to develop form that moment on.
7. Year 5 (or later). After the final year the pilot equipment must be removed (by law) and oysters and substrate can then also be monitored (but do not have to not removed).

A cost estimate is provided in Table S1. The unforeseen posts are relatively large (ca. 30%) because it is uncertain if specific tasks can be combined and accomplished in one day. This is partly related to the availability of suitable weather. Ship time costs are calculated for one-day campaigns. These will be lower for two consecutive days, because the mobilisation / demobilisation costs will remain the same.

Table S1: Cost estimate of a flat oyster restoration pilot (general components).

Activity / costs	Ship time (€)	Material (€)	Scientific personnel (€)	Totals (€)
Survey pilot area (physical characteristics, biodiversity)	26.000		3.000	29.000
Design and work method statement			8.000	8.000
Planning (assumed to be done by principal)				p.m.
Permits			4.000	4.000
Pilot equipment cost (oysters, spat collectors and substrate)		22.500		22.500
Pilot deployment	26.000		5.000	31.000
Inspection & monitoring (annually except for year 5, i.e. 4 years in total)	104.000		12.500	116.500
Recruitment monitoring (deploying/analysing spat collectors; 2 years)	52.000		2.100	54.100
Substrate deployment (5 years)	104.000	20.000		124.000
Deployment spat-on-shell (4 years) to extend pilot		124.000		124.000
Biodiversity monitoring (3 years)		9.000	9.000	18.000
Removal + monitoring (final year)	26.000		2.000	28.000
Final report			8.000	8.000
Unforeseen	156.000	63.700	28.000	247.700
Subtotal	494.000	239.200	81.600	814.800
Onward planning + pilot management (5 years, 10% of subtotal, assumed to be done by principal)				p.m.
Total pilot cost (5 years)	494.000	239.200	81.600	814.800

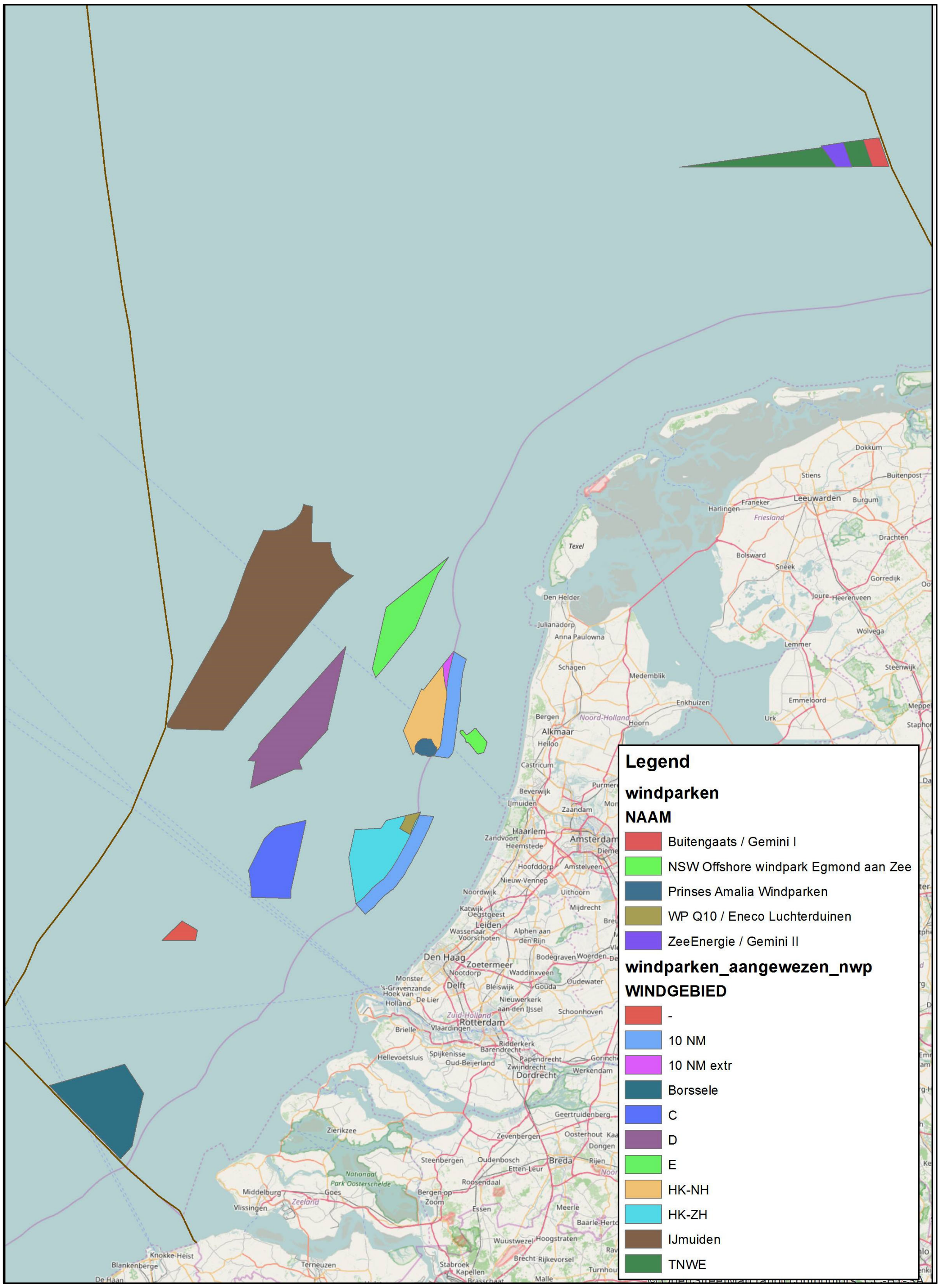

Figure 1. Map of the locations of existing and planned wind farms in the Dutch section of the North Sea (DSC: Dutch Continental Shelf). From Smaal *et al* (2017).

1 Introduction: flat oyster reef restoration

1.1 General introduction

Smaal *et al.*, (2015) provide general information on flat oyster history, growing conditions and the ecological value of flat oyster beds. Flat oysters once covered a large area, approximately 20.000 km^2 in the North Sea, near-shore as well as offshore. This shows flat oysters can survive and reproduce in rather deep marine waters, up to 50-60 meters and maybe even more. The importance from the viewpoint of nature restoration is that flat oyster beds provide a natural hard-substrate habitat in a predominantly soft-bottom marine environment and change other environmental conditions as well by filtering, nutrient recycling, providing shelter and carbon storage. This habitat is home to a diverse biotic community.

For North American waters, field surveys and ecological modelling showed that fish and mobile crustaceans thrive on oyster beds (Ermgassen *et al.*, 2015, 2017). We assume that this is plausible for the North Sea too. Hence, North Sea marine life, including fish and mobile crustacean production, increases when flat oyster beds are restored.

Smaal *et al*., (2015) have also reasoned that flat oyster restoration[2] in the North Sea should be feasible. In general, abiotic conditions (including bottom shear stress and stability, current velocity, salinity, sediment composition, temperature, water depth and absence of bottom disturbance) and biotic conditions (diseases, food availability, predators) should allow flat oyster growth and reproduction in large parts of the North Sea near-shore and offshore.

Since bottom-trawling fishery is excluded in wind farms, an essential condition for flat oyster restoration is met here. According to Smaal *et al.*, (2017), basic flat oyster growth and reproduction preconditions are also met in (parts of) several wind farms off the Dutch coast. The most suitable are the two wind farms Zee-Energie and Buitengaats (together constituting the Gemini wind farm). Moderately suitable are Luchterduinen, OWEZ and part of Borssele (Figure 1).

There are two additional basic requirements for flat oyster restoration: (1) a (nearby) source of larvae; and (2) sufficient supply of substrate suited for settlement. If these additional requirements are not fulfilled (and if abiotic and biotic conditions are favourable), then adult oysters have to be deployed in combination with the appropriate settlement substrate (Sas *et al*., 2016, Smaal *et al*., 2017).

1.2 Offshore oyster restoration

To date, offshore oyster restoration projects have been very rare, worldwide. Most current projects are in estuaries or near-shore areas. The first offshore project worldwide was started last year, in the German North Sea area[3].

