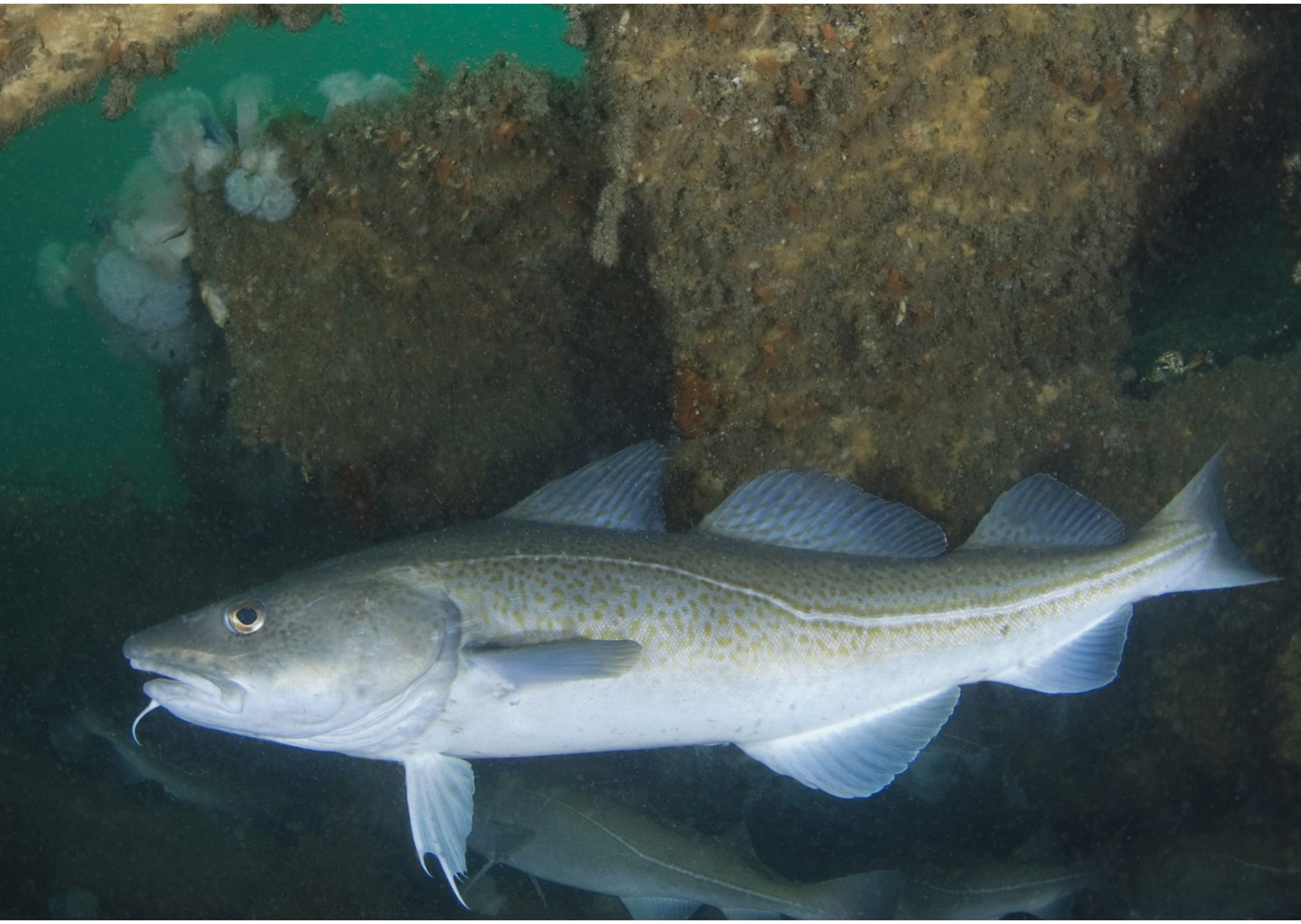


Nature-Inclusive Design: a catalogue for offshore wind infrastructure

Technical report

The Ministry of Agriculture, Nature and Food Quality

17 March 2020

Project	Nature-Inclusive Design: a catalogue for offshore wind infrastructure
Client	The Ministry of Agriculture, Nature and Food Quality

Document	Technical report
Status	Final version
Date	17 March 2020
Reference	114266/20-009.718

Project code	114266
Project Leader	I. Prusina PhD
Project Director	M. Klinge MSc

Author(s)	A. Hermans MSc[1], O. G. Bos PhD[2], I. Prusina PhD[1]
Checked by	M. Klinge MSc
Approved by	M. Klinge MSc

Initials

Marcel Klinge

Digitally signed by Marcel Klinge
Date: 2020.06.23 16:35:04 +02'00'

Address

[1]Witteveen+Bos Raadgevende ingenieurs B.V. | Deventer
Koningin Julianaplein 10, 12e etage
P.O. Box 85948
2508 CP Den Haag
The Netherlands
+31 70 370 07 00
www.witteveenbos.com
CoC 38020751
[2]Wageningen Marine Research
PO Box 57
1780 AB Den Helder
The Netherlands

TABLE OF CONTENTS

APPENDICES

1

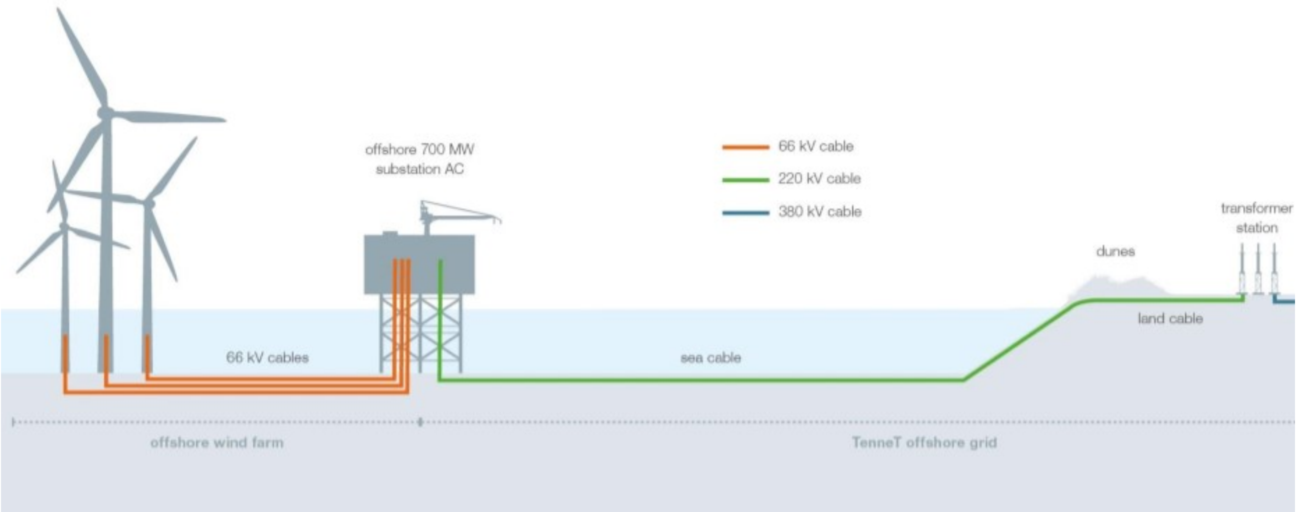
INTRODUCTION

1.1 Terms and starting points

1.1.1 Glossary of terms

In this report, Nature-Inclusive Design (hereinafter: NID) refers to options that can be integrated in or added to the design of an offshore wind infrastructure (Figure 1.1) to create suitable habitat for native species (or communities) whose natural habitat in the Dutch North Sea has been degraded or reduced. Here, NID options can be part of a wind turbine (monopile) or an offshore substation, a scour protection layer or a cable protection measure.

Figure 1.1 Schematic representation of an offshore wind farm (wind turbines and subsea power cables) and an offshore grid (substation, subsea power cables, transformer station). Source: TenneT TSO B.V.



In the following table, the terminology used throughout this report is explained.

Table 1.1 Explanation of the important terms used in the report

TERM	DEFINITION
Enhancement of ecological functioning	increasing habitat suitability for native species in the North Sea ('*nature enhancement*')
Nature-Inclusive Design options	measures that are integrated in or added to the design of an offshore wind infrastructure to increase suitable habitat for native species
Nature requirements	ecological requirements, including abiotic and biotic factors, necessary to improve ecological functioning
Suitable habitat	an area with a specific set of physical factors within which species can find food, shelter, or conditions for reproduction
Hard substrate	biological material (e.g. shells), geological material (e.g. pebbles, stones, rocks), or man-made structures (e.g. shipwrecks, monopiles, jackets) in the sea; hard substrate can provide functions to marine fauna and flora, e.g. settlement substrate for larvae, shelter for all life stages, feeding and nursery grounds
Offshore wind infrastructure	integral part of an offshore wind farm, related exclusively to the sea and sea bottom, such as a monopile, substation, scour (erosion) protection for the monopile and substation and subsea power cables
CapEx	capital expenditure or the cost of developing (a wind farm)
OpEx	an operational expenditure or an ongoing cost for operating (a wind farm)

1.1.2 Starting points and constraints

This technical report is supplemented with the Nature-Inclusive Design catalogue (Appendix III). The catalogue provides an overview of the NID options and details the technical specification, dimensions, ecological benefits, costs and supplier or designer per option. The technical report describes the consultation process by ecological experts and industry representatives and selection process for NID options and the ecological and technical considerations that underlie the NID options.

The following conditions are set by The Ministry of Agriculture, Nature and Food Quality in relation to NID options and this report:
- NID options should contribute to ecological functioning of the autochthonous species of the Dutch North Sea, with a focus on strengthening species and habitats that need a development towards recovery (e.g. species and habitat types for which protected areas have been designated on basis of the EU Habitats Directive and that don't have a favourable conservation status; species of the Dutch action plan for the recovery of vulnerable species of sharks and rays in the North Sea; species of national Dutch red lists; species or habitats of the OSPAR List of Threatened and/or Declining Species and Habitats) (see Bos et al. 2016).
- In addition, possibilities for NID options beneficial for commercial species (co-use) can be considered;
- simultaneously supporting the spread of non-indigenous (allochthonous) species as a result of the NID is assessed as undesirable.
- a number of previously published reports (see section 2.2) on NID in the Dutch North Sea function as the knowledge base of this report.
- NID options that are included should be beyond the stage of ideas and should be ready-to-use; they at least have been successfully applied elsewhere in a pilot project or have been assessed as ecologically promising and practically applicable; this should be substantiated, including literature references and/or expert opinions.

The scale to which NID options should contribute to the restoration of the native biodiversity in the ecosystem is not yet defined by the governmental bodies (e.g. scale of an offshore wind farm, scale of Dutch North Sea or scale of international North Sea). In order to address the concept of scale in relation to the ecological benefits of an NID option, as well as its cost, the calculations in this report are based on a reference offshore wind farm consisting of:

- 60 monopiles.
- two offshore substations.

Capital expenditures (CapEx) in relation to NID options are estimated based on the following starting points:
- deterministic estimation.
- costs are per monopile (and based on a total quantity of 60 monopiles in a wind farm).
- two NID options on the scour protection around the monopile (except for scour layer (m^2) and fish hotel (1 pcs)).
- additional scour protection layer options are based on an area of 20% of the total scour protection layer with a diameter (ø) of 30 m.

1.2 Background

The North Sea is a complex ecosystem pressured by many functions, such as coastal development, shipping industry, the fishing industry, oil and gas industry, renewable energy industry, military use and recreation. At the same time, the Netherlands is pressured by the global climate agreement to sustainably produce and use energy. The extensive spatial claim for further development of offshore wind energy may conflict with the space required for the ecological functioning of the ecosystem according to the frameworks of Natura 2000 and the European Marine Strategy Framework Directive (MSFD). Based on the national Article 17 report of the Habitats Directive (Min LNV, 2019), the Dutch conservation status for 4 out of 5 marine habitat types of community interest is "bad". This is why the interest in NID for offshore wind farms has been increasing in the recent years (see section 2.2).

The Ministry of Agriculture, Nature and Food Quality (further referred to as LNV) and Rijkswaterstaat (RWS) aim to stimulate enhancement of ecological functioning during the development of offshore wind projects. One of the tools available is to include nature regulations in wind farm site decisions and related permitting. According to the regulations, the permit holder must make demonstrable efforts to design and build the wind farm in such a way that it actively enhances the sea's ecosystem, helping to foster conservation efforts and goals relating to sustainable use of species and habitats that occur naturally in the Netherlands (see e.g., Netherlands Enterprise Agency (RVO), 2019).

Enhancement of ecological functioning can be achieved by using measures that can be integrated in or added to the design of an offshore structure to kick-start rehabilitation of degraded North Sea habitat. By smartly integrating these measures, additional value may be created for some of the key species of the North Sea, while at the same time complying with or contributing to the objectives within the framework of the European nature protection legislation.

To support the regulations for future wind farm site decisions or related instruments, LNV has commissioned Witteveen+Bos (W+B) and Wageningen Marine Research (WMR) to compile a catalogue with technically sound and ecologically promising NID options, with recommendations on steps to be taken to make each NID option tailor-made for the location and the offshore asset.

1.2.1 Rich North Sea (De Rijke Noordzee)

Within the Rich North Sea programme (De Rijke Noordzee), Bureau Waardenburg investigated the options for biodiversity enhancement *within* the existing offshore wind farms, particularly focusing on the restoration of biogenic reefs (Bureau Waardenburg, 2020). Our report and the report from Bureau Waardenburg can be seen as complementing each other, both supporting the wind industry to make an NID a new standard in offshore practice.

1.3 Objective

The aim of the project is to create a catalogue of NID options that can be applied in the Dutch offshore wind farms. An important part of the creative process is to include the end-users from an early start to ensure the feasibility of NID options offered in the catalogue. The feasibility is reflected in both ecological and technical aspects. The NID options in the catalogue are to be ready-to-use with clear design guidelines and associated risks and costs. The catalogue is to support the Dutch Government to elaborate on nature regulations in the future wind farm site decisions or related instruments, and to support asset owners, wind developers and contractors (hereinafter: end-users) in implementing NID as a new standard in offshore wind development industry, including to be able to meet the regulations indicated.

1.4 Outline

In chapter 2 the methodological steps undertaken to produce the NID catalogue are described . This includes an overview of designated wind farm locations in the North Sea (section 2.1), a knowledge base (section 2.2), a legal framework on which the nature regulations and target species are based upon (section 2.3), a list of selected target species (section 2.4), an NID inventory (section 2.5), and finally, expert session with the end-users as part of the industry-proofing process (section 2.6). The results of these steps are elaborated in chapter 3, where an overview of NID options is given. Chapter 4 describes ecological considerations for NID, including description of target species (section 4.1) and ecological functions and benefits (section 4.2). Technical considerations are detailed in chapter 5, where design process is described (section 5.1), followed by a risk analysis (section 5.2) and cost estimation (section 5.3). Chapter 6 concludes the performed work with points of attention and provides the concept for ecological cost-effectivity analysis. References are listed in chapter 7. The summary memorandum from the interview sessions with the end-users is in Appendix I, and an example of an estimation of life cycle cost for NID is given in Appendix II. The full NID catalogue can be found in Appendix III.

1.5 Review process

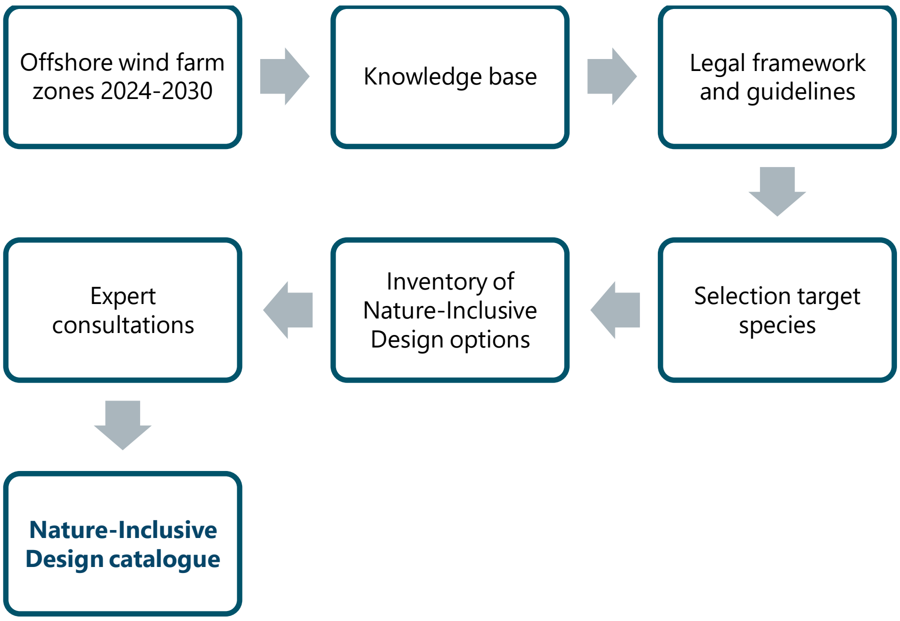
Besides the expert sessions as part of the creative process of this report, the high level of multidisciplinarity has been further ensured through independent external and internal reviews. Professors Peter Herman and Steven Degraer provided us with valuable scientific input on NID. Our colleagues Arjen van Dalfsen, Ingrid Mouwen and Erik Schulte Fischedick contributed to the chapters on design process, risk analysis and estimation of life cycle costs, respectively. Edo Knegtering from the Ministry of Agriculture, Nature and Food Quality reviewed the report from his client perspective and through the policy lenses in particular, and Eline van Onselen from the Rijke Noordzee perspective. We wish to thank all of them for helping us to refine the NID catalogue for offshore wind infrastructure.

2

MATERIALS AND METHODS

Methods used to create the NID catalogue for the offshore wind farm zones in the Netherlands are set out in this chapter. The process is formed by combining existing knowledge on enhancement of ecological functioning, the European and national legal framework and industry-proofing design concepts by means of expert consultations. The overview of the working steps is shown in Figure 2.1.

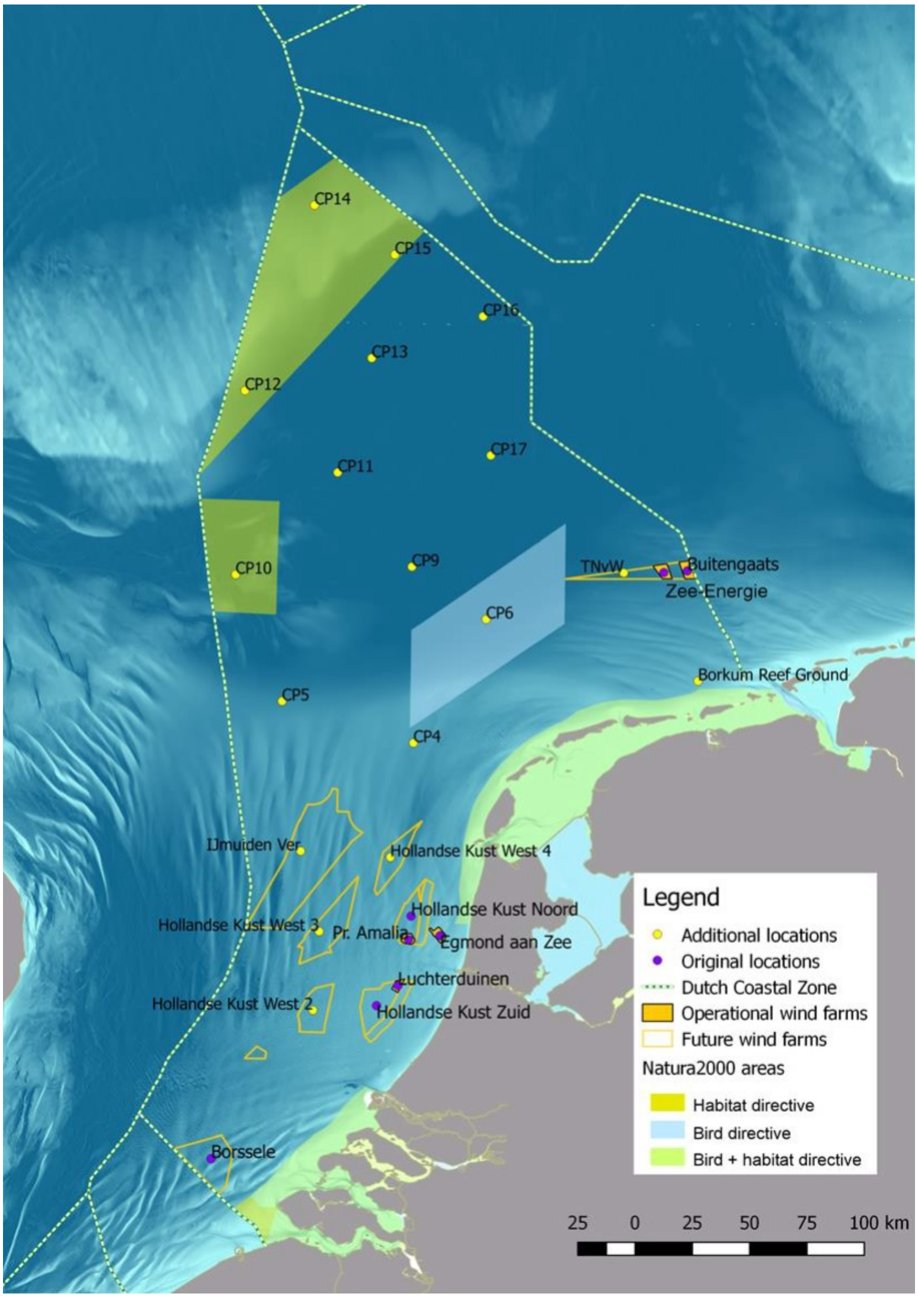
Figure 2.1 Overview of the steps taken in this project to form the Nature-Inclusive Design catalogue



2.1 Dutch offshore wind farm zones 2024-2030

In this study the focus is placed on the applicability of NID implementation in wind farms to be built between 2024 and 2030 in the Dutch North Sea. The wind farm zones considered in this report are the same locations as described in the reference study by Kamermans et al. (2018) (see figure 2.2):
- Hollandse Kust (zuid) (HK(z));
- Hollandse Kust (west) (HK(w));
- Hollandse Kust (noord) (HK(n));
- IJmuiden Ver (IJver);
- Ten noorden van de Waddeneilanden (TNW);
- 12 additional potential/fictional locations on the Dutch Exclusive Economic Zone (EEZ) (CP4-CP6 and CP9-CP17).

Figure 2.2 Map from Kamermans et al. 2018, indicating operational wind farms (polygons with purple dots, locations investigated also in Smaal et al. 2017), planned wind farms (polygons with yellow dots), and additional/fictional wind farm locations (yellow dots).



2.2 Knowledge base

The frameworks and guidelines that have been developed in previous studies regarding NID in the Dutch North Sea have been reviewed for this study. The most influential works are listed below:

Nature - inclusive building

- Building with North Sea nature (report in Dutch: Bouwen met Noordzee-natuur): is elaborating on a number of recommendations to LNV to take building with nature one step further and bring it into practice (Rozemeijer et al. 2017).

Species list and distribution maps of policy-relevant species

- A list of species in the Dutch North Sea (report in Dutch: Soortenlijst Nederlandse Noordzee): provides an integral overview of indigenous species and non-indigenous species in the Dutch North Sea, including an annex with policy-relevant species (Bos et al. 2016).
- Biogenic reefs in the North Sea (report in Dutch: Biogene riffen in de Noordzee: actuele en potentiële verspreiding van rifvormende schelpdieren en wormen): describes the (potential) distribution of reef-building species in the Dutch North Sea by means of maps and a table; data are presented for European flat oyster (*Ostrea edulis*), blue mussel (*Mytilus edulis*), northern horse mussel (*Modiolus modiolus*), honeycomb worm and Ross worm (species not individually distinguished) (*Sabellaria* sp.), Ross worm (*Sabellaria spinulosa*) and sand mason worm (*Lanice conchilega*) (Bos et al. 2019).

Flat oyster restoration

- Possibilities for promoting flat oysters in offshore wind farms (report in English: Flat oysters on offshore wind farms: opportunities for the development of flat oyster populations on existing and planned wind farms in the Dutch section of the North Sea): specifically indicates which existing and upcoming wind farm locations are potentially suitable for the introduction of flat oysters (Smaal et al. 2017).
- Opportunities for the development of flat oyster populations (report in English: European flat oysters on offshore wind farms: additional locations): investigates biotic and abiotic factors of importance for flat oyster survival, growth, reproduction and recruitment, and compares the 8 wind farm locations of Smaal et al. (2017) and the 18 new locations throughout the North Sea (Kamermans et al. 2018).

Scour protection and nature restoration

- Possibilities for enhancement of natural reefs (report in English: Rich reefs in the North Sea). This report explores the possibilities of promoting the enhancement of natural reefs and colonisation of artificial hard substrate in the North Sea. It highlights several reef forming species including honeycomb worm (*Sabellaria alveolata*), Ross worm (*Sabellaria spinulosa)*, sand mason worm (*Lanice conchilega)*, European flat oyster (*Ostrea edulis*) and the northern horse mussel (*Modiolus modiolus*) as well as a variety of species using hard substrate, including, e.g., dead man's fingers (*Alcyonium digitatum*) and jewel anemone (*Corynactis viridis*) (van Duren et al. 2016).
- Possibilities for adapting scour protection in order to strengthen nature (report in English: Eco-friendly design of scour protection: potential enhancement of ecological functioning in offshore wind farms, towards an implementation guide and experimental set-up). This report provides clear guidelines for the eco-friendly design of scour protection structures around monopiles in planned wind farms to enhance ecological functioning, focusing on two umbrella species, Atlantic cod and flat oyster (Lengkeek et al. 2017).
- From the monitoring and evaluation programs of wind farms Princess Amalia Wind Farm (PAWP) and Offshore Wind farm Egmond aan Zee (OWEZ), research has been carried out into the value of benthos which establishes itself on the wind turbines and erosion protection (see e.g., Tamis et al. 2017). This research thus describes the potential of hard substrate without NID options.

Co-use of wind farms

- Possibilities for increased lobster production (report in English: Desktop study on autecology and productivity of European lobster (*Homarus gammarus*, L) in offshore wind farms): develops a model to describe the growth of the European lobster under assumed conditions on the anti-scouring of monopiles in Dutch OWFs Amalia and Luchterduinen (Rozemeijer et al. 2019).

Policy

- The balance of the living environment (report in Dutch: Natuur Balans Noordzee): provides a substantiated insight into the current quality of the physical living environment and in the extent to which the set policy goals are achieved (Tamis et al. 2019).

In addition to these reports, available site data on soil, water conditions and obstructions of the new wind farm zones published by the Netherlands Enterprise Agency (RVO) have been studied. Moreover, NID options in other geographical areas have been studied through peer-reviewed literature. Active habitat restoration is a relatively recent research topic and therefore studies with sufficient replicability and scalability are often lacking. However, lessons learned in other areas are combined with the above mentioned studies to fully encompass the possibilities for practical implementation of Nature-Inclusive design in Dutch offshore wind farms in the North Sea.