Since experiences are rare, it is not certain whether it is feasible to restore flat oyster beds in offshore areas, including the North Sea. The main uncertainties are (see Sas *et al.*, 2016):

- Do the currently available flat oysters survive under offshore conditions? Since the oyster beds disappeared form the offshore North Sea, about 100 years ago, populations have remained in estuarine areas, which differ considerably in water depth, wave dynamics, temperature and algal species (food of flat oyster). Adaptation of these populations to estuarine conditions may have made them less suited to survive, grow and reproduce in the open North Sea.

- Will restoration of flat oysters lead to a self-sustaining population? If the flat oysters do survive, grow and reproduce in these offshore conditions, larvae may drift away from their

[2] We employ the term ‘restoration’ instead of ‘re-introduction’, since there were extensive flat oyster beds in the North Sea area (though not always exactly there where wind farms are located or planned).
[3] https://www.awi.de/en/science/biosciences/shelf-sea-system-ecology/main-research-focus/european-oyster.html

parent population, to settle and reproduce (‘recruit’) elsewhere. This would preclude the formation of self-sustaining oyster beds, particularly in the current situation where oysters beds elsewhere in the North Sea are absent.

Getting insight in these aspects is why offshore flat oyster restoration pilots should be accompanied with basic monitoring (see Chapter 3) and why it is recommended to start with a small ‘test’ population (600 individuals, see Chapter 6).

1.3 Overview

We first list the pilot objectives, and subsequently present requirements and constraints of the design, legal requirements, sourcing of the oysters, basic pilot components and offshore implementation, costs estimates and project planning. Activities include equipment removal when the pilot is finalised.

2 Objectives of flat oyster restoration pilot in wind farm

There are two objectives of a flat oyster restoration pilot:

1. To test the feasibility of actively restoring offshore flat oyster populations, in particular in a wind farm. It is recommended to start with a small test population, but if successful and to extend it with more oysters, as this can become the nucleus of a larger oyster bed.

2. The secondary objective is monitoring the success factors of oyster restoration (‘learning by doing’) to optimize the pilot design itself, to maximize the survival, growth, reproduction and recruitment conditions of the oysters and to develop more cost-efficient monitoring methods.

There are two conditions to the flat oyster restoration pilot:

1. ‘Learning by doing’: Since it not clear, whether currently existing flat oyster populations are still adapted to offshore conditions and whether (or under which conditions) flat oyster larvae settle near their parent population, it is essential to monitor survival, growth, reproduction and recruitment.

This type of monitoring should be sustained for at least 5 years, in order to allow adaptive optimization of pilot design and management (‘learning by doing’) and to account for inter-annual differences in conditions. Besides, monitoring of biota in and around the pilot is recommended, to demonstrate the positive effect of flat oyster beds on biodiversity.

2. Avoid negative effects of the pilot. All care should be taken to avoid or eliminate potential negative pilot effects. In particular, risks of introduction of diseases or invasive alien species with the oysters should be avoided. Also, the pilot equipment has to be removed after pilot finalisation.

3 Design requirements, constraints and risks

Flat oyster pilots include experimental structures, such as racks with oysters, reef domes, racks and spat collectors with settlement substrate to provide the two, basic requirements for oyster restoration: (1) a source of larvae; and (2) a sufficient supply of settlement substrate. These components are more discussed in detail in chapter 6.

In addition, offshore pilots have specific requirements and constraints related to the water depth, marine environment, hydrodynamics, wind farms and ship time limitation. In this section these factors are briefly discussed for the racks, spat collectors and settlement substrate.

Flat oysters in racks
In order to work with a well-defined and retraceable flat oyster population, a representative number should be contained. The best containment methods are racks, with wide meshes (several cm). These allow water (containing oxygen and algae) to enter and excrements to leave the contained population. Employment of inner cages, also with wide meshes and 'holders', in which the oysters are placed at equal distance so that they do not hinder each other's filtering activity, is recommended.

The outer racks should be sufficiently sturdy and heavy, so that they remain undamaged and firmly in place under the severe North Sea conditions. At least 3 racks should be deployed, in order to account for damage to the population, such as by unexpected sand waves covering the racks. Each rack contains 100 adult oysters and 100 young oysters at a minimum. Before put into racks, oysters have to be individually measured and weighed and placed inside the racks/cages/holders.

Hoisting of racks
Employing divers in offshore wind farms is undesirable for most Dutch windfarm owners, and should therefore be avoided. In order to observe survival, growth and reproduction of the pilot's oyster population, racks should be retraceable and hoistable to the surface. This implies that they should be placed at a well-defined location on the seabed, by means of a vessel equipped with a crane and dynamic positioning instruments.

This type of vessel is also required to avoid risks to wind farm equipment. The required crane lifting capacity is relatively small, pilot equipment loads will not exceed 2,000 kg. Except for the removal stage, when equipment such as reef balls can become overgrown and fixed to the sea floor. This requires a crane with 5,000 kg lifting capacity.

Hoisting the racks also allows regular inspection and maintenance. In particular, attached organisms (epibionts) should be regularly removed (at least once a year), since this will tend to block the meshes. By doing this quickly (within 1 days), hoisting will not harm the oysters in the racks. If an oyster bed starts to develop on the sea floor around the racks, there is a risk of damage to these oysters by hoisting and replacing the racks, but this risk is relatively low.

Artificial reef structures
Artificial reef structures are placed in order to protect the pilot whilst providing additional substrate at the same time. The design of cages and reef domes is robust and resistant to entanglement of fishery hooks. Because of the water depth at the pilot site and size of the cages and reef domes (max. 1 m above sea floor) there are no risk for passing vessels. The risks and impact of the pilot, including all structures, natural and artificial substrates and live oysters on species and habitats are evaluated in the pre-assessment. It is concluded that there are no risks for protected birds, mammals and habitats. In addition, there are no risks that birds are attracted to the pilot site, because the water depth is too high.

Spat collectors and settlement substrate
Spat collectors are nets or mesh bags with clean dead shells (cockles, mussels, oysters) to detect and measure settlement of oyster larvae. These structures will be deployed together and close to racks and reef domes and collected with a ROV later in autumn, when oyster spat is large enough to detect.

Dead shells can also be placed directly on the sea floor over a relatively large area. To prevent dilution over a very large area, they will be contained and deployed in biodegradable nets. All dead shells need to be clean and without attached organisms (epibionts) to enhance settlement rate of oyster larvae.

4 Legal requirements

4.1 Introduction
Flat oyster restoration pilots, which introduce artificial structures in the marine environment, may require several types of permits. For the use of live animals, which are imported from other (EU or third countries), import licenses are required.

4.1 Nature Conservation Act
In the Netherlands, the Nature Conservation Act (Wet Natuurbescherming) of January 1, 2017 is the national implementation of the EU Habitat and Bird Directives and includes the protection of Natura 2000-areas and species listed in the annexes. The ministry of Agriculture, Nature and Food Quality ('Landbouw, Natuur en Voedselkwaliteit') is the responsible authority.

For each project an orientation phase or preliminary assessment ('Voortoets') is usually required to investigate if significant negative impacts on the conservation targets for species and habitats, for which a Nature 2000 area has been designated, can be excluded with certainty. If the conclusion is not affirmative, then an appropriate assessment ('Passende Beoordeling') is required to investigate in more detail if and how negative impacts can be prevented, if needed by altering the plan. When the conclusion is reached that negative impacts can be excluded with certainty, a permit application can be filed.

The type of pilot we will describe is relatively small and the oyster material to be employed free from diseases and treated against invasive species (see Chapter 5). Hence, we do not assume that there will be a significant impact on the designated North Sea nature values, so that an appropriate assessment will not be required. However, this type of pilot is new, so experiences are very limited. Hence, we assume that time to be spent on the full permit procedure is basically short, including the preparation of a preliminary assessment, with a wide uncertainty interval i.e. 2-10 days.