2.3 Legal framework

The relevant regulatory frameworks and guidelines were selected based on their applicability in relation to NID in offshore wind farms in the Dutch North Sea.

Definitions

The global guidelines for artificial reefs are the London Convention and London Protocol guidelines (IMO & UNEP 2009). They provide definition and purpose as well as the requirements for construction and placement of artificial reefs. The guidelines have been prepared to help signing countries in assessing proposals for artificial reef placement, development of regulations and update on existing guidelines and regulations.

The London Convention defines artificial reef as:
"An artificial reef is a submerged structure deliberately constructed or placed on the seabed to emulate some functions of a natural reef such as protecting, regenerating, concentrating, and/or enhancing populations of living marine resources. Objectives of an artificial reef may also include the protection, restoration and regeneration of aquatic habitats, and the promotion of research…"

The OSPAR guidelines on Artificial Reefs in relation to Living Marine Resources (OSPAR 2013) consider guidelines for artificial reefs in the North East Atlantic specifically. The guidelines were developed to consider the potential adverse effects of placement of artificial reefs.

The regional sea convention OSPAR for the North-East Atlantic defines artificial reefs as:
"An artificial reef is a submerged structure placed on the seabed deliberately, to mimic some characteristics of a natural reef. It could be partly exposed at some stages of the tide. These guidelines address those structures specifically built for protecting, regenerating, concentrating and/or increasing the production of living marine resources, whether for fisheries of nature conservation. This includes the protection and regeneration of habitats."

The NID options included in this report fall within the definitions for artificial reefs as detailed by The London Convention and the OSPAR convention.

European legislation

European legislation and policy-relevant for the North Sea is the Marine Strategy Framework Directive (2008/556/EC) which requires member states to achieve 'Good Environmental Status' in the European seas by 2020. The European Habitats Directive (1992/43/EC) and the Birds Directive (1979/409/EC) are important for protection and restoration of biodiversity in Natura 2000 areas and can aid in selecting target species. In addition, the Convention on Biological Diversity (CBD) and the EC Biodiversity Targets (to meet the International Biodiversity Convention) should be kept in mind when considering Nature-Inclusive design (Naylor et al. 2012).

The Environmental Impact Assessment Directive (85/337/EEC and its amendment 2014/52/EU) and the Strategic Environmental Assessment Directive (2001/42/EC) require an assessment of the environmental impacts of planned construction projects, including mitigation and alternative measures. The Marine Spatial Planning directive (Directive 2014/89/EU) provides a framework for each member state appointing relevant use of maritime space, in order to be able to have sustainable Blue Growth according to the principles of Ecosystem Based Management (European Union 2014). Regulation (Directive 2006/88/EC) on animal health requirements for aquaculture animals and products thereof, and on the prevention and control of certain diseases in aquatic animals aims to raise standards of aquaculture health throughout the EU and to control the spread of disease while maintaining the freedom to trade. An artificial reef can potentially also contribute to other relevant legislation, such as Descriptor 6 on seafloor integrity of the 2008/56/EC Directive (European Union 2008) which focusses in part on return and restoration of biogenic reefs from the MSFD guidelines.

National legislation
Guided by these legislative frameworks, the Dutch government has developed regulations in wind farm site decisions during the last years:
- In the wind farm site decisions for the Wind Farm Zones Borssele and Hollandse Kust (zuid) a regulation for nature inclusive building was included as follows: The permit holder must make demonstrable efforts to design and build the wind farm in such a way that it actively enhances the sea's ecosystem, helping to foster conservation efforts and goals relating to sustainable use of species and habitats that occur naturally in the Netherlands. In this respect the permit holder is required to create an action plan, to be delivered to the Minister of Economic Affairs and Climate Policy no later than 8 weeks before the planned start of construction. Construction work must adhere to this plan.
- In the wind farm site decisions for Hollandse Kust (noord) V new and more specific requirements were introduced in regulation 4 Mitigative measures sections 8a to 8e. In this regulation, material type, cavity size, surface area etc. are specified.
- For future wind farm site decisions, Hollandse Kust (west) VI & VII, IJmuiden Ver, Ten noorden van de Wadden and onwards, a new form of regulations may be considered. This report is compiled to serve as a basis to support future permit requirements.

Important to note is the responsibility of the permit holder to make an NID plan. Depending on the content of the proposed plan additional permits may be required. This may be especially relevant if a potential risks for Natura 2000 areas/ targets can be identified, as for example introducing non-indigenous species or diseases (Bonamia) due to the specific NID options (e.g. with European flat oysters).

2.4 Target species selection

Scour protection and monopiles offer habitat to hundreds of sessile and mobile species (Bouma & Lengkeek, 2012; Vanagt & Faasse, 2014; Coolen et al. 2018). This includes species that use this habitat for foraging and substrate to attach eggs to. Target species for this study were selected based on their policy relevance and occurrence at hard substrates (see Table 2.1).

A longlist of policy-relevant species and biogenic habitats is given by Lengkeek et al. (2017), see Table 2.1. Their list includes species protected under the Habitats Directive, typical species for marine Natura 2000 habitat types, species from the Dutch action plan for the recovery of vulnerable species of sharks and rays in the North Sea, Red List species, and species and habitats for which targets have been defined in the Dutch Marine Strategy (rays and sharks, European flat oyster). For 30 selected focal species the authors provide information on habitat requirements and the function of hard substrate to the species (nursery, attachment surface, foraging, reproduction, hiding space, shelter, etc.).

The following species were not selected:
- Species that will profit from any addition of hard substrate, e.g. scour protection or gravel (in contrast to adding specific NID options). These species include the soft coral dead men's fingers (*Alcyonium digitatum*), Ross worm (*Sabellaria spinulosa*), dahlia anemone (*Urticina felina*) and sea snail (*Liparis liparis*).
- Species that specifically need gravel beds as a habitat to settle (e.g. the shellfish *Dosinia exoleta* and *Arcopagia crassa*, and the worm *Gone doneri*), because gravel is usually not a material used in the Netherlands for the scour protection.

The following policy-relevant species in need of protection or restoration were taken for further consideration (Table 2.2):
- Species that need hiding places, shelter, feeding area or use the area as a nursery area and species that will profit from creating additional smaller and larger crevices. These species include Atlantic cod (*Gadus morhua*) and poor cod (*Trisopterus minutus*) in different life stages. Atlantic cod is considered an umbrella species: measures taken to enhance habitat for this species will result in the enhancement of a suite of co-occurring species at the same time (Lengkeek et al., 2017). Poor cod is not an umbrella species. A variety of sizes of crevices for Atlantic cod or poor cod will also result in hiding spaces for their prey species (crustaceans, worms, shellfish, etc.).

- Different shark species (e.g. small-spotted catshark *Scyliorhinus canicula*) may profit from the addition of larger structures beneficial for egg deposition, while gravely grounds may be used by them as feeding area. This idea has not yet been tested in practice; and
- The European flat oyster *Ostrea edulis* since it is a habitat engineer and it is considered an umbrella species in Lengkeek et al. (2017). It provides a biogenic reef structure that attracts many other species (Lengkeek et al., 2017). Although it does not require specific NID structures, it does require reintroduction of adults or introduction of juveniles as spat on shell.

The following commercially interesting species were taken for further consideration, since co-use of wind farms for aquaculture also gains a lot of attention:
- North Sea crab (*Cancer pagurus*) and European lobsters (*Homarus gammarus*). Both species will profit from the creation of crevices and hiding places; and
- Cuttlefish and squid (*Sepia officinalis*, *Alloteuthis subulata, Loligo* sp.) will profit from structures to which they can attach their eggs.

From the list above, based on the inventory of possible NID options (see section 2.5) and the uncertainties regarding how beneficial the structures will be for these species, the following species were however not taken into consideration any further:
- Shark and ray species; and
- Cuttlefish and squid.

Options for these groups could be elaborated in the future.

The considerations listed above have resulted in the target species list detailed in Table 2.2.

Table 2.1 Overview of focal species and habitat information by Lengkeek et al. (2017). For each species the policy relevance is given (typical species for one or more marine HD habitat types in the Netherlands, indicator species for the MSDF assessments of seafloor integrity, OSPAR species and NL Red list species), as well as the function of large structures and gravel beds for the different stages of the species (A=adult, J=Juvenile, E=eggs).

Species group	**Name**	**UK name (Dutch name)**	**Typical species for HD habitat type**	**MSDF indicator species for HD habitat type**	**Policy framework**	**OSPAR**	**NL Red List**	**Large structure**	**Gravel beds**	**Primary function o the substrate**
Algae	*Lithothamnion sonderi*	Coraline algae species	H1170	H1170				A	A	Attachment surface
Anemones and corals	*Alcyonium digitatum*	Dead men's thumb (dodemansduim)	H1110C, H1170	H1170				JA	JA	Attachment
Anemones and corals	*Urticina felina*	Dahlia anemone (zeedahlia)	H1170	H1170				JA	JA	Attachment surface
Bivalves and gastropods	*Aequipecten opercularis*	Queen scallop (wijde mantel)	H1170						J	Nursery
Bivalves and gastropods	*Aporrhais pespelecani*	Pelicans foot (pelikaansvoet)	H1170						E	Attachment / foraging
Bivalves and gastropods	*Arcopagia crassa*	Blunt tellin (stevige platschelp)	H1170						A	Infauna gravel
Bivalves and gastropods	*Buccinum undatum*	Whelk (wulk)	H1110ABC, H1140A, H1170					EJA	EJA	Attachment / foraging / reproduction
Bivalves and gastropods	*Monia patelliformis*	Ribbed saddle oyster (mantel-dekschelp)		H1170				A	A	Attachment surface
Bivalves and gastropods	*Ostrea edulis*	European flat oyster (platte oester)			MSFD: reintroduction flat oyster	OSPAR		JA	JA	Attachment, reproduction
Bivalves and gastropods	*Simnia patula*	Sea snail species (gestreepte pegelhoren)	H1170					EJA	EJA	Attachment surface/foraging
Crabs and lobsters	*Galathea intermedia*	Small squat lobster (rugstreep-oprolkreeft)	H1170	H1170					JA	Hiding space/foraging
Fish	*Gadus morhua*	Atlantic cod (kabeljauw)	H1110C			OSPAR	Near Threatened	A	J	Nursery/foraging /shelter

Fish	*Liparis liparis liparis*	Sea-snail (slakdolf)	H1110AB				Vulnerable	A	A	Hiding space / reproduction
Fish	*Micrenophrys lilljeborgii*	Norway bullhead (dwergzeedonderpad)	H1170						EJA	shelter
Fish	*Microstomus kitt*	Lemon sole (tongschar)	H1110C				Near Threatened	A	A	Shelter
Fish	*Phrynorhombus norvegicus*	Norwegian topknot (dwergbot)					Near Threatened	JA	JA	Shelter
Fish	*Raniceps raninus*	Tadpole-fish (vorskwab)					Endangered	JA		Hiding space/foraging
Fish	*Trisopterus minutus*	Poor cod (dwergbolk)					Near Threatened	JA	JA	Foraging/hiding space
Polychaete worms	*Chone duneri*	A polychaete species	H1170	H1170					A	Infauna gravel
Polychaete worms	*Sabellaria spinulosa*	Ross worm (gestekelde zandkokerworm)	H1170	H1170				JA	JA	Attachment surface
Sharks and rays	*Dasyatis pastinaca*	Common stingray (pijlstaartrog)			NL Shark protection plan				A	Foraging
Sharks and rays	*Leucoraja naevus*	Cuckoo ray (grootoogrog)			NL Shark protection plan				A	Foraging
Sharks and rays	*Mustelus asterias*	Starry smooth-hound (gevlekte gladde haai)			NL Shark protection plan				A	Foraging
Sharks and rays	*Mustelus mustelus*	Smooth-hound (gladde haai)			NL Shark protection plan				A	Foraging
Sharks and rays	*Raja brachyura*	Blonde ray (blonde rog)			NL Shark protection plan				A	Foraging
Sharks and rays	*Raja clavata*	Starry ray (stekelrog)			NL Shark protection plan	OSPAR	Endangered	A	EJA	Foraging
Sharks and rays	*Scyliorhinus canicula*	Dogfish (hondshaai)			NL Shark protection plan			E	EJA	Foraging
Sharks and rays	*Scyliorhinus stellaris*	Nursehound (kathaai)			NL Shark protection plan			EJA		Foraging
Sponges	*Haliclona (Haliclona) oculata*	Mermaid’s glove (geweispons)	H1170					JA	JA	Attachment

Table 2.2 Selected target species for NID options and their policy relevance. Species that are not further considered based on the inventory of NID options are indicated with an #.

Target Species	Relevance
Policy-relevant species	
Atlantic cod *Gadus morhua*	OSPAR species* Habitat Directive typical species of H1110C NL Red List (Near Threatened)
Poor cod *Trisopterus minutus*	NL Red list (Near Threatened)
European flat oyster *Ostrea edulis*	OSPAR species MSFD target**
# Sharks and rays Elasmobranchs	OSPAR species MSFD target*** NL Red List: Starry ray: endangered
Commercial species	
Atlantic cod **** *Gadus morhua*	Commercial species
European flat oyster **** *Ostrea edulis*	Commercial species
European lobster *Homarus gammarus*	Commercial species
Edible crab *Cancer pagurus*	Commercial species
#Cuttlefish and squid	Commercial species

* OSPAR Commission (2008).
** Target D6T5 - return and recovery of biogenic reefs including flat oyster beds (Min IenW & Min LNV, 2018).
*** Target D1C2 - Improving the population abundance of sharks and rays in the North Sea and above all in the coastal zone (Min IW & Min LNV, 2018)
**** Although being a commercial species, the focus in this report is on policy-relevance
\# Not further selected due to a lack of knowledge

For each of the selected species, a quick scan of selected literature was done to collect basic information on biology, habitat requirements, production, presence in offshore wind farms (OWF) and the implication for NID designs. This overview is provided in Chapter 4.

The target species selected for this study have been used as input to conduct the inventory of the viable NID options.

2.5 Inventory of Nature-Inclusive Design (NID) options

In order to comprise an overview of NID options for the target species a systematic review of peer-reviewed journals, scientific and technical reports, conference proceedings and datasheets of various producers/suppliers was conducted. The sources used were selected based on relevance to this project, e.g. proven technology or assessed as ecologically promising (see Appendix III and the references therein). Each NID option was assessed on its ecological viability and before being added to the catalogue. This resulted in proven or promising NID options from both technical and ecological perspective, that were categorized based on their similarities in ecological habitat requirements, impact on design, risk and installation method. Note that the selected NID options have not yet been applied on a large scale in the Dutch North Sea.

This systematic review resulted in an overview of NID possibilities that served as an input for the expert consultation phase. The NID options were judged by ecological experts and industry representatives based on their design applicability, risk and cost aspects.

2.6 Expert sessions

The NID options that resulted from the systematic review were discussed with ecological experts and industry representatives. The aim was to assess the technically and ecological viability of the options and to involve the end-users in the development of the NID options. Suppliers of possible ecological enhancement modules were consulted to get further insight in the ecological viability of catalogue's options.

Interviewing method

The starting input for the interview, an overview of NID possibilities, was the same for all interviewees. If new NID options were suggested during these consultations, they were added to the initial list, but not used in the subsequent interviews. One week prior to the interview, the document folder was sent to the interviewees and included: a memo containing an introduction to the project, background information, rules of engagement and the interview questions, and NID datasheets. The exception were the suppliers with whom the interviews were conducted specifically in relation to their product, therefore not with a standardized set of interview questions.

All the interviews were conducted with at least two project members, in most cases one from Wageningen Marine Research (ecological expertise) and one from Witteveen+Bos (ecological/technical expertise). Each interview/consultation resulted in minutes of the meeting which were checked by the interviewees prior to their finalisation. After all the interviews were completed, a summary of the findings was included in a memo (see appendix II) and sent to all interviewees independently for information and quality control. The aim of this interdisciplinary review was to detect any inaccuracies on the overall interview findings.

Nineteen interviews were held in August and September 2019 with a group of selected end-users (see Table 2.3). The interviewees included various industry players, from wind developers and contractors to specific suppliers. Representatives of knowledge institutes were consulted to determine the link between ecological and technical considerations. Moreover, specific technical, financial and ecological aspects were also discussed with a number of experts in Witteveen+Bos and Wageningen Marine Research.

Table 2.3 List of end-users contributing to the expert interviews

Type of end user	Company or institute
Wind developer	Ørsted
	Eneco
	Vattenfall
	Gemini
Contractor	Van Oord
	Boskalis
Knowledge institute	Deltares
	TU Delft
	Wageningen University and Research
Consultancy	Bureau Waardenburg
Product supplier	Sumitomo Deutschland GmbH
	Jaeger Mare Solutions GmbH
	Ecocean

Type of end user	Company or institute
	ECOncrete
	ARCMarine

The results from the interviews were used to define technical requirements for nature-inclusive building, and provide NID options in the catalogue that are judged viable from both technological and ecological perspective. It is important to mention that the final list of categories in this report differs from the one described in the summary, as new input and findings were gathered throughout the project, including the external review process. For the transparency of the process, the summary of expert consultations as was provided to the interviewees is shown in Appendix I. The final list of NID options is shown in the next chapter and presented in more details in the NID catalogue (see Appendix III).

3

NATURE-INCLUSIVE DESIGN CATALOGUE

3.1 Overview of Nature-Inclusive Design options

The proven technology or ecologically promising NID options have been organised in three categories based on the aspect of the offshore infrastructure they apply to:

1 Add-on options - refer to structural additions in a design of an offshore substation (or a monopile), thus making NID its integral part.
2 Optimized scour protection layer - refers to an optimization of a standard scour protection design for a monopile or a substation.
3 Optimized cable protection layer - refers to an optimization of a standard cable protection design for a subsea power cables or cable crossings.

In Table 3.1 the NID options per category are shown. The options presented in this table are detailed in our NID catalogue, which forms an integral part of this technical report (see Appendix III).

Table 3.1 List of categories with listed Nature-Inclusive Design (NID) options

Category	Specific NID option
1 Add-on options*	Biohut®
	Cod hotel (Cotel)
2 Optimized scour protection layer	Additional rock layer
	Adapted grading armour layer
	Placing unit on or in the scour protection layer:
	– Habitat pipes
	– Fish hotel (WUR)
	– Reefball® and Layer cakes
	– Reef cube®
	– 3D printed units
	– ECO armour block®
	– Oyster gabions
	– Biohut®
3 Optimized cable protection layer	Filter Unit®
	Basalt bags
	ECO Mats®
	Reef cube bag™
	Reef cube matt™

*at the current stage of the technical development, adding an additional element to the design of a monopile is undesirable in offshore conditions. This option is currently feasible for implementation on offshore substations.

During the expert consultations and the external review process, several NID options were mentioned or conceived including:

- **Stable scour protection design** - allows for reef formation due to increased settlement success of sessile species due to reduced bed movement of the erosion protection. This option has not been included in the catalogue as it is not primarily aimed at the target species identified for this report (see Target species selection in section 2.4).
- **Hotel for elasmobranchs (Elotel)** - a structure that allows elasmobranchs (e.g. dogfish) to attach their eggs.
- **Hotel for squids (Sqotel)** - a structure that allows squids and cuttlefish to attached their egg capsules;
- **Shell/rock glue** - using different types of autochthonous material and glue to create a larger, stable structure to provide settlement for reef forming species.
- **Reef fields** - using triangular or square patterns of low rock berms covering approx. 4 m^2 of seabed per running meter to create a large area of hard substrate with minimal rock consumption.
- **Monopile hole** - using a new design of a monopile where water replenishment hole can act as a shelter or even used for measurement instruments and cameras for continuous monitoring.

Although these options seem ecologically interesting and technically viable, there is currently not enough information available to include these options in this report and the catalogue.

4

ECOLOGICAL CONSIDERATIONS

The previous chapter describes an overview of the NID options (Table 3.1). This chapter gives an overview of the ecological implications of the different NID options. More detail on the target species (section 4.1) and their ecological functions and benefits (section 4.2) is provided.

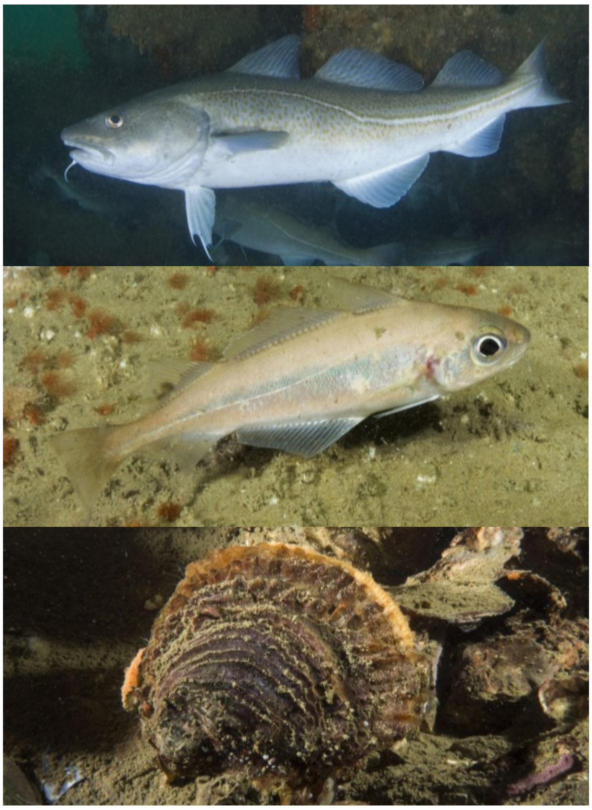
4.1 Target species

For each of the selected target species (see section 2.4), a quick scan of selected literature was done to collect basic information on biology, habitat requirements, production, presence in offshore wind farms (OWF) and the implication for NID designs. See Figure 4.1 for an overview of the target species.

4.1.1 Policy-relevant species

In this section, selected policy-relevant species are described in more details.

Figure 4.1 (top) Atlantic cod *(Gadus morhua)* (photo: Peter Verhoog); (middle) Poor cod *(Trisopterus minutus)* (photo: Oscar Bos, WMR); (bottom) European flat oyster *(Ostrea edulis)* in the Grevelingen (photo: Oscar Bos, WMR)



Atlantic cod (*Gadus morhua*)

Table 4.1 Species information for Atlantic cod (*Gadus morhua*). C represents the confidence level: 1 information based on peer-reviewed or grey literature; 2: information extrapolated from non-targeted research; 3: information based on expert judgement or alike.

Species	Atlantic cod (*Gadus morhua*)	C
Biology		
Presence	Atlantic cod aggregate in loose schools that roam both over the seabed and in mid water (Heessen et al. 2015).	1
Site fidelity	Larger specimens show site fidelity. They are often found near wrecks (Heessen et al. 2015, Oscar Bos p.o.) and in OWF (Ruebens et al. 2013, Winter et al. 2010).	1
Juvenile diet	Juveniles start feeding on plankton, and switch to shrimp, crabs, worms as well as small fish (Breve, 2010).	1
Adult diet	Adult mainly feed on other fish (Breve, 2010).	1
Body dimensions		
Shape	1 x 0.33 x 0.33 (O.G. Bos, estimation)	3
Length-weight relationship	log10(W) = a + b*log10(L), where W = weight (g), a = -6.919 and b = 3.819 and L = length (mm). Min length: 50 mm, max 550 mm (Robinson et al. 2010).	1
Typical size in North Sea	Atlantic cod caught in fish surveys vary between 9 to 75 cm, with a median of about 15 cm. In shallow waters (<20 m) the median size is 10 cm, in deeper waters (> 20 m) the median size is 25 to 30 cm (Heessen et al. 2015).	2
Typical weight in North Sea (kg)	Based on median sizes and length-weight relationship it ranges from 0.173 to 0.347 kg/ind,	2
Max age	25 y	1
Typical age in North Sea	In the North Sea, cod older than 10 years are rarely seen. The dominating age classes are the 1 (10-25 cm) and 2 year olds (20-40 cm) (ICES Fishmap factsheet).	1
Habitat requirements		
Eggs deposition	Atlantic cod spawn once a year, preferably near or on the seafloor (Breve, 2010). North Sea cod spawn between January and April within a range between 1 and 8 ºC and a preference for 5 to 7ºC (references in Wright et al., 2018). Larvae are pelagic up to 2.5 months before settling (FishBase, 2019).	1
Settlement	See juveniles	1
Juveniles	Juvenile cod prefer complex habitats in shallow waters (10-30 m) which protect it from predators (FishBase, 2019).	1
Adults	Atlantic cod are attracted to hard substrate (Reubens et al. 2013). Cod use larger crevices for shelter, at least at shipwrecks (O.G. Bos, p.o.).	2
Offshore Wind farms		
Presence	In the OWEZ wind farm, cod caught for telemetry experiments ranged from 22 to 46 cm, hence these were mainly juveniles (Winter et al. 2010). Research using telemetry in a Belgian offshore wind farm has shown that during summer and autumn, adult cod aggregate around artificial hard substrate (individuals stayed mostly within 50 m distance from the turbine pole) and show strong site fidelity and residency. During winter low densities were present (Reubens et al. 2013). Dutch research using telemetry has shown similar patterns (Winter et al. 2010). Danish telemetry research in the Danish Blue Reef project, where a natural reef was restored showed that cod spent more time and showed more fidelity, after reef restoration, probably because the reef provided more sheltering and more foraging opportunities (Kristensen et al. 2017).	1

Species	Atlantic cod (*Gadus morhua*)	C
Production		
Stock	Spawning Stock Biomass (SSB): about 100,000 tonnes in ICES area in Subarea 4, Division 7.d, and Subdivision 20 (North Sea, Skagerrak, Eastern English Channel) (ICES CIEM stock assessment).	1
Area	North Sea: 750,000 km^2; Skagerrak: 47,000 km2; Eastern English Channel: 75,000 km^2: total 872,000 km^2	1
Kg/km2	Given the numbers above, a typical average SBB weight would be 115 kg/km^2	3

Poor cod (*Trisopterus minutus*)

Table 4.2 Species information for poor cod (*Trisopterus minutus*). C represents the confidence level: 1 information based on peer-reviewed or grey literature; 2: information extrapolated from non-targeted research; 3: information based on expert-judgement or alike.

Species	Poor cod (*Trisopterus minutus*)	C
Biology		
Presence	The species is encountered in the North Sea in various fish surveys at sandy bottoms and near ship wrecks (Bos et al. 2016). Small poor cod are often seen in and around ship wrecks and in cracks and crevices in rocky areas (Ruiz 2008).	2
Site fidelity	Species is not territorial. Small poor cod are attracted to hard substrate (Ruiz, 2008).	3
Juvenile diet	NA	
Adult diet	Feeds on crustaceans, small fish, and polychaetes (Magnussen & Magnussen, 2009)	1
Body dimensions		
Shape	Similar to Atlantic cod	3
Length-weight relationship	log10(W) = a + b*log10(L), where W = weight (g), a = -4.976 and b = 2.970 and L = length (mm). Min length: 52 mm, max 150 mm (Robinson et al. 2010).	1
Typical size in North Sea	North Sea: between 52 and 150 mm (Robinson et al .2010). According to FishBase (not specifically North Sea): common length: 20 cm (https://www.fishbase.se/summary/481).	2
Typical weight in North Sea (kg)	1.3 and 31 g, based on L-W relationship and sizes of 52 to 150 mm	2
Max age	5 y (FishBase: https://www.fishbase.se/summary/481)	1
Typical age in North Sea	NA	
Habitat requirements		
Eggs deposition	Spawning occurs in spring (Magnussen & Magnussen).	2
Settlement	NA	
Juveniles	Are often seen in cracks and crevices in rocky areas (Ruiz, 2008).	1
Adults	The poor cod swims in small schools, usually near hard substrate such as wrecks or rocks (https://www.anemoon.org/flora-en-fauna/soorteninformatie/soorten/id/301/dwergbolk) (in Dutch).	2
Offshore Wind farms		
Presence	Not reported for OWEZ or PAWP OWFs (Bos et al., 2016).	2
Production		
Stock	NA	
Area	NA	
Kg/km^2	NA	

European flat oyster (*Ostrea edulis*)

Table 4.3 Species information for European flat oyster (*Ostrea edulis*). C represents the confidence level: 1 information based on peer reviewed or grey literature; 2: information extrapolated from non-targeted research; 3: information based on expert-judgement or alike.