The decision period, the time period between application and the decision to issue a license by the relevant authority, is 13 weeks maximum, which can be extended with a period of 7 weeks maximum. From the date of issue of the license, third parties can file motivated objections against the license for a period of 6 weeks. The legal fees highly depend on the type and scale of the planned activities, but are usually very low for small project plans such as these.

4.2 Water Act
The Water Act (2009) regulates the management of surface water and ground water and also improves the relation between water policy and spatial planning. Each project or plan will be assessed with respect to the impact on quantity (safety and availability) and quality (sanitary and environmental effects, pollution) of surface and ground water. The Ministry of Infrastructure and Water Management is the responsible authority. A preliminary assessment is recommended to investigate if a license is needed. The procedure is usually less extensive than for the Nature Conservation Act.

The decision period, the time period between application and the decision to issue a license by the relevant authority, is 8 weeks maximum, which can be extended with a period of 6 weeks maximum. From the date of issue of the license, third parties can file motivated objections against the license for a period of 6 weeks maximum. The legal fees highly depend on the type and scale of the planned activities, €50-100 for small project plans such as these. Again, for the described type of pilot, total time expenditure for the permit will probably be short, but with some uncertainty, i.e. 2-10 days.

4.3 EU Directive "Checks on the imports of live animals"
Checks on the imports of live animals are regulated in EU Directive 91/496/EEC and EU Regulation 282/2004 and implemented by the Netherlands Food and Safety Authority (NVWA). Commission Regulation (EC) No 282/2004 of 18 February 2004 describes the necessary documents for the declaration of, and veterinary checks on, animals from third countries entering

the Community. The exporting company or institute has to take care of the necessary licenses and documents, so we do not assume that this takes additional time for the pilot initiator.

5 Sources and logistics of flat oysters for restoration projects in wind farms

5.1 Flat oyster characteristics

Without a larvae source, introduction of oysters is necessary for kick-starting restoration of a flat oyster population in the North Sea. This involves collecting oysters elsewhere and placing them into the water at the pilot site. The best placement period is early spring, before May 15. Summer is not appropriate, since this is the spawning period, which causes the oysters to be weak, so that they may die due to transport and replacement stress. Deployment in autumn and winter, given the appropriate weather conditions, is also possible.

For this type of pilot we recommend to employ a mixture of young (less than 3 years old) and adult (over three years old) oysters (see also Appendix 1 for more details), under the conditions that these oysters can be sourced without damaging the parent population and its habitat and that they are free of diseases and invasive alien species (Table 1). The reason to work with a mixture of adults and youngsters is that adult oysters can be females, whereas young oysters are always males. Hence, a mixture of a sufficient amount (more than a few hundred) is very probably productive from pilot year 1 onwards, whereas a population of small oysters, being all males, will remain unproductive for several years.

Adult flat oysters are grown in cultures in several countries surrounding or close to the North Sea (Norway, Sweden, Denmark, the Netherlands, United Kingdom, Ireland, France). Besides, there are some natural beds, e.g. in Norway. Transplanting oysters from these populations to the wind farm pilot can provide risks of spreading of diseases or non-native invasive species. In Europe, two diseases can be present in the oysters: the parasites *Marteilia refringens* and *Bonamia ostreae,* which cause large-scale mortalities in the flat oysters[4].

In addition, other species attach to oyster shells in the waters where the oysters grow. When these species are not present in the area where the oysters are transported to, they are by definition ‘alien species’. Some species can reproduce and disperse rapidly in the new area and become an ecological problem (‘invasive alien species’). These risks must be minimised when considering the source of the flat oysters for pilots in wind farms.

When harvesting oysters in cultures or natural beds, care should be taken that this is done in a sustainable way: negative effects to the flat oyster bed, the population present or other parts of the ecosystem around the bed must be avoided.

A group of 20.000 individuals could probably kick-start a population (expert judgement). This is under the assumption that 20% of that group consists of mature females and that survival from egg to adult is 0.01%. But this depends on the local hydrodynamics, as new oysters need to settle close to the parents in order to ensure reproduction (e.g., Smaal *et al.*, 2017).

As stated before, we recommend starting with a small population (600 oysters in total, of which 300 adults and 300 young) to test survival, growth, reproduction and recruitment under offshore conditions. Given the calculation presented above, oyster bed restoration requires the deployment of many more individuals.

5.2 Sources of flat oysters

Methods for acquiring flat oysters include harvesting from natural beds, spat collection and culture in the field, as well as hatchery production. In nature, oysters reproduce by releasing sperm in the water (spawning), which is taken in by the female oysters. Fertilisation takes place in the female oyster and larvae develop inside the mother animal. After about 10 days larvae are released and spend another 10 days in the water before they are ready to settle onto a hard substrate.

[4] Council Directive 2006/88/EC of 24 October 2006 on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals

Recently settled oysters are called ‘spat’. Spat grows to ‘seed’ (small oysters) that is the starting material for oyster culture. When hard substrate is provided at the time when oyster larvae are settling, oyster spat can be collected with spat collectors (Figure 2a). The most appropriate settlement substrate consists of empty shells. They should be clean and deployed just before the larvae are released by the mother animals, since flat oyster larvae do not settle on shell with a biofilm or other species, which are attached to organisms (epibionts). Young oysters, which settled on shell substrate, are referred to as ‘spat-on-shell’.

Spat from collectors can be harvested anytime. When growth conditions are good, spat collected in summer can be harvested for ongrowing at the end of the same year. In a hatchery, small oysters are produced in two steps: larvae and spat are produced indoors (Figure 2b), grow-out up to seed size generally takes place in an outdoor nursery, but can be done indoors in filtered seawater as well (Figure 2c).

Figure 2. (a) Spat collectors (picture Jacob Capelle), (b) larval rearing tank (picture Oscar Bos) (c) indoor nursery (picture Pauline Kamermans).

There are several options to obtain disease-free oysters without alien invasive species on the shells of the oysters. These are summarised in Table 1. Collection in the field must always involve a treatment to remove alien species that may be present on the shells of the oysters. Treatment involves brushing the oysters, dipping them in brine or chlorine in fresh water and washing. This reduces the risk considerably, but, when large numbers of oysters are treated, they cannot be inspected individually after treatment. Furthermore, small oysters harvested from spat collectors may not survive the treatment. The use of filtered seawater in hatcheries can prevent the contact between flat oysters with natural surface water and thereby reducing the risk of spreading invasive alien species.

Table 1. Sources of flat oysters for restoration projects in wind farms with options, restrictions and reliability of alien species absence (expert judgement).

Option	Restrictions	Reliability of alien species absence
Wild fishery	Harvest from disease-free area and treat oysters to remove alien species	High
Spat collection	Harvest from disease-free area and treat oysters to remove alien species	Medium
Hatchery production	Produce in disease-free environment, no treatment of oysters needed to remove alien species as long as nursery is indoors	Very high

Purchasing market-size oysters from a fishery or oyster farm will cost around €0.50 for oysters of 50-75 gram. If harvested by diving they are more expensive, €2-3 per oyster. Oysters under market size are generally not sold as a product. Spat collected in the field is used by the farmer for grow-out and also not sold as a product.

Hatchery seed costs about €40 for 1,000 oysters of 1 cm. As stated before, a productive starting population requires different sizes, because small oysters (younger than 3 years) are all males and large oysters can be females.

Natural disease-free populations of flat oysters are present in bays in Norway, Sweden, England, Scotland and Ireland. In some of these bays oyster culture takes place and spat or adults can be collected.

According to our information, Hotate AS in Norway can harvest adult and young flat oysters in a natural disease-free population with a low risk of presence of invasive alien species (Hafrsfjord, Norway). Oysters are harvested carefully, by divers, and then treated against alien species (see Appendix 2). Then the oysters can be shipped to the Netherlands. Small amounts (several times 600 oysters for several pilots) will not affect the natural population in Hafrsfjord. For pilots in The Netherlands, we have therefore assumed that these oysters, with the described treatment procedure, will be used.