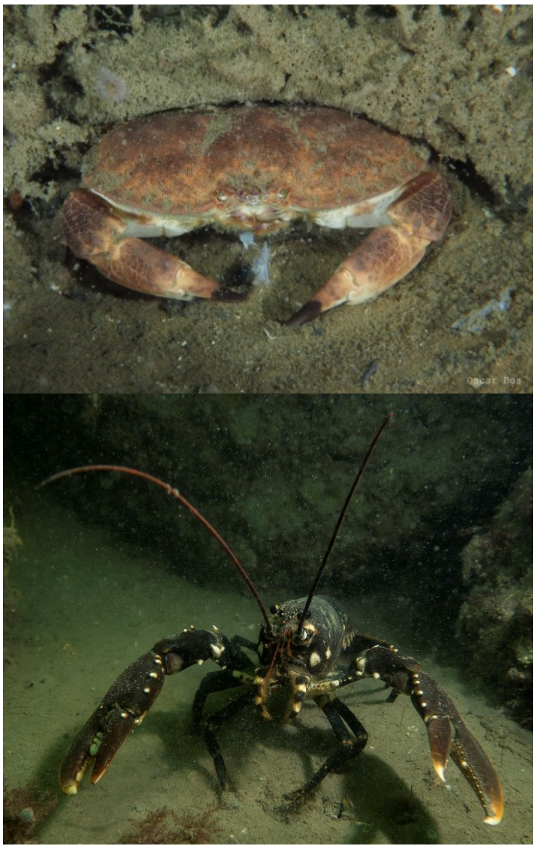
Species	European flat oyster (*Ostrea edulis*)	C
Biology		
Presence	European flat oysters live on the bottom and can form biogenic reefs, and are therefore also called bio-engineers (Smaal et al. 2015). In the past flat oyster beds formed an important part of the North Sea ecosystem, but nowadays the species has almost disappeared. Overfishing and seabed disturbance but also natural factors such as diseases (parasitic disease caused by *Bonamia* sp.) have played a role (OSPAR Commission, 2009; Smaal et al. 2017). An oyster bed is defined as a reef when the density is at least 5 ind/m2 (OSPAR Commission, 2009).	1
Site fidelity	European flat oysters form reefs (OSPAR Commission, 2009, Christianen et al. 2019)	1
Juvenile diet	Phytoplankton	1
Adult diet	Phytoplankton	1
Body dimensions		
Shape	Oval shaped, one side is flat, the other concave	3
Length-weight relationship	w(g)= 0.83 width(mm) + 15.02 (based on oysters used for Gemini restoration project)	3
Typical size in North Sea	The European flat oyster can grow up to 22 cm but are often smaller. In the Voordelta, oysters ranged between 1 and 11 cm (median: 7 cm) (Sas et al. 2018, Christianen et al. 2019).	3
Typical weight in North Sea (kg)	In Zeeland, European flat oysters are sold commercially between 50 and 90+ g.	3
Max age	20 y (FAO: http://www.fao.org/fishery/culturedspecies/Ostrea_edulis/en)	2
Typical age in North Sea	Age determination of European flat oysters from the Voordelta still needs to take place (Witbaard in prep.). Probably 1-10 years.	3
Habitat requirements		
Eggs deposition/Reproduction	European Flat oysters do not deposit eggs. They breed larvae internally instead. Flat oysters start as a male and become female when they grow older, but can also switch back. Flat oysters display brood care, i.e. larvae develop in the mantle cavity of the female and are released after 1-2 weeks at a length of 170-190 micrometre. They swim around in the water column until a suitable settlement substrate (e.g. oyster shells) is found. As a result of the relatively short free swimming phase, the potential dispersal distance is limited. Once established, a population can reinforce itself since larvae occupy dead shell material (Smaal et al. 2015).	1
Settlement	For settlement, European flat oyster recruits require hard substrate (dead shells, rocks, live shells). At the time of larval production, sufficient settlement material (e.g. dead mussel shells) should be available for the larvae to settle on (Smaal et al. 2015). NID options with dead shells or other hard substrate will probably be beneficial.	1
Juveniles	Recruits continue to grow on hard substrate (dead shells, rocks, live shells) (Smaal et al. 2015).	1
Adults	European flat oysters can be attached to NID options such as reef balls and 3D-printed structures, but they can also be deposited on the scour protection. Flat oysters build biogenic reefs that function as a habitat for many species.	1
Offshore Wind farms		
Presence	A number of pilots are currently (2019) conducted in Dutch OWFs, in which experimental tables with oyster cages are deployed on the seabed to follow their growth and survival (e.g. Luchterduinen, Gemini), or in which oysters are placed on the seafloor (Gemini) (Smaal et al. 2015, Sas et al. 2016, 2018, 2019, van der Have & van der Zee, 2016, Didderen et al. 2019a,b, Christianen et al. 2019). The flat oysters appear to survive well, as long as they are not buried under the sand with the sand waves.	1

Production		
Stock	In the Voordelta, around 40 ha of a mixed bed of European flat oyster and Pacific oyster (*Magallana gigas*) is naturally present (Sas et al. 2018). No other natural reefs are present yet. Pilot restoration efforts should operate on the scale of hectares, while full size oyster beds have an even larger scale, of the order of km^2 (Smaal et al. 2015).	2
Area	The scale of an natural oyster bed is 1ha to km^2 (Smaal et al. 2015).	2
Kg/km^2	A reef is defined as 5 ind/m^2 (OSPAR Commission, 2009). In the Voordelta, the density is 7 ind/m^2.	2

4.1.2 Commercial species

In this section, selected commercial species are described in more details.

Figure 4.2 (top) Edible crab *(Cancer pagurus)* on shipwrecks in the North Sea (photo Oscar Bos, WMR); (bottom) European lobster *(Homarus gammarus)* in the North Sea (photo Oscar Bos, WMR)



Edible crab (*Cancer pagurus*)

Table 4.4 Species information for edible crab (*Cancer pagurus*). C represents the confidence level: 1 information based on peer reviewed or grey literature; 2: information extrapolated from non-targeted research; 3: information based on expert-judgement or alike.

Species	Edible crab (*Cancer pagurus*)	C
Biology		
Presence	The edible crab is a very well recognizable large crab with a reddish brown to brownish grey colour. The species is very common on hard substrates and is valued as a commercial species. It can grow up to large size (30 cm carapace width).	1
Site fidelity	As an adult, *C. pagurus* can move considerable distances (10s of km), as has been shown by tagging studies (Bennett, 1995).	1
Juvenile diet	Small bivalves and smaller crustaceans (e.g. Mascaro & Seed, 2001)	1
Adult diet	Bivalves and crustaceans (e.g. Mascaro & Seed, 2001)	1
Body dimensions		
Shape	Length: approx. 45 cm (carapace max 30 cm) Width of carapace more than twice the length (https://www.anemoon.org/flora-en-fauna/soorteninformatie/soorten/id/120/noordzeekrab).	1
Length-weight relationship	For the North Sea: log10W=a+b+log10(L), where a=-3.945, b=3.053, L ranges between 13 and 176 mm carapace width (CW) (Robinson et al. 2010).	1
Typical size in North Sea	Between 13 and 176 mm CW (Robinson et al. 2010). Size in commercial landings in North Sea: median size 145 mm CW (Masefield, 2017).	2
Typical weight in North Sea (kg)	Between 0.3 and 814 g, based on L-W relationship and sizes of 13 to 176 CW (mm). At ship wrecks, edible crabs usually have large sizes (up to 25 cm, OG Bos, p.o.). This would yield a weight of 2376 g, or 2.4 kg.	2
Max age	NA	
Typical age in North Sea	NA	
Habitat requirements		
Eggs deposition/Reproduction	Eggs are planktonic (Bennett, 1995). The edible crab produces eggs that hatch into planktonic larvae that remain in the water column for 2 months, after which they settle (Bennett, 1995).	1
Settlement	The first life stages of edible crab use structurally complex habitats as nursery habitats to seek shelter (Krone et al. 2017). NID options with complex surfaces and space to seek shelter are probably beneficial.	1
Juveniles	Juvenile life stages profit from complex habitats for shelter (Krone et al. 2017). NID options with complex surfaces and spaces to hide will be beneficial.	1
Adults	Adults seem to have less preference for specific habitats (Krone et al., 2017). At shipwrecks, adults can be observed both in sheltered areas and less sheltered habitats, and seem to prefer oval or round shaped shelters (Oscar Bos, p.o.), but this has not been tested yet. For adults, NID options with spaces for shelter will be beneficial.	1 3
Offshore Wind farms		
Presence	In OWF studies in the Netherlands and Germany edible crabs are generally observed both on the monopiles and on the scour protection (Bouma and Lengkeek, 2012; VanAgt & Faasse, 2015; Krone et al. 2017). In the German OWF, densities were estimated to be 4.8 m^2 (Krone et al, 2017) (different size and age classes). In the Danish Horns Rev park, the monopiles hosted hundreds of juvenile edible crabs per m^2, while larger life stages were found in lower densities within the scour protection (Leonhard & Pederson, 2006). Krone et al. (2017) estimate that OWF could be responsible for a 120% gain in the local edible crab population.	1

Species	Edible crab (*Cancer pagurus*)	C
Production		
Stock	In the period 2009-2016 landings of edible crab in the Netherlands varied between 522 and 2715 tonnes, with values varying between 645 to 2944 Euros per tonne (Eurostat).	1
Area	NA	
Kg/km^2	NA (no data on fished area available)	

European lobster (*Homarus gammarus*)

Table 4.5 Species information for European lobster (*Homarus gammarus*). C represents the confidence level: 1 information based on peer-reviewed or grey literature; 2: information extrapolated from non-targeted research; 3: information based on expert-judgement or alike.

Species	European lobster (*Homarus gammarus*)	C
Biology		
Presence	European lobsters are frequently seen in the Delta area in Zeeland (Rozemeijer & Van de Wolfshaar). In the Dutch North Sea, European lobsters are present at most ship wrecks (O.B. Bos, p.o.). In Germany, shipwrecks host one or a few lobsters per wreck (Krone & Schröder, 2011).	2
Site fidelity	European lobsters are in general sedentary animals with home ranges varying from 2 to 10 km (Prodöhl et al. 2007). In Zeeland, lobsters usually hide in burrows. At shipwrecks, they tend to hide in crevices (O.G. Bos, p.o.).	2,3
Juvenile diet	NA	
Adult diet	Lobsters are primarily nocturnal animals feeding on blue mussels, hermit crabs and polychaetes (Prodöhl et al. 2007).	1
Body dimensions		
Shape	The carapace length is roughly 1/3 of the total body length. The width of the European lobster is roughly equal to the carapace length. The antennas, when folded forward, stick out roughly 0.5 times the carapace length (O.G. Bos, p.o.).	3
Length-weight relationship	A length-weight relationship for this species in de Oosterschelde is W = 0.0016*CL2.803, where CL = carapace length (Rozemeijer & van de Wolfshaar 2019).	2
Typical size in North Sea	Body lengths of European lobsters are given by Rozemeijer & van de Wolfshaar (2019): "Body length up to 60 centimetres and weighing up to 5–6 kilograms, although specimen of more than one meter are encountered too. Commercial catches in Cornwall (UK) showed large males of > 150mm CL and females of 140-150mm (Hepper, 1978, figure 6). In Norway up to 140 CL for both males and females. The largest specimen on record measured 1.26m and weighed 9.3kg, caught in 1931 in Fowey, England". The average size classes caught in Cornwall (UK) were between 75 and 90 mm CL.	2
Typical weight in North Sea (kg)	Around 1.5 kg (Tangelder et al. 2015)	2
Max age	72 y (Sheehy et al. 1999)	1
Typical age in North Sea	1-10 y (Helgoland; Schmalenbach, 2011)	2
Habitat requirements		
Eggs deposition/Reproduction	Eggs are carried by the female, larvae are released in the water column.	1
Settlement	In the early benthic phase, lobsters are dependent on structurally complex habitats (references in May, 2015). NID options with complex surfaces and spaces to hide are expected to be beneficial.	1

Juveniles	Juvenile European lobsters up to 40 mm prefer to shelter and feed in their burrows. Larger juveniles emerge to forage outside of their burrows (references in Bannister & However, 1991). In this phase, they need shelter between cobble or boulders (Galparsoro et al. 2009). NID options with complex surfaces and holes or spaces to hide are expected to be beneficial.	1
Adults	Adult European lobsters can be found in spatially simpler habitats. The lobsters are thought to prefer habitats at the boundary between sedimentary and rocky-bottoms (Galparsoro et al. 2009). NID options with larger holes to hide in are expected to be beneficial.	1
Offshore Wind farms		
Presence	The density of large European lobsters in the natural environment is probably low. We chose for 1 large lobster per 4 m2 (=0.25 ind/m^2). This density is lower than in Zeeland, but much higher than around shipwrecks (Oscar Bos, p.o.) and may therefore be too high. The smaller size classes are supposed to occur more frequently, based upon Cornwall fisheries statistics. In Germany, shipwrecks host one or a few lobsters per wreck (Krone & Schröder, 2011).	3
Production		
Stock	In the period 2009-2016 landings of European lobster in the Netherlands varied between 26 and 81 tonnes, with values varying between 2521 to 17519 Euros per tonne (Eurostat).	1
Area	NA	
Kg/km^2	Not known for the Dutch North Sea. In Northumberland, estimates vary from 2-484 kg/km^2 (refs in Rozemeijer & Van de Wolfshaar, 2019).	2

4.2 Ecological benefits

In general, the ecological benefits of the proposed NID options have not yet been researched and quantified and can therefore be considered as knowledge gaps. The expected benefits are to increase the numbers or biomass of the target species and increase the associated biodiversity. To do so, the NID options need to be of advantage to the target species in one or more parts of their life cycles. Table 4.6 gives an overview of the ecological functions for the 3 categories of NID options that help to increase survival during one or more phases in their life cycle. For most options it is impossible to predict even an order of magnitude of increase of biomass or numbers of target species due to a lack of supporting data.