Other companies that produce disease free oysters in polls are Bømlo Skjell AS, Storestraumen østers Innerøyen and Sogn Poll. And in Denmark Aquamind can start producing flat oysters in breeding ponds. Hatcheries that presently produce disease-free flat oysters are located in the United Kingdom (Seasalter Walney Ltd https://morecambebayoysters.co.uk), in France (Ostrea Marinove SCEA http://www.marinove.fr; Novostrea Bretagne SAS https://www.novostrea.net) and in Ireland (Tralee Bay http://traleebayhatchery.com/).

Considering adverse weather conditions, it may be necessary to keep the oysters, once arrived in The Netherlands, at the deployment harbour (e.g. Wageningen Marine Research, IJmuiden) for a maximum of 2 weeks. In this period, they will have to be kept alive in an enclosure supplied with running seawater.

5.3 Oyster costs

Our information is that total costs for harvest, treatment and transport to the Netherlands of disease-free flat oysters (such as the Hotate AS oysters) will amount to €2-5 per oyster. The cost interval is strongly dependent on the batch size. The cost of keep the oysters alive at the harbour, measuring and weighing and placing them inside the racks/cages/holders will amount to €1-10 per oyster. This cost interval is strongly dependent on the time the oysters have to be kept alive at the harbour, before being deployed.

All in all, the cost will amount to €3-15 per flat oyster, or €1,800 to €9,000 for a pilot with 600 oysters.

6 Flat oyster pilot: components and layout

6.1 Basic components, size and layout

A basic restoration project in an area where no oysters are currently present, consists of (1) introducing adult and young flat oysters to generate a supply of larvae and (2) deploying settlement substrate (preferably empty and clean shells, or other clean material). A pilot to study and optimize oyster restoration includes several temporary components, such as (3) racks, with inner cages and holders for oysters, (4) reef domes or other artificial reef structures for protection against pilot disturbance, pilot traceability and biodiversity enhancement and (5) spat collectors to monitor larval settlement (Figure 3,Table 2).

Oyster racks, reef domes and other structures are to be positioned on the sea floor by a vessel equipped with dynamic positioning on GPS coordinates (‘DP ship’), equipped with an Remotely Operated under water Vehicle (‘ROV’) with camera and multibeam sonar. In that case, they are retraceable, even in the usually turbid North Sea.

We have assumed that placement precision in the North Sea is about 30 meters (pers. comm. Jan Glas, Van Oord). It is probably better, but we use a wide safety margin. The resulting surface area of racks with oysters and reef domes or other reef structures therefore is ca. 1 ha per oyster rack to minimize risk of collision during deployment (Figure 3).

Data on equipment items (costs, dimensions, weight and production time) are provided in Appendix 1.

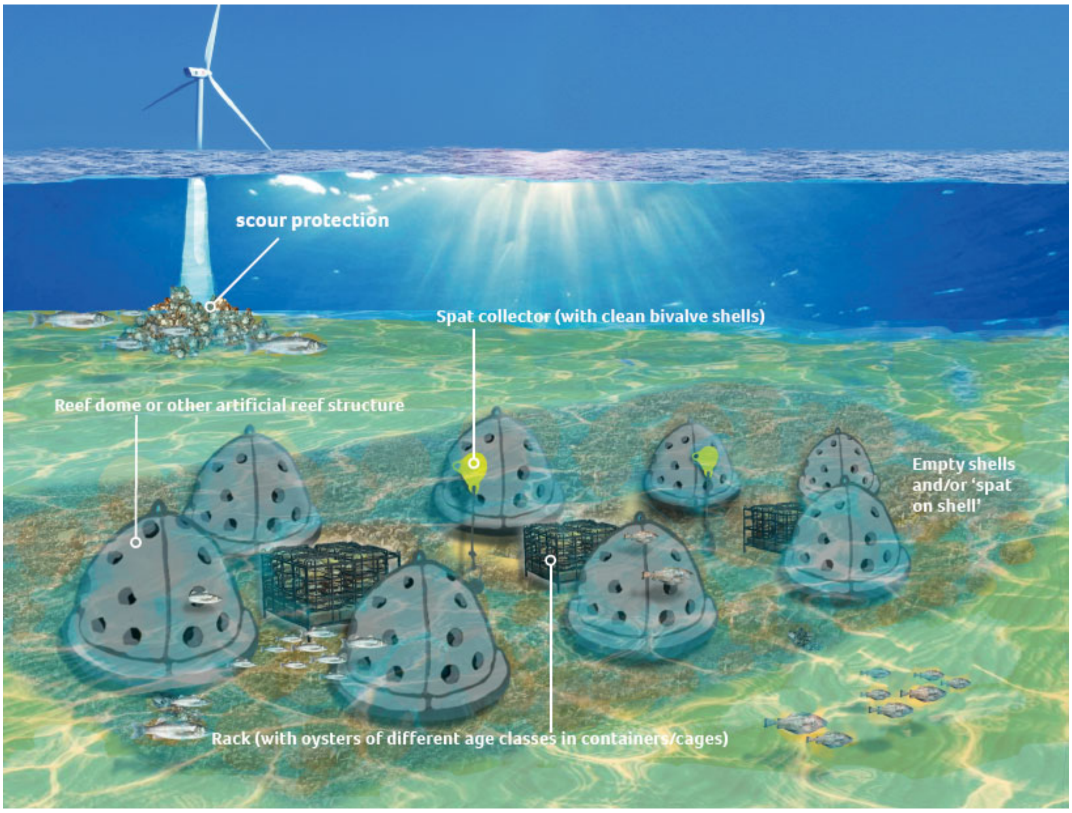

Figure 3. Layout for a typical offshore flat oyster pilot. Spat collectors will be positioned between reef domes and cages. The drawing is not according to scale. The total area with shells will be ca. 100 x 300 m (see text).

Table 2. Components of oyster restoration and pilot projects in areas without a source of larvae and limited supply of settlement substrate.

component	goal	comment	status	requirements
flat oysters	create source of larvae	different age-classes	essential	free of diseases
				clean, no epibionts
settlement substrate	recruitment	shells, cockles, oysters	essential	clean, no epibionts
racks, with inner cages	containing and retracing oysters	hoistable	essential	stability, open to water exchange
reef domes and/or other reef structures	protection, substrate for biodiversity enhancement	hoistable	optional	stability
spat collectors	monitoring recruitment	hoistable	optional	to be deployed when oysters produce larvae

6.3 Shells as settlement substrate

Clean and empty bivalve shells are suitable settlement substrate for flat oysters in natural habitats (Christianen *et al*., 2018; van der Have *et al*., 2017). In addition, flat oyster culture farmers use clean mussel shells to collect spat. The suitability of this substrate was confirmed by experiments of WMR in Lake Grevelingen (Kamermans *et al*., 2004; van den Brink, 2012: van den Brink et al, 2013). Clean cockle, mussel and oyster shells are all suitable. Availability differs: usually there is a good supply of clean mussel and cockle shells, but a much smaller supply of clean oyster shells.

We recommend to distribute substrate shells with an average layer thickness of 0,5 cm per m^2, since shellfish farmers have good spat settlement success with this density. As yet, we cannot define how much substrate area should be used. Covering the full pilot area of ca. 3 ha would require 150 m^3, which is of course a considerable amount to deploy offshore.

For optimal settlement the best timing to deploy substrate is in the period when peak numbers of larvae are in the water column. This period depends on the temperatures during spring and occurs in the period June – July in coastal waters (Sas *et al*., 2017) and therefore possibly later in offshore North Sea. When deployed earlier than June-July, the substrate will tend to become overgrown with marine growth, impairing the oyster settlement. Continuous temperature measurement (as provided by Rijkswaterstaat monitoring stations) combined with spat collectors (to be deployed around the pilot for at least 2 years) have to be used in order to establish the appropriate substrate deployment time.

Since currents will cause shell material to drift away from the pilot location, given water depth of 20 meters or more, a method to release the shells close to the bottom (e.g., with biodegradable nets) should be employed. This method has yet to be developed.

6.4 Oyster racks

Oysters are monitored in racks, which are positioned at the sea floor (Figure 4; the recommended offshore rack design is on the right). They consist of a steel frame (1,0 x 1,4 x 0,5 m, with 4 legs of 0,25 cm length). These racks (135 kg) are weighted with concrete slabs (342 kg) and weigh ca. 477 kg in total (excluding the oysters and inner cages).

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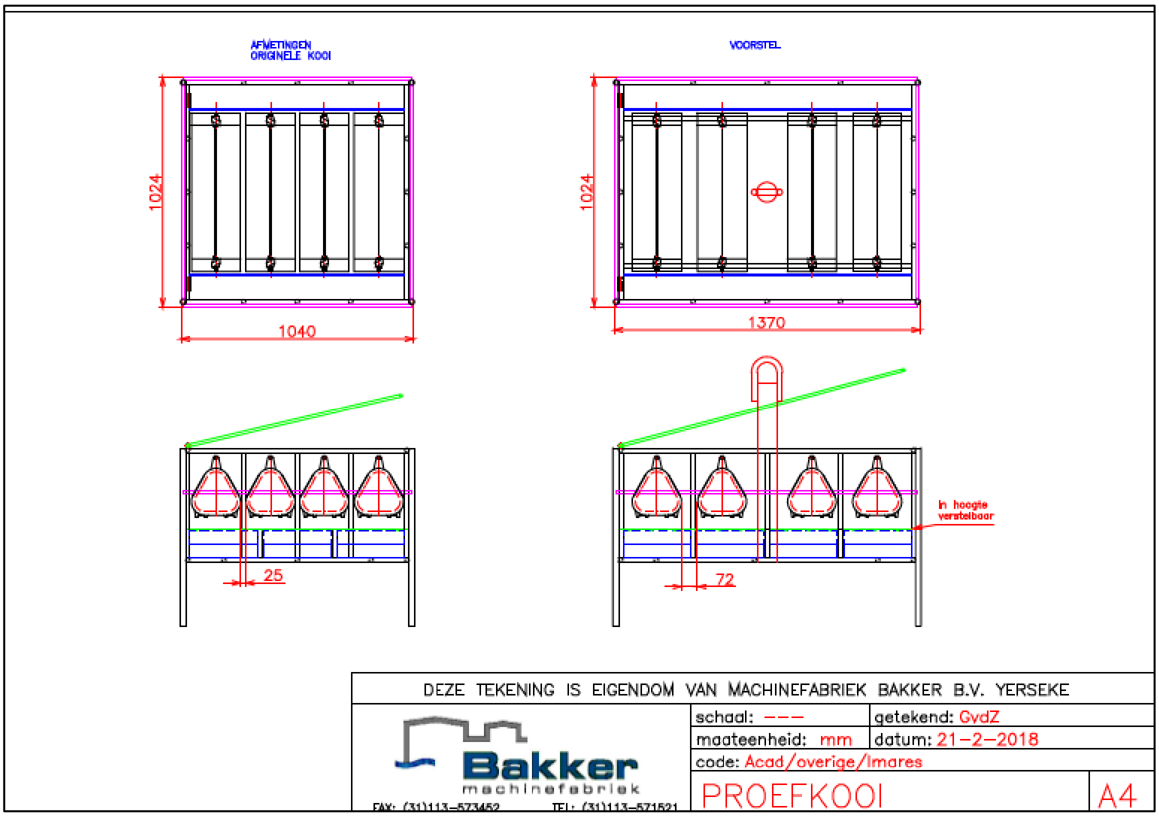

Figure 4. Rack design for flat oyster pilots.

Flat oysters are individually placed in PVC holders (Figure 5) in inner cages, in order to monitor their survival and growth individually. The cages enable easy removal and placement out of and into the racks.

This brings the total rack weight to ca. 500 kg. The racks are fitted with a cover, which can be opened and closed for oyster handling and an attachment point for a hoisting cable.

According to experiences in the Voordelta area (Sas *et al.,* 2017) with smaller racks (shown on the left of Figure 4) and in the German North Sea (Reuchlin, 2018) with a somewhat different design (without legs), these racks are stable and remain in place under near-shore North Sea conditions.

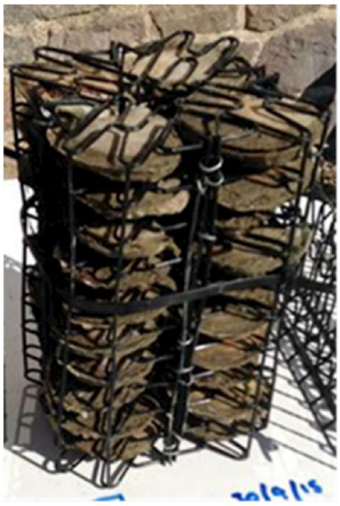

Figure 5. Holder for individual flat oysters.

Oyster racks are to be equipped with a system that enables them to be traced and hoisted to the surface. In order to avoid hindrance to shipping movements within wind farms by buoys on the surface, we recommend to use a system as depicted in Figure 6 below, to be fitted to the attachment point on the oyster rack. As stated above, the pilot equipment should be placed with reasonable accuracy, by a DP ship. Then, an ROV with camera steered from the DP ship can locate the buoys and attach a cable to the rack. The buoys are small (20 cm diameter) so as to not interfere with the ROV and the attachment/hoisting operation.

Should one want to test other substrate material, this can be put into the same type of racks that are employed for the oysters (Figure 4; somewhat strengthened if necessary) and deployed around the pilot too. This type of racks can contain ca. 0.7 m^3 of stones, so that total weight will not exceed 2,000 kg. These being even heavier than reef domes, will then also rest stably on the sea floor.

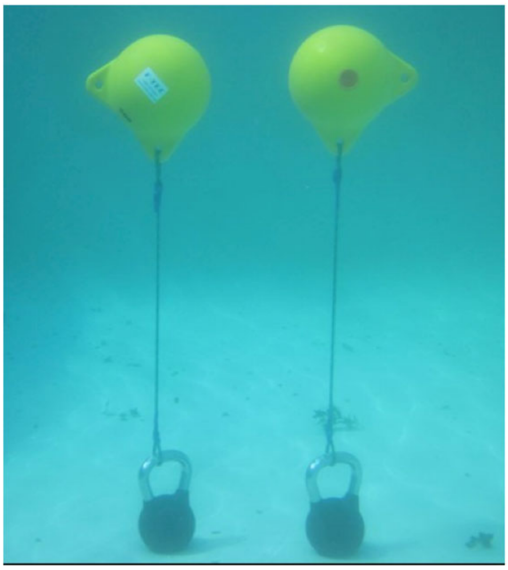

Figure 6. Buoys to be attached to oyster racks and other equipment on the sea floor, in order to enable hoisting.

6.5 Reef domes

Reef domes are concrete, dome-shaped structures with holes and an attachment point for hoisting on the top (Figure 7; 1 m diameter and 1 m height, Lengkeek *et al*., 2017). These are placed around the pilot site to provide artificial hard substrate, an extra orientation point for retracing the pilot and protection against disturbance (van Duren *et al*., 2016). They weigh ca. 800 kg. These reef domes are shown to be stable in North Sea conditions in other experiments, such as the Voordelta.

Reef domes and other artificial structures put around the pilot must be removed once the pilot is finalised. Therefore, they should also be fitted with a system as shown in Figure 7, in order to enable hoisting them up and transporting them away

Figure 7. Reef dome being deployed at sea in the Voordelta.

6.6 Spat collectors

Spat collectors can be employed to investigate the occurrence of flat oyster settlement near the pilot. Since oyster beds can only be self-sustaining if settlement occurs near the parent population, larval settlement is a crucial factor.

Spat collectors consist of clean dead shells (mussels, cockles, oysters) in mesh bags to provide experimental settlement substrate for oyster larvae (Figure 8). They are attached to concrete stones and again small, submerged buoys and should be attached for hoisting them up. We estimate that up to 10 collectors are required to get an impression of spat settlement around the pilot.

The advantage of spat collectors is that they can be deployed easily, at the time when the larvae are (supposed to be) in the water. Alternatively (or additionally), settlement substrate can be deployed in the oyster racks, but the disadvantage of that method is that the complete racks then have to be hoisted up and let down in order to put the substrate into them at the appropriate time. That is a relatively costly operation.

Figure 8. Spat collector unit with shells in mesh bags (nets) and yellow buoy.