Based on assumptions on densities and biomass, a number of estimates have been made of the contribution of NID options to an increase in densities and biomass of the target species (Table 4.7). These estimates will need to be validated through pilot studies and monitoring programmes in the future. The calculations suggest that, compared to a situation with a sandy or muddy seafloor, additional biomass production and biodiversity enhancement should be possible.

Table 4.6 Expected ecological functions of NID options for target species. S- shelter (adults), N- nursery (larvae, juveniles), As- attachment substrate

		Policy-relevant species			Commercial species	
		Atlantic cod	Poor cod	European flat oyster	Edible crab	European lobster
1 Add-on options	Biohut®	N	N			
	Cod hotel (Cotel)	S/N	S/N			
2 Optimized scour protection layer	Additional rock layer	S/N	S/N	As	S/N	S/N
	Adapted grading armour layer	N	N	As	S/N	N
	Placing unit on or in the scour protection layer:					
	- Habitat pipes	S/N	S/N		S/N	S/N
	- Fish hotel (WUR)	S/N	S/N		S/N	S/N
	- Reefball® and Layer cakes	S/N	S/N	As	S/N	S/N
	- Reef cube®	N	N	As	S/N	S/N

	- 3D printed units	S/N	S/N	As	S/N	S/N
	- ECO armour block®	N	N	As	N	N
	- Oyster gabions	N	N	As	N	N
	- Biohut®	S/N	S/N		N	N
3 Optimized cable protection layer	Filter Unit®	N	N		N	N
	Basalt bags	N	N		N	N
	ECO Mats®			As		
	Reef cube bag™	N	N		N	N
	Reef cube matt ™	N	N	As	N	N

Table 4.7 Estimates of ecological benefits in terms of production for the selected species. C represents the confidence level: 1 information based on peer reviewed or grey literature; 2: information extrapolated from non-targeted research; 3: information based on expert-judgement or alike.

Policy-relevant species		C
	Atlantic cod (*Gadus morhua*)	
Ecological role	Atlantic cod is a keystone species that is historically known for shaping and stabilizing its environment as a top-predator. It is also a commercially important species that has been overfished (OSPAR Commission, 2014).	
Ecological benefits of NID options	In comparison to a sandy seafloor, it is expected that adapted scour protection will result in a more attractive feeding habitat for Atlantic cod and other fish, with increased numbers of prey items, such as small crustaceans and juvenile fish. The effect of additional NID options with hiding spaces and larger holes is that they offer shelter for different life stages of Atlantic cod, so that cod densities will increase. In Lengkeek et al. (2017) Atlantic cod was described as an umbrella species. The idea is that co-occurring fish species (e.g. other cod-like species) will profit from the introduction of NID options as well. On their turn, Atlantic cod and co-occurring fish species can serve as prey for larger predators such as seals. These expectations are partly based on the results of the Danish blue reef project, where restoration of a stony reef in a sandy area resulted in a large overall increase of biomass of different species groups, including crustaceans and juvenile fish, and a three to six fold increase in Atlantic cod. Stomach analysis showed a coupling between the diet of fish and the presence of benthic prey. The reef functioned as a nursery area for cod with a lot of crevices where juvenile cod could hide (Stenberg et al. 2015).	
Add-on	There is no information on the production of cod in OWF. However, assuming that an NID would be able to support e.g. 100 small cod each year to grow up to 30 cm structure (O.G. Bos, estimation) then the production per NID option would be 100 x 0.347 kg = 34 kg of cod/NID option. Add-on options are only possible on jackets at this stage, and not on monopiles. Therefore we assume 1 jacket per OWF equipped with 2 add-on NID units, resulting in a production of 68 kg of cod.	3
Optimized scour protection	No estimates have been made, since the number of hiding spaces/scour protection is not known.	
Optimized cable protection	No estimates have been made, since the number of hiding spaces/scour protection is not known.	
	Poor cod (*Trisopterus minutus*)	
Ecological role	Poor cod is a small member of the cod family. The poor cod is not well studied and is of no economic importance. The species schools near the bottom and in mid-water and is an opportunistic predator and feeds on small prey such as shrimp, worms, young crabs and juvenile fish (Heessen et al, 2015). Because of its small maximum size (26 cm) they serve as food for larger fish (Magnussen & Magnussen 2009) and probably for larger predators such as seals.	
Ecological benefits of NID options	NID options are expected to serve at least as hiding space for juvenile poor cod and possibly for adults.	
Add-on	No estimates are made, since no information is readily available on number or densities.	3
Optimized scour protection	No estimates have been made.	
Optimized cable protection	No estimates have been made	

	European flat oyster (*Ostrea edulis*)	
Ecological role	European flat oyster is a keystone habitat altering species (Lengkeek et al. 2017) that contribute to the ecosystem functioning. They increase biodiversity and form a reef habitat for many other species, such as epibenthic fauna and flora (e.g. tunicates, anemones, algae), mobile invertebrates (e.g. crab and lobster) and fish (species that need hard substrate for shelter as a juvenile, or as spawning ground). Furthermore, the ecosystem functioning is enhanced by improving growth conditions of phytoplankton, contribute to nutrient cycling and thereby to primary production. Also ecosystem services are provided including water quality improvement. If sufficient oysters are present, they could be harvested for commercial use (Smaal et al. 2015).	3
Ecological benefits of NID options	The NID options are supposed to offer habitat for oysters to settle and in this way contribute to the kick start of oyster reefs.	
Add-on	Not applicable.	
Optimized scour protection	European flat oysters can be attached to objects or they can be deposited on the scour protection. It is important that at the time of larval production, sufficient settlement material (e.g. dead mussel shells) are available for the larvae to settle on. It is not yet clear what the minimum number of oysters is required to kickstart a reef. We have no information on how fast oyster restoration will occur. This will depend on the way of restoration (seeding, putting adult oysters, natural recruitment, etc.). To calculate the total oyster number present on the scour protection after a successful occupation of the habitat, we assume maximum densities of 7 ind/m^2, as have been found in the Voordelta (Sas et al. 2018). Assuming a surface of 687 m^2 of available scour protection (oysters are not restricted to the 20% coverage of the optimized layer), this would yield 4811 oysters/pile. One OWF with 60 turbines could therefore according to this calculation yield 288,660 oysters. Whether such densities can be reached needs to be investigated through monitoring.	3
Optimized cable protection	For this, also a density of 7 ind/m^2 could be assumed, and multiplied with the available area.	3

Commercial species

	Edible crab (*Cancer pagurus*)	
Commercial value	In the period 2009-2016 landings of edible crab in the Netherlands varied between 522 and 2715 tonnes, with values varying between 645 to 2944 Euros per tonne (Eurostat, https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do).	
Add-on	Not applicable.	
Optimized scour protection	The total number of crabs per monopile and surrounding scour protection is estimated as follows: Assuming an available surface of the scour protection of 687 m2 (scour protection footprint based on a diameter of 30 m minus pole footprint based on a diameter of 5 m), and assuming a density of 4.8 ind/m^2 (based on Krone et al. 2017), the scour protection could produce 3299 crabs. In this example it is assumed that 100% of the scour protection is suitable for crabs. Assuming a carapace width (CW) of 150 mm, and a weight per crab of 0.500 kg, the total weight per scour protection would be 1649 kg. For an OWF with 60 monopiles, this would be 98,940 kg. If only 20% of the surface would be suitable, the number would be 19,788 kg. Both numbers seem to be rather high.	3
Optimized cable protection	The same reasoning can be followed as above: assume a density of 4.8 ind/m^2, and multiply with the available area.	3

	European lobster (*Homarus gammarus*)	
Commercial value	In the period 2009-2016 landings of European lobster in the Netherlands varied between 26 and 81 tonnes, with values varying between 2521 to 17519 Euros per tonne (Eurostat,https://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do).	
Add-on	Not applicable.	
Optimized scour protection	If each monopile and its surrounding scour protection would produce 2 adult lobsters per year of 85 mm CL, the biomass production would be 2 * 0.410 kg = 0.820 kg per monopile per year. For an OWF of 60 monopiles this would be 120 lobsters (49.2 kg/y). In this example it is assumed that 20% of the scour protection is suitable for lobsters, but that due to territorial behaviour only 2 lobsters would be able to live around one pile.	3
Optimized cable protection	Production will depend on the type of cable protection and the size. However, densities of lobster will be typically low.	3

5

TECHNICAL CONSIDERATIONS

During the consultations with the industry stakeholders, a general concern was expressed that non-proven NID options bring 1) uncertainties in the design process, 2) present technical and ecological risks and 3) increase project costs. In order to reduce the uncertainties associated with implementing NID or ecological requirements in a technical design, an example design process is detailed in section 5.1. The technical considerations specifically relevant to NID for offshore wind infrastructures are specified below the design process. Specific risks that were mentioned by offshore professionals during the consultation process are detailed in section 5.2. This chapter is concluded with an overview of the estimated costs per measure in section 5.3.

5.1 Design process

When including nature requirements in designs becomes the industry standard for offshore (wind) developments, ecological functional requirements will become an integral part of the design from the early beginning of the process. Including nature in the design in an integral manner will most likely result in negligible costs and minor additional risks.

However, to date there is not enough experience with NID in the offshore domain to understand which NID option will result in the highest ecological benefits. The NID options presented in this report are by design an addition to or an alteration of the primary offshore structure; therefore directly interfering with the design of a monopile, substation, scour protection or cable protection/crossing.

In order to gain more insight into the ecological functioning of NID and to reduce the uncertainties of NID implementation, an intermediate step is required. In this phase of NID development it is important to have an overview of the different steps to be taken to include NID in an offshore infrastructure design and give insight where the required information can be obtained. An example design process is detailed in Figure 5.1. This figure shows for each step the *source* of the required information as well as the intended *result* from this step. It is important to note that this is not a linear process, but rather iterative where adjustments might be required to refine a final design.

The steps include:

1. **Starting point** - The first step in the NID design process (detailed in Figure 5.1) is the definition of the 'Starting points'. In this step the following items are defined:
    1. choice of a (preferable) asset within the integral offshore construction plan on which to implement the NID;
    2. target species, which can be derived from policy regulations, and will result in the ecological functional requirements needed to design the NID option.
2. **Choose NID option** - In step two the specific NID option is chosen, based on the options provided in the catalogue (or new developments). The catalogue is to support the definition of the ecological design requirements. For new developments ecological experts can be consulted to obtain the required information.
3. **Determine the environmental conditions** - The environmental conditions at the planned location can be obtained through different reports (Kamermans, 2018, Bureau Waardenburg, 2020), Netherlands Enterprise Agency (RVO), or by field measurements or metocean databases. This step is to result in a set

of governing environmental conditions, required to determine the environmental loads on the NID. In an offshore location the NID may be exposed to wave and current loads, wind and ice loads (when implementing NID above water or on the water surface), gravity, density currents and sand waves.

4 **Determine technical requirements** - Different codes and standards provide technical requirements for structural design, transport and installation and safe functioning. Based on these documents and further requirements from the users and contractors, a set of functional requirements, technical design requirements and transport and installation requirements is defined. These will include the interface with the main structure, strength, stability (anchoring/ gravity based/foundation), sedimentation and erosion, monitoring (access), installation method and natural (autochthonous) material choice. There are several fail mechanisms that need specific attention including construction failure (strength, stability, deformation, fatigue), corrosion leading to constructive failure, scour leading to instability and unwanted marine growth attracting additional hydrodynamic loads. For the transport and installation phase, the transport method, installation method, lift load, splash zone interaction and when applicable pile driving load, impact load and decommissioning needs to be considered. Furthermore, there are some specific technical requirements that are important to consider when implementing NID, see Table 5.1. These requirements were collected by consulting offshore design experts, NID experts in the nearshore/aquatic domain and ecological experts.

5 **Initial design** - The results from the previous steps are used as input for the initial design. In this step, the NID option from the catalogue is transformed into a location specific design which meets the defined requirements. Based on initial calculations, an initial geometry is defined and initial design drawings are made. Furthermore, initial locations on the structure/scour protection are defined. The initial design can be used for stakeholder consultation.

6 **Validate initial design** - The initial design should be validated according to the normative codes and standards to gain permission for deployment. For example, the strength, stability and fatigue life of a structure should be validated by structural calculations. This step results in an initial design report, including all relevant and necessary validations steps. The validated initial design can be used for stakeholder consultation.