Flat oyster larval production is supposed to be temperature-dependent, although it is not known how the exact relation is in offshore conditions. Therefore, we recommend performing continuous temperature monitoring during the summer period, or employ Rijkswaterstaat monitoring, so that the relation between temperature development and spawning moment can be established during the pilot. After 2 years of deploying spat collectors and temperature measurement, the relation should be sufficiently clear, so that they need not be employed anymore.

6.7 Extra pilot components

When the oysters appear to thrive after at least a year, it can be considered to extend the pilot. The most cost-effective method to do this is by distributing ‘spat-on-shell’ around the pilot. This consists of young oysters, settled on empty shell material. Again, a method should be developed to release this material close to the bottom, to prevent it drifting away from the pilot.

Since the deployment of spat-on-shell will probably prove to be an important pilot option, we have included this in the total cost estimate.

In order to facilitate monitoring, the following extra components can be added:

- Larval monitoring, in order to detect the presence of larvae in the water. This yields a more precise indication of the moment larvae are being produced. Monitoring can be performed by employing a suction pump with hose, to sample water from near the bottom around the pilot. The water sample should be brought ashore and analysed in a laboratory for the presence of flat oyster larvae.
- Valve position monitors. These are sensors connected to an oyster sample in the pilot, which detect whether the sample shells open or close. If that is the case, the oysters are still active and therefore alive. The sensors are even able to detect spawning activity. The measurement is continuous, but the unit has to be collected in order to read the data. This yields precise information of their condition throughout the year, which is particularly useful to determine the moment of spawning and when they appear not to survive or grow properly.

We have not included these monitoring options in the cost estimate.

7 Implementation: location selection, deployment, monitoring and maintenance

7.1 Introduction

An oyster pilot consists of several steps: (1) Planning and preparation, including selection of pilot location (desktop, field survey) and adaptation of the general design of the pilot to offshore conditions; (2) deployment of the components and finally (3) monitoring, removal and evaluation.

7.2 Pilot location choice

As stated before, several locations in Dutch offshore wind farms should be suitable for flat oyster pilots. We have assumed that basic abiotic and biotic conditions are met everywhere in the areas, but that bottom dynamics is a factor to be accounted with in more detail. The most important aspects are:

- Bottom sediment should be sufficiently solid, i.e. sandy or somewhat silty, so that racks do not sink in more than a few centimetres.
- Sand waves of more than a few centimetres per year should be avoided; otherwise racks may become covered, which will result in the death of the oysters.

We recommend choosing a location, which is as far away as possible from wind farm foundations and cables. This ensures that maintenance activities on this equipment do not disturb the pilot and vice versa.

Another aspect of location choice is larval drift, caused by currents. We recommend choosing a location on the side of the wind farm that is upwards from the dominant current. This gives the best chance that larvae settle in the downstream part of the wind farm itself, once they drift away from the parent population.

7.3 Survey of pilot location

We recommend carrying out a survey on sediment composition, in order to confirm the mapping for pilot location, and on biota present at the proposed pilot site area (several km^2). This should be done with a sediment grab, multibeam sonar, camera and/or drop cam. Select a smaller area for the pilot (10 ha) based on small-scale suitable conditions.

7.4 Design pilot

The proposed pilot location will determine the boundary conditions of the design of the pilot and subsequent requirements for deployment and monitoring. In offshore conditions the cost for deployment and monitoring are increasing rapidly with increasing scale and complexity of the pilot. Feedback from offshore HSE experts on the draft design and related work method statement, and subsequent adaptation is essential in an early stage of pilot development.

7.5 Obtaining permits

The activities required for obtaining permits are described in Chapter 4.

7.6 Deployment

Ships equipped with Dynamic Positioning on GPS are required to deploy the racks with oysters (young and/or mature oysters), reef domes or other artificial reef structures, spat collectors and shell material, as anchoring is not permitted in wind farms. Racks with oysters and reef domes are best deployed in spring before reproduction occurs. When oysters are brooding or spawning (June – July) they are very susceptible to stress and may not survive translocation. Thus, summer (June-July) is not recommended for deployment. Deployment can also be done after 15 October in autumn or winter, when there is no immediate reproduction. Autumn, winter or spring, are also the appropriate periods for deploying spat-on-shell.

Spat collectors and clean shell material (settling substrate) have to be deployed in the period that the first oyster larvae are released into the water by the mother animals, i.e. in June - July. Spat collectors can be deployed by the same methods as the oyster racks. Substrate deployment around the pilot should take currents and water depth into account, so a method to release this close to the sea floor is required. This is yet to be developed.

If the oysters appear to survive, grow and reproduce well, it is recommended to deploy 'spat-on-shell', preferably in different stages, to first test whether this survives and grows well and to subsequently extend the area/amount if this appears to be the case.

The planning time of deployment is case-specific, depending on parameters such as pilot design, distance to harbours, sea floor conditions, water depth, vessel availability and (expected) weather conditions. In order to make a case-specific planning, Appendix 1 provides production/deployment time estimates of pilot components.

7.7 Inspection and monitoring

Year 2. After deployment in year 1, standard activities include inspection (once every year by hoisting the racks and monitoring the oysters and environmental conditions. If necessary, racks will be cleaned and repaired. Monitoring include measuring survival and growth of oysters (spat and adult oysters) and measuring environmental conditions (temperature, continuous, with data logger). The concentration of oyster larvae can be estimated with suction pumps or nets for sampling plankton, at the same time when substrate is deployed and biodiversity in monitored in the period June – August. The data logger can be collected in Aug-Sept or during recruitment monitoring in autumn.

7.8 Recruitment monitoring

Settlement of oyster larvae can be monitored by deploying (dead) shell substrate on the soft sediment and by deploying spat collectors in the period when oyster larvae are in the water column. The young oysters (spat) can be visually counted, when spat has grown large enough after 2-3 months. This implies that spat collectors will be taken to the surface in autumn. Grab samples can be taken from the dead shell substrate from the autumn onwards.

All these activities can be done in autumn, except for deploying spat collectors and counting oyster larvae, which should be done in June-July. We recommend to annually analyse and evaluate monitoring results, in autumn/winter, and to improve the pilot where evaluation shows this to be useful.

7.9 Biodiversity monitoring

Years 3-5. The total number of species present at the pilot site can be estimated by visual inspection with dropcam, ROV and grab samples of the soft sediments. The optimal period to do this is the summer, when most macroscopic biota have larger-sized developmental and adult stages.

7.10 Removal

At the end of the pilot, all equipment has to be removed, with the exception of loose shell material and oysters. Removal can be done with the same vessel (DP ship with ROV and crane) as used for deployment, but hoisting force must be larger, in particular to remove reef domes or other artificial reef structures which tend to become attached to the sea floor by biota growth. After removal, monitoring of the deployed oysters and substrate can be executed. Hence, in the final pilot year, an extra monitoring visit is not necessary.

8 Cost estimates

8.1 Introduction
In this chapter, cost estimates of principal pilot components and activities are provided. The data presented in Appendix 1 constitute the basis of these estimates. All cost data are without VAT.

Since ship time will prove to be a large part of total costs, this will be elucidated separately in the next paragraph.

All costs estimates are derived from market prices. References cannot be provided, since most data are obtained from commercial companies, who do not want the data sources or conditions to be disclosed.

8.2 Ship time cost
As stated previously, deployment, monitoring and removal activities usually have to be performed by a vessel equipped with a crane, dynamic positioning on GPS orientation and a ROV with camera and multibeam sonar. The total cost of €26,000 per day is built up as follows:
- Vessel rent, including crew: €7,000
- ROV rent, including pilot: €2,500
- Fuel cost: €1,500
- Mobilisation, including transfer from homeport at max. 50 km distance to pilot location: €7,500
- Demobilisation, including: €7,500

These costs can be reduced when an offshore company or other ship owner undertakes a flat oyster pilot and uses its own equipment. Ship time is calculated for 1-day campaigns. For consecutive days costs are lower, because mobilisation / demobilisations costs remain the same.

8.3 Initial survey costs
Sea floor condition and biota present at and around the pilot site should be surveyed with a DP ship with ROV, equipped with sediment grab, camera and multibeam sonar. We estimate that this can be done in 1 to 2 days, so the cost will amount to €26,000 to €52,000. Analysis time is assumed to be 3 person * days with a tariff of €1,000 per person per day, which would amount to an extra €3,000.

8.4 Design, permit and planning costs
The production of a pilot design and work method statement depends strongly on case-specific parameters, but on the basis of our experience, it takes 8 to 20 person * days. If done on a commercial basis, again assuming a tariff of €1,000 per person per day, this would amount to €8,000 to €20,000.

Once a design is available, including the sourcing of the appropriate oysters (free of diseases and invasive alien species), permits should be relatively easy to obtain on the basis of the design and an indication of the desired location (see Chapter 4). However, there are always uncertainties, hence we assume that the time expenditure for procedures lies in a relatively wide range: 4-20 days. We assume legal fees are negligible. This yields a cost estimate of €4,000 to €20,000.

The planning of campaigns for deployment once again depends on pilot-specific conditions, but will probably also take several person x weeks, i.e. €10,000 to €20,000.

Total design, permit and planning cost - assuming all work will be done on a commercial basis - will therefore amount to €22,000 to €60,000.

8.5 Pilot equipment and deployment cost

The materials required for a basic pilot are listed in Chapter 5. These are, with their associated costs (see Appendix 1 for unit cost estimates):

- Flat oysters (300 adult and 300 young individuals, measured/weighed and placed in holders/cages/racks): €1,800 to €9,000.
- Racks, with inner cages and holders for the oysters, plus hoisting equipment (buoy etc.). We assume a total of 3 racks with 12 inner cages and holders. Total cost of this assembly will amount to €5,000.
- Reef domes or other artificial reef structures, plus hoisting equipment. Assuming 8 reef domes, this assembly will cost €9,200. If other reef structures are employed, costs will be somewhat different, but this will cause a negligible difference in overall pilot costs.
- Spat collectors, in order to better identify the moment of spat fall. Assuming 10-20 spat collectors, plus hoisting equipment, the cost will amount to €2,500 to €5,000.
- Settlement substrate (empty and clean shells), to be deployed in June-July: growers distribute 50 m^3 per ha. We have therefore assumed to employ this density around the pilot. We assume that 1 to 3 ha will be deployed, i.e. 50-150 m^3. This would cost between €4.000 and €12.000. A method has yet to be developed to deploy this around the pilot, taking into account water depth and water currents. For the cost estimate, we assume that this basically costs 1 day of a relatively simple ship (though with GPS), which can distribute the substrate while moving over the pilot, since substrate deployment need not be done with high accuracy This vessel cost estimate is €4,000-€8,000 per day. We have assumed that all substrate can be deployed in a single day.

All in all, total equipment cost of the assumed basic pilot design will amount to €22,500-€48,200.

Oyster racks (3) and reef domes (8) can probably be deployed in 1 day, costing €26,000. Spat collectors can also be deployed in 1 day, again costing €26,000 The ROV can be used to guide placement. Substrate deployment will cost €4,000-8,000.

Deployment supervision by scientific personnel is assumed to cost €5.000.

8.6 Monitoring, maintenance and substrate/spat-on-shell deployment cost

Monitoring and maintenance in all pilot years will have to take place at least once a year. It includes:

- Hoisting the oyster racks, inspecting them and if necessary doing repairs;
- Removing the oysters from racks and cages, inspecting them for survival and measuring their growth;
- Taking oyster samples, to be inspected in a laboratory for reproduction activity;
- Putting the oysters back into the cages and racks, then lower them to the pilot location on the sea floor;

The cost of these activities would be:

- Ship time, for hoisting the oysters racks, analyse the oysters and putting them out again. Assuming this can be done on board of the vessel, this would cost 1 day of ship time, otherwise 2 days, costing €26,000 to €52,000.
- 2 days assistant time and 0,5 day senior scientist time for oyster removal from racks and cages, inspection and measurement and replacing them into the cages. Assuming WMR tariffs of €950 per day for an assistant and €1455 for a senior scientist, this would amount to ca.€2,650.
- 0,5 day assistant time for rack cleaning and repairs, amounting to €475.
- This amounts to a total per year of ca. €29,100 to €55,100.

Potential extra activities include:

- Deploying and analysing spat collectors. Deployment can be done in 1 day, so this requires €26,000. Collecting the spat collectors can be done on the same day as hoisting the oyster racks, so no extra ship time is required for this activity. Spat analysis should be done in a dedicated laboratory, It is assumed that this requires 2 hours of transport (costing €100) and 1 day assistant time (costing €950), yielding analysis costs of €1,050 per year. Hence, spat settlement monitoring will cost ca. €27,000 annually. We assume that after 2 years of spat settlement monitoring, the moment and amount of settlement will be determined with sufficient accuracy.

- Distributing clean substrate, every year. As stated previously, a method has yet to be developed to do this. For the cost estimate, we assume that this basically costs €4,000-€8,000 per day for the required ship and €5,000 to €15,000 for substrate material.
- Deploying spat-on-shell in different stages (in autumn/winter), after year 1, to firstly test whether this survives and grows well and to subsequently extend the area/amount if this appears to be the case. We assume that equipment costs are the same as for substrate deployment (i.e. €4,000-€8,000 per year). The amount of spat-on-shell to be distributed is assumed to be 100.000 individuals in the first year and 1 million in the 3 subsequent years. Spat-on-shell costs are €40 per 1000 individuals, amounting to a cost over 4 years of €124,000.

Biodiversity monitoring (recommended after year 2) can probably be combined with the other activities, without causing extra shipping cost. Employment of equipment (ROV/camera/drop cam) will cause a relatively small extra cost, estimated to be €3,000-€5,000. Extra reporting time is expected to be ca. 3 days, amounting to €3,000, amounting to a total of €6,000 to €8,000 per year.

8.7 Management cost

Overall project management, including analysis and evaluation of interim monitoring results and planning of improvements for the next years, is hard to estimate, since there are no experiences with this type of pilot. We therefore assume 10% of the above total costs for management as a rule of thumb, i.e. €50,000 to €80,000 in total.

8.8 Removal cost and final reporting

Removal of equipment can probably be performed on a single day, amounting to €26,000 for ship time. If removal is accompanied with a final monitoring inspection, the costs mentioned in par. 8.6 should be added, with the exception of cleaning and repair cost. Assistant time for handling the oysters will also be lower, since they do not have to be replaced into the racks.

A final scientific report is estimated to cost between 8 and 20 person * days, i.e. €8,000 to €20,000.

8.9 Total cost estimate

In summary, the total flat oyster pilot cost estimate, for a period of 5 years, is presented in table 3.

Table 3. Cost estimate of general offshore flat oyster pilot.

Activity / costs	Ship time (€)	Material (€)	Scientific personnel (€)	Totals (€)
Survey pilot area (physical characteristics, biodiversity)	26.000		3.000	29.000
Design and work method statement			8.000	8.000
Planning (assumed				p.m.
Permits			4.000	4.000
Pilot equipment cost (oysters, spat collectors and substrate)		22.500		22.500
Pilot deployment	26.000		5.000	31.000
Inspection & monitoring (annually except for year 5, i.e. 4 years in total)	104.000		12.500	116.500
Recruitment monitoring (deploying/analysing spat collectors; 2 years)	52.000		2.100	54.100
Substrate deployment (5 years)	104.000	20.000		124.000
Deployment spat-on-shell (4 years) to extend pilot		124.000		124.000
Biodiversity monitoring (3 years)		9.000	9.000	18.000
Removal + monitoring (final year)	26.000		2.000	28.000
Final report			8.000	8.000
Unforeseen	156.000	63.700	28.000	247.700
Subtotal	494.000	239.200	81.600	814.800
Onward planning + pilot management (5 years, 10% of subtotal)				p.m.
Total pilot cost (5 years)	494.000	239.200	81.600	814.800

9 Project period and time schedule

During the project lifetime (5 years minimum), the following activities are recommended (see Table 4 below):