7 **Final design** - Based on comments on the validated initial design, from both the stakeholders and permit authorities, the initial design is turned into the final design. This design phase results in a final design report and final design drawings of the NID option. With these documents, the construction phase can start.

After the final design, the following steps may be followed (depending on the design): construction → transport and installation → monitoring → decommissioning.

Figure 5.1 Nature-Inclusive Design plan process

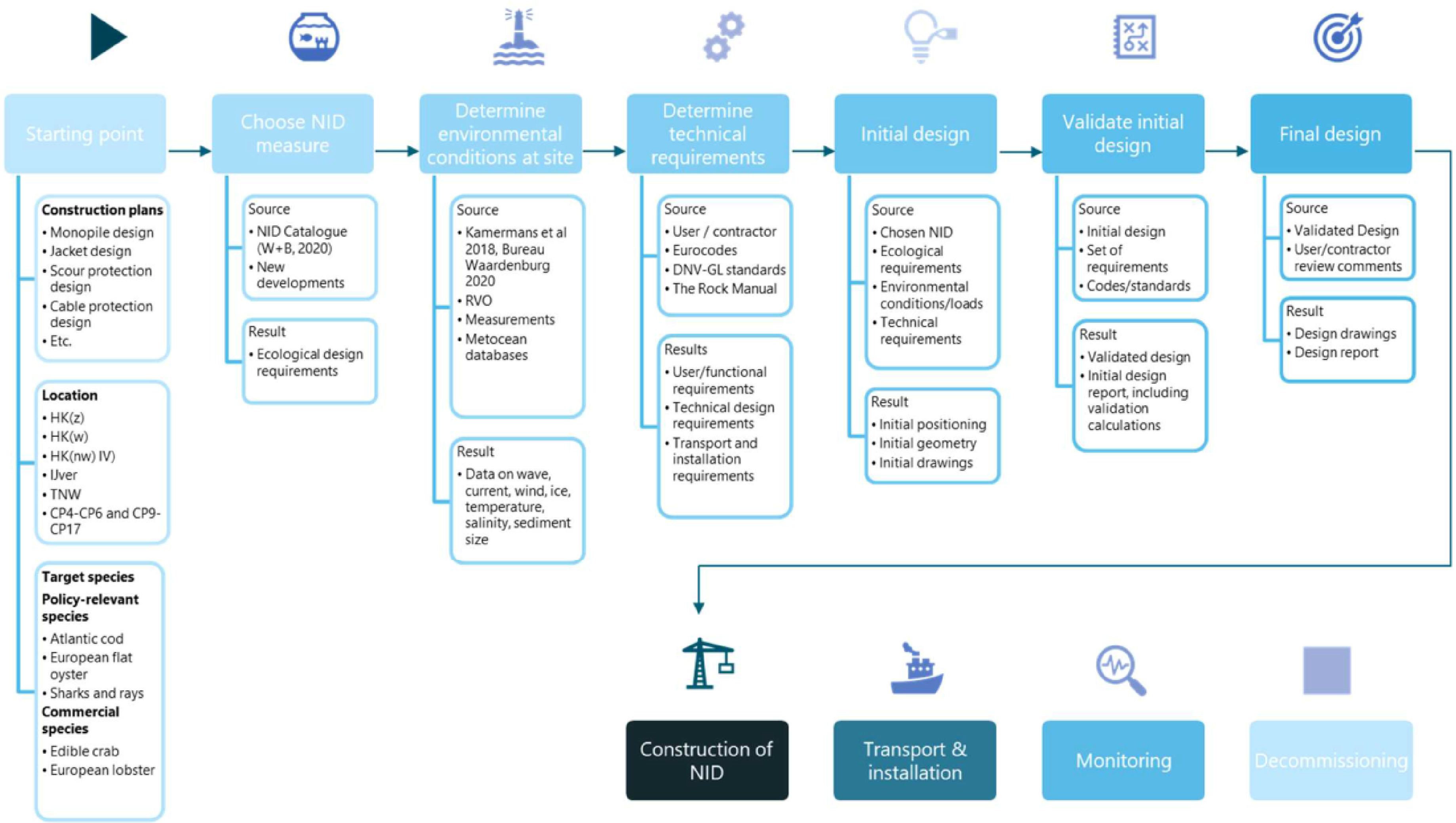


Table 5.1 Overview of specific technical requirements for NID options, developed through expert sessions and listed per category

Category	Technical requirement	Description
All	Material choice	It is highly favourable to use biodegradable or autochthonous materials, where possible e.g. rock, gravel, sand, shell, wood or rope or re-usable materials as steel. When using concrete it is important to consider using mixtures that reduce CO_2 emissions and the potential of chemical leakage in relation to regular concrete. With autochthonous materials it may be not required to decommission the structure. The material options differ per NID.
	Monitoring access	Especially in the early phases of NID implementation it is important to monitor the ecological success and the structural integrity. The requirements for ecological monitoring have to have specific consideration in the design phase in terms of access (ROV for video surveys), possibilities to retrieve and replace (elements of) the NID for monitoring on deck (for example for oysters' growth rims) and easy water sample collection (funnels for hoses). The specific monitoring requirements depend on the type of NID and the parameters chosen to define the ecological success. For more information refer to the latest Bureau Waardenburg report (2020).
Add-on units	Pile driving forces	Pile driving forces can be severe. When an NID is attached to a structure prior to pile driving, the forces associated should be considered. This force is not only exerted on the NID structure but also, if applicable, on the filling material (shells, rock). Add-ons at this current stage of the technical development are only feasible for offshore substations.
	Transport	Implementing an NID option prior to installation requires a review of the transport process. For example, if a structure would be integrated into a monopile it might influence the stacking method during transport. Add-ons at this current stage of the technical development are only feasible for offshore substations.
	Planning	The moment of integration of an NID needs to be considered carefully, e.g. working with live oysters places restrictions on the duration the oysters can be kept out of the water. There are also non-biological considerations as pile driving forces and transport method. Furthermore, offshore ROV operations and submerged welding introduce risks and costs.
Optimized scour protection layer	Boulder size	When adjusting (sections of) the scour protection, the maximum boulder size should be considered to allow pile driving for installation of the monopile.
	Internal stability armour layer	Internal stability of armour layer in relation to larger rock grading used to increase crevices sizes should be considered.
	Stability and interface	When placing elements (reef balls, oyster gabions etc.) on the scour protection, the stability and interface of these NID units and the interface with the armour layer should be considered for hydraulic loads.
Optimized cable protection layer	Cable heating effect	The NID structure itself and the expected marine growth should be taken into consideration when calculating the expected temperature range of the cable. The NID should be designed in such manner that no additional insulation of the cable is induced.
	Cable maintenance	Possible cable maintenance is required during the life span. This requires space and disrupt the (formation of) the reef on the NID. When designing the NID, it should be taken into account that maintenance can be carried out with a minimal amount of disruption to the NID, e.g. the ability to lift a cable mattress and place it adjacent to the cable during repairs, and replacing it after completion.

5.2 Risks

Every NID option carries certain technical and ecological risks that have to be considered from an early phase (design) and monitored in the later phase (operational) in order to properly mitigate these risks and prevent negative consequences. During the expert consultations, the top five technical (T 1-5) and top five ecological (E 1-5) risks were identified. Table 5.2 offers a qualitative analysis of the risks associated with implementing NID, which are detailed below.

5.2.1 Technical risks

Risk T-1: Structural failure of primary structure

The risk of structural failure of the primary asset was perceived as the largest risk of implementing NID as an add-on to the main asset, e.g. on a monopile. This was mainly due to the uncertainties associated with introducing an additional (non-essential) element to the offshore infrastructure. This risk can be caused primarily by uncertain environmental loads and will result in (temporary) loss of the function of the asset. The likelihood of this risk was perceived as small, but if the risk would occur the consequences would be very high. This risk would have no effect on the ecological function. The risk can be effectively mitigated by conducting periodical inspections and if required conducting maintenance. The design of the NID should be modular so that is can be removed if and when maintenance efforts are deemed too high or the structure is in danger of failing.

Risk T-2: Structural failure of NID

The NID structure itself can also experience failure, due to the same reasons as the primary asset e.g. uncertainties of environmental loads and the behaviour of the structure. The consequence is that the NID structure can displace (move) or detach from the primary asset and in both cases the NID is at risk of causing damage to the primary asset. The likelihood is believed to be average, where the displacement of a stand-alone NID is deemed as a larger risk than detaching from the main asset. The technical impact could be high and the ecological impact would be negative as the (potential) ecological function would be lost. Mitigation measures could involve periodic inspection, maintenance and removal of the NID.

Risk T-3: Biofouling

Biofouling is a known effect of placing any hard substrate underwater. Within the context of this report biofouling is a marine growth that prevents the target species from utilising the NID structure. A well know example are the mussels clogging the mesh and preventing fish from entering a structure. Other consequences are additional drag of the NID. The likelihood of this risk is very high and the technical impact can also be high if the additional drag is not included in the drag forces on the NID structure. The ecological impact is a slightly negative as it will prevent the target species to utilise the provided structure. There is no large negative impact as the impact consists only of a loss of ecological potential. Mitigation measures to reduce the technical risk can consist of accounting for sufficient drag in design, periodic inspection and removal of NID if required. The ecological risk can be mitigated by designing the structure for the policy-relevant species as much as possible (see risk E-4). In addition, the space between surfaces should be sufficient to allow for some growth of non-target species without function loss.

Risk T-4: Design failure in placement phase

The installation phase might introduce the risk of incorrect placement e.g. upside down, sideways or in disarray in relation to other NID structures or the primary asset. This can be caused by unexpected environmental circumstances as weather conditions or local seabed anomalies. Another cause could be the use of sub-optimal equipment. As NID placement is an additional effort and offshore vessels are expensive there is a risk of using the equipment that is over- or underfitted for the purpose of the job. The consequences range from improper placement to damage of the NID and/or primary asset. The likelihood of this risk is considered high and the ecological impact as slightly negative. This risk can be mitigated by selecting the correct weather window for the placement, ensuring the use of a recent morphological survey with the resolution fitting the size of the NID and using the optimal equipment.

Risk T-5: Unforeseen costs

Although it is often mentioned that it is not the primary risk, unforeseen costs are frequently mentioned as an important risk. The amount of the unforeseen costs is difficult to specify, namely as this risk is associated with uncertainties in every project phase and range from permitting, rules and regulations (current and future) delays, scope (size and number of NID structures), vessel mobilisation, possibilities to combine placement with other activities etc. The main cause of these uncertainties is the lack of experience with NID implementation. The likelihood of unforeseen costs are high, but the consequence is low as these costs are most likely still relatively small compared to the total project budget. The mitigation measure is close communication with experts from all disciplines, the regulatory bodies and include a buffer within the project budget.

5.2.2 Ecological risks

Risk E-1: Lack of ecological success

The biggest ecological risk is that the NID option does not yield the desired ecological success. The main cause for this is a lack of experience and unforeseen environmental circumstances. The consequences are wasted resources, both economical and material. In addition, NID as a concept is at risk for reputational damage making it harder to make it a standard in offshore development. Likelihood of this occurrence is perceived as high whereas the technical impact is neutral and the ecological impact is negative. It is difficult to mitigate this risk due to the unpredictability of environmental factors and multitude of variables. NID could be implemented as a 'no-regret' measure ensuring that the obtaining of a 'net' ecological result is not the primary objective. In addition, the objectives of NID implementation could also be defined in terms of obtaining experience with the implementation process, placement, interface with offshore works, permitting, etc.

Risk E-2: Settlement of non-indigenous species

This risk is of specific concern for species that compete for the available hard substrate. The cause is that the introduction of hard substrate can also attract other species than the desired policy relevant species. The consequences could be no, or a smaller population of, the indigenous species. The likelihood of this risk to occur is high, whereas the technical impact is neutral but the ecological impact is negative. For the settlement of the policy relevant European flat oyster this risk is especially of concern. This risk can be reduced for example by timing the placement in the water column just prior to the settlement season, preventing the risk of algae competing for the same space. Another possibility is to optimise the settlement surface for the targeted species by coating it with shell material of the species and ensuring the surface has the optimal pH. Another measure is stock enhancement of the target species on/near to the NID.

Risk E-3: Competition between target species

Initial experience indicates that an NID or an artificial reef is being colonised by one species, and that it is difficult to design an NID structure for multiple target species. The causes can be an overlapping use of habitat or predation. This could result in an increased mortality of (one of) the target species as the other species outcompetes the first. The likelihood of this risk to occur is high, whereas the technical impact is neutral but the ecological impact is negative. A better understanding of the habitat requirements and functioning of NID options is required to mitigate this risk.

Risk E-4: Absence of target species

A concern is that the NID measure will not be successful due to a lack of (larvae or juvenile) target species. This could occur due to a lack of stock population, unsuitable environment, lack of settlement cues from the environment. The consequence is that the NID has limited or no success in attracting the targeted species. Depending on the species the likelihood of this risk to occur is high, whereas the technical impact is neutral but the ecological impact is negative. This risk can be mitigated by selecting the NID option based on an appropriate assessment of the site and target species. In addition permanent or temporality stock enhancement could be considered.

Risk E-5: Food limitation for target species

In addition to the need for an adequate stock population sufficient food should be available at the implementation site. Food limitation can be caused by limited biological activity or multiple organisms competing for the same food source. This could result in decreased settlement success. The likelihood of this risk to occur is average, whereas the technical impact is neutral but the ecological impact is negative. The only mitigation measure is to conduct appropriate baseline monitoring to determine the food availability and base the site selection on these data.

Table 5.2 Overview of the top 5 technical and ecological risks associated with Nature-Inclusive Design (NID) resulting from expert consultations. Risk is calculated as likelihood multiplied with the sum of technical and ecological impacts.