- Year 1. To survey the pilot area for physical suitability and biodiversity (‘T_0 monitoring’) in April – May of year 1 and to deploy the oysters before the start of the summer period, i.e. ultimately by 15 May. By doing so, the population will probably be productive that same year. If deployment previous to 15 May is not possible, deployment should be postponed to October or later in the year.
- Years 1-5. To deploy new, clean substrate (empty bivalve shells) in June – July of each year, i.e. when oyster larvae are in the water. Deployment of the substrate at this time ensures it is clean of fouling organisms and hence promotes flat oyster larvae settlement. We recommend developing an effective method to deploy the substrate on the seabed in a controlled way to facilitate monitoring.
- Year 2. To inspect the pilot components in the subsequent autumn to spring, when also oysters are to be measured for survival and growth and substrate is to be investigated for young oyster settlement.
- Years 1-2. To monitor settlement of juvenile oysters (‘spat’) by employing spat collectors, in the first 2 pilot years (after that period, the spat settlement pattern should be clear).
- Years 3-5. Optional extension. If the oysters appear to survive, grow and reproduce well: to deploy new oysters in large amounts, to extend the bed. Probably, the most cost-effective method to do this is by deploying spat-on-shell.
- Years 3-5. Biodiversity monitoring is recommended from year 3 onwards, since the flat oyster bed may start to develop form that moment on.
- Year 5 (or later). After the final year the pilot equipment must be removed (by law) and oysters and substrate can then also be monitored (but do not have to not removed).

Table 4. General planning of an offshore flat oyster pilot (red) and optional extension pilot (black).

Spring (April-May)	Summer (June - July)	Summer (Aug-Sept)	Autumn-early spring (Oct - March)
Year 1			
Survey pilot area Pilot deployment	Deploy substrate/spat collectors		Inspection and monitoring
Year 2			
	Deploy substrate/spat collectors		Recruitment monitoring Deploy spat-on-shell
Year 3			
	Deploy substrate Biodiversity monitoring	Inspection and monitoring Deploy spat-on-shell	
Year 4			
	Deploy substrate Biodiversity monitoring	Inspection and monitoring Deploy spat-on-shell	
Year 5 (or later)			
	Deploy substrate Biodiversity monitoring	Deploy spat-on-shell Removal and monitoring	

10 Recommendations

It is recommended to:

- Develop innovative monitoring techniques, which do not require DP2 vessels, and thereby reduce monitoring costs considerably.

- Execute further research of suitable sources of mature oysters, spat and spat on shell.

- Develop an efficient and accurate method to deploy dead shell substrate on sea floor within the pilot area.

- Determine the minimal and optimal number of initial oysters to restore successfully a sustainable oyster bed.

- Determine an appropriate contingency budget, specially taking into account site and vessel specific weather downtime.

11 Literature

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Appendix 1. Equipment details for flat oyster pilot in wind farm

Nr	Pilot equipment	Objective	Production/acquisition/execution cost (excl. VAT)	Dimensions	Weight	Production/deployment time
1	**DP2 ship, crane and ROV + MB sonar**	Deployment, maintenance and monitoring activities	€26.000 per day (incl. mob/demob and deployment from harbour at ca. 50 km distance from pilot)	Crane capacity at least 2,000 kg for deployment, and at least 5,000 kg for removal.	N.R.	Variable, depends on ship availability
2	**T_0, base line**	Monitoring sea floor and biota at prospective pilot location	1 day with DP2 ship and ROV/sonar: €26.000	3 ha	N.R.	Variable, depends on ship availability
3	**Temperature data logger** near bottom at pilot location	Predict onset of probable first peak in larval swarming in June/August	€ 100	10 x 2 x 2 cm	0,1 kg	Available off the shelf
4	**Racks** (3) on sea floor	Retracing and identifying pilot oysters on sea floor	€1450 per rack	1.0 x 1.4 x 0.5 m Legs: 25 mm x 290 mm	135 kg, with ballast 477 kg	1 month
5	**Buoys** attached to racks (1 per rack)	Locate racks; attached chain is used for hoisting to surface	€150 per set (incl. lifting gear, rope, shackle).	Buoy diameter = 0.2 m Rope length = ca. 2 m	N.R.	Available off the shelf.
6	**Cages and holders** (4 per rack) for oysters	Holding oysters in place and at distance of each other	€15 per cage + holder	To be fitted into the racks	1 kg (cage + holder)	Available off the shelf
7	**Flat oysters**, 50/50 of 2 age classes (200 per rack, total = 600)	Initial population, to monitor SGRR and to function as larval source	€2-5 per oyster (€3-15 per oyster incl. keeping alive at harbour)	7 per l for adult oysters and 20 per l for young oysters (to be placed in holders/cages/racks)	20 g per young oyster 80 g per adult oyster	1-2 months

Appendix 1. Continued.

Nr	Pilot equipment	Objective	Production/acquisition/execution cost (excl. VAT)	Dimensions	Weight	Production/deployment time
8	Clean **shell material**, per m^3	Substrate for oyster spat (ca. 50 m^3 per ha)	€100 per m^3	1 m^3	Ca. 800 kg	Available off the shelf (but supply may be limited because of simultaneous other demand)
9	**Scour protection stones** (natural hardstone)	Substrate for oyster spat	€150 per m^3	1 m^3	Ca. 1500 kg	Available off the shelf
10	**Reef domes (2)**	Protection and substrate	€1000 per reef dome	Diameter 1 meter, height 1 meter	800 kg	1 month
11	**Spat collectors** (2-10), incl. anchor stone	Monitor spat fall	€100 per spat collector	1 meter length, 30 cm diameter	10 kg	1 week
12	**Larval monitoring** (suction pump + lab analysis)	Sample larval presence near pilot	€1050 (1 day lab analysis + €100 for pump employment per sample)	N.R.	N.R.	2 weeks deployment time for the pump
13	**Valve position monitors** (2, for 16 oysters)	Monitor oyster activity	€8000 + €1500 for equipment rack (if required; possibly the monitors can be fitted to the oyster rack)	Ca. 1.6 x 1.6 x 1.0 m (rack dimensions)	100 kg	1 month
14	**Spat on shell** (10 mm, per 1000 oysters)	Extend pilot oyster population	€40 per 1000 oysters	50-100 l	25-50 kg	Variable

Appendix 2. Alien species treatment protocol in Norway

Area of origin

Flat oysters are individually picked by divers and collected in nets without water in Hafrsfjord, Norway, by Hotate AS and transported to Scalmarin AS, where they are treated. Scalpro AS, an approved fish transporter, ships the oysters to the Netherlands.

Problem

Flat oyster epibionts (organisms attached to oyster shell, e.g., macroflora and macrofauna) can include invasive alien species (IAS). Flat oyster transports, therefore, potentially can introduce IAS in new areas, such as Marine Protected Areas and aquaculture areas.

Prevention

Apply effective treatment on all flat oysters, which are transported, including imports and translocations from one area to another.

Aim

To remove or eliminate effectively all epibionts on flat oysters.

Protocol

The following protocol is effective in removing all epibiota from the shells of the flat oysters without harming the oyster or the environment and includes the following steps:

1. Manually inspect oysters from the field to remove any other large and obvious organisms.
2. Tumble 20 kg of oysters in 30 L of freshwater (or so that oysters are submerged when stationary) for 5-7 minutes in a cement mixer.
3. Leave oysters in running seawater for 3+ days to allow them to recover and reseal their shells after damage from the tumbling process.
4. Submerge oysters in freshwater, then add 5ml p L of 15% laboratory grade sodium hypochlorite for 15-20 minutes.
5. Wash oysters in freshwater to remove sodium hypochlorite and any loose, dead epibionts.

Recommendations

- Treat and transport oysters in winter to minimise initial amount of epibiota growth.
- Do not exceed the recommended relative amount of oysters in the cement mixer. If there are too many oysters, it will reduce the effectiveness of the tumbling.
- Prior to exposure to chlorine, submerge or physically jolt the oysters so that they close to prevent chlorine uptake.
- During submersion in the chlorine, make sure the oysters are well spaced so that the chemical has optimal access to the whole surface area of the oyster.