#		Risk description	Cause	Consequences	Likelihood	Technical impact	Potential ecological impact	Risk	Mitigation measures
T-1	Technical	Structural failure of primary structure	Uncertainties in the environmental loads	(Temporary) loss of function	2 small	5 very high	1 neutral	Medium	Periodic inspection and scheduled maintenance
T-2		Structural failure of NID	Uncertainties in the environmental loads	Damaging primary structure	3 average	4 high	3 negative	High	Periodic inspection, repairments, removal of NID
T-3		Biofouling	Settlement of non-organisms on structures	Additional drag, blocking of habitat by non-target species	4 high	4 high	2 small negative	High	Account for in design, periodic inspection and removal of NID if required
T-4		Design failure in placement phase	Environmental circumstances different than expected, use of sub-optimal equipment	Damage to primary structure, improper placement	2 small	4 high	2 small negative	Medium	Correct weather window, detailed morphological survey, optimal equipment
T-5		Unforeseen costs	Uncertainties, lack of experience	Overdimensioning	4 high	1 neutral	1 neutral	Low	Interdisciplinary collaboration, contact regulatory bodies, financial buffer
E-1	Ecological	Lack of ecological success	Uncertainties, lack of experience, unpredictable environmental factors	Resources wasted and NID reputation damage	4 high	1 neutral	3 negative	Medium	No regret measure, define goals of pilot accordingly
E-2		Settlement of non-indigenous species	(non specific) artificial structures	No or smaller population of indigenous (target) species	4 high	1 neutral	3 negative	Medium	Specify design for target species, stock enhancement of target species
E-3		Competition between target species	Overlapping habitat, predation	Increased mortality target species	4 high	1 neutral	1 neutral	Low	Gain experience
E-4		Absence of target species	Lack of stock population, unsuitable environment, lack of settlement cues from environment	Limited biological impact	4 high	1 neutral	1 neutral	Low	Site assessment, stock enhancement
E-5		Food limitation for target species	Competition for food, limited biological activity	Decreased settlement success	3 average	1 neutral	3 negative	Medium	Site selection, baseline monitoring

5.3 Cost estimation

Besides being technically and ecologically viable, a clear estimation of costs of an NID option and the resulting ecological benefits of employing such a measure are crucial prerequisites to make NID a standard in offshore wind practice. This is supported by a generally expressed concern during expert consultations that technical uncertainties and risks associated with NID options translate into an increase of the overall project cost.

A deterministic estimate of investment costs was performed for each NID option in the catalogue. Here, it is important to note that quantities (dimensions and number of elements) are assumed and of utmost importance for the total costs (reduction effect of fixed costs such as engineering and fabrication process). In order to make an NID cost indication, the costs estimation calculations presented in this report are based on a reference wind farm comprising of 60 monopiles with:
- standalone solutions: 2 elements per monopile.
- area solutions: 20% of scour protection area, based on ø30 m.

The investment cost estimation included onshore and offshore activities, direct (material) and indirect costs (site organisation, mobilisation, facilities, risk), contingency, construction, engineering, permits and insurances. The overview of costs per NID option is give in table below.

The total life cycle costs (LCC) are comprised of the initial investment costs (capital expenditures, CapEx). Operational expenditures (OpEx) such as monitoring is not included in this overview (for the cost estimate of monitoring activities refer to the report of Bureau Waardenburg, 2020). Although removal of NID might not be needed in the future wind farms, decommissioning (end of life cycle) is part of the current regulations, therefore it has also been included in this overview.

CapEx are estimated based on the following starting points:
- Deterministic estimation/
- Costs are per monopile (and based on a total quantity of 60 monopiles in a wind farm).
- Two NID options on the scour protection around the monopile (except for scour layer (m^2) and fish hotel (1 pcs).
- Scour protection layer options are based on an area of 20% of ø 30 m.

Table 5.3 Summary of Life Cycle Costs for different NID options based on a total quantity of 60 monopiles in a wind farm with two NID options per monopile (total 120 structures) with the exception of the fish hotel (1 pcs), while scour protection layer options are based on an area of 20% of ø 30 m.

	Onshore	Offshore	Decommissioning	Engineering & permitting	Total costs per monopile
	CapEx				Over life time (25 yrs)
Add-on					
Biohut®	€ 2.699	€ 0	€ 296	€ 677	€ 3.672
Cotel	€ 2.431	€ 0	€ 162	€ 586	€ 3.180
Optimized scour protection layer					
Optimized scour protection layer (by design)	€ 0	€ 0	€ 0	€ 0	€ 0
Optimized scour protection layer (add. layer, during placement)	€ 0	€ 5.187	€ 10.374	€ 3.518	€ 19.080
Optimized scour protection layer (add. layer, afterwards)	€ 0	€ 0	€ 0	€ 0	€ 0
Placing unit on or in scour protection layer:					
Habitat pipes	€ 1.621	€ 486	€ 1.362	€ 784	€ 4.253
Reefball® and Layer cakes	€ 1.621	€ 1.621	€ 2.107	€ 1.209	€ 6.559
Reef cube® 1 m^3/pcs	€ 357	€ 1.621	€ 2.107	€ 924	€ 5.008

3D printed units	€ 3.242	€ 1.621	€ 2.107	€ 1.576	€ 8.546
ECO armour block®	€ 3.080	€ 1.621	€ 2.107	€ 1.539	€ 8.347
Biohut®	€ 2.699	€ 0	€ 296	€ 677	€ 3.672
Cod hotel (Cotel)	€ 2.431	€ 0	€ 162	€ 586	€ 3.180
Oyster gabions	€ 3.890	€ 1.621	€ 2.107	€ 1.722	€ 9.341
Optimized cable protection layer					
Rock bag (filter unit or basalt bag)	€ 1.621	€ 973	€ 1.524	€ 931	€ 5.048
ECO Mats®	€ 5.187	€ 1.621	€ 2.107	€ 2.016	€ 10.931
Reef cube matt™	€ 0	€ 0	€ 0	€ 0	€ 0

In Figure 5.2 an example of the calculation is provided for the ECO armour block. For further details on the calculations presented in this report reference is made to Appendix II.

Figure 5.2 Example of cost calculation for ECO armour block based on a total of 2 pieces.

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	2019	Date:	29-10-2019
Project:	NID catalogue for OWF	Version:	01	Project code:	114266
Sub-item:	Eco armour block	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total		total incl. overhead
132									
	INVESTMENT COSTS	2,00							
10	**Onshore activities**								
1013310	Supply Eco Armour block	2,00	pcs	€	850,00	€	1.700,00		
1013400	Onshore transport (from factory to port)	2,00	pcs	€	100,00	€	200,00		**onshore**
	Total Onshore activities			**€**	**1.900,00**			**€**	**3.080**
20	**Offshore activities**								
2013390	Transport and placement of elements	2,00	pcs	€	500,00	€	1.000,00		**offshore**
	Total Offshore activities			**€**	**1.000,00**			**€**	**1.621**
30	**Offshore activities decommissioning (after 20 years)**								
3013330	Removal and transport of elements	2,00	pcs	€	650,00	€	1.300,00		**decomm**
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**1.300,00**			**€**	**2.107**
	Direct costs					**€**	**4.200**		
NTD1321	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	4.200	€	420		
	Direct costs incl. allowance					**€**	**4.620**		
IK1326	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	4.620	€	92		
IK1327	Site facilities	1,0%		€	4.620	€	46		
IK1329	Site organisation (eg. foreman, site managers)	10,0%		€	4.620	€	462		
IK13210	General costs	8,0%		€	5.221	€	418		
IK13211	Profit	3,0%		€	5.638	€	169		
IK13212	Risk	2,0%		€	5.638	€	113		
	Indirect costs ('contractors overhead')	28%				**€**	**1.300**		
VZBK	**Costs foreseen**					**€**	**5.920**		
RBK1323	Contingency	15,0%		€	5.920	€	888		
RBK	**Contingencies**	15%				**€**	**888**		
									1,621
BK1.3b	**Construction costs Eco armour block**					**€**	**6.808**	**€**	**6.808**
VK132	**Real estate Eco armour block**					**€**	-	**€**	-
EK1321	Detailed engineering contractor	2,0%		€	5.920	€	118		
EK1322	Engineering consultancies (design)	6,0%		€	5.920	€	355		
EK1323	Client's organisation (tendering, permitting)	10,0%		€	5.920	€	592		
EK1324	Site supervision, site management	4,0%		€	5.920	€	237		
EK132	**Engineering Eco armour block**	22%				**€**	**1.302**		
OK1321	Remaining costs (e.g. permits, insurances)	4,0%		€	5.920	€	237		**eng + permit**
OBK132	**Remaining costs Eco armour block**	4%				**€**	**237**	**€**	**1.539**
INV132	**Total investment costs Eco armour block**					**€**	**8.347**	**€**	**8.347**

Relative costs

The additional investment of an NID option in relation to the overall project costs of OWF development are marginal. The total installation costs of a North Sea wind farm is based on an estimation of 12-megawatt turbine in a reference wind farm of 60 turbines.

$$60 \text{ (turbines)} \times 12 \text{ MW } = 720 \text{ MW}$$

$$720\ MW\ x\ LCoE \frac{€3450}{kW} = \pm M€2.500$$

The average CapEx of the proposed NID options is less than 0,1% (< 0,1 %) of the total offshore wind farm investment.

6

POINTS OF ATTENTION

During the expert sessions several topics were addressed related to the policy and requirements as part of the government efforts to regulate the use of future offshore wind farms.

Ecological benefits

Ecological benefits of NID options are difficult to quantify at this point in time, since the effects of NID options on most target species and associated biodiversity have not yet been researched in the Dutch North Sea. It is recommended to quantify the effects through dedicated monitoring programmes. Whether the benefits will be considered significant, will depend on the scale at which they are supposed to contribute to nature restoration (e.g. scale of the OWF or North Sea). This is still an open question.

Strategic monitoring

A strategic monitoring program driven by the government could be considered to obtain the required scale for robust monitoring results. Moreover, strategic funding for monitoring would allow for combined monitoring efforts and therefore reduce costs, increase quality by standardisation, experience and sample size and allow for comparability of the results.

Co-use

Policy-wise there is a discrepancy between the efforts for nature restoration and implementing co-use in offshore wind farms (e.g. small-scale fisheries, protein production, seaweed farming). It is recommended to have an integral policy where two efforts are interlinked. This specifically relates to the area within a wind farm but outside the safety zone of a wind turbine (50 m).

Decommissioning

If an NID option is made with natural (possibly biodegradable or autochthonous), non-leaking materials and they are proven effective its removal as part of the decommissioning process should be open for discussion. What is the expected lifetime of an NID solution?

Maintenance and nature conservation

Regulation is required for managing NID options when maintenance or repair activities of an asset is required.

Reduce risks and costs

Current and future offshore wind farms will be built without subsidies. Therefore, offshore wind farm operators need to have a clear understanding of the costs, risks and ecological benefits of NID options. Most NID options presented in this catalogue however have not yet been tested in the North Sea. To understand their ecological benefits in terms of increased biomass or number of target species, we recommend executing and monitoring a number of pilot studies in which such information is obtained for different NID options.

Ecological Cost-Effectivity analysis

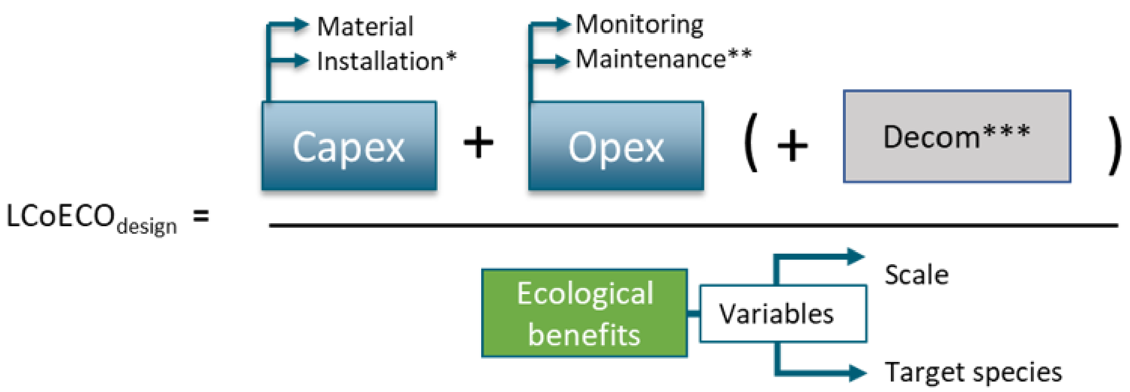
In the energy production, the Levelized Cost of Electricity (LCoE) is used to determine the average cost of one megawatt hour (MWh) of electricity. The LCoE formula is used to compare (offshore) wind farms' locations in terms of economic efficiency and to choose the location with the lowest cost per MWh by dividing the sum of the capital and operational cost by the annual energy production at that location

(Ruijgrok et al. 2019). At the moment, there is no well-founded way to choose which NID will be the best option, where best is defined as the highest yield of ecological benefits per invested euro. This challenge can be solved by introducing the ecological parallel of the LCoE, the function of Levelized costs of Ecology (LCoECO). If the ecological benefits are clearly described for each of the proposed options, it is possible to perform a cost-effectivity analysis to determine the most cost-effective NID option with the highest ecological benefit per target species.

The LCoECO might also address the concept of scale. There are concerns that implementing NID will only have an effect on the ecology at a local scale and not influence the overall ecosystem. Installing a sufficient number of NID could potentially result in the desired large-scale effect. The minimum required number of NID can be determined by calculating the number of individuals required for a sustainable population (of a target species) on the basis of the reproduction and the species' speed of dispersion. Using initial settlement as a predictor of an ecological success, not only the number but also the required spatial gradient of NID implementation can be determined.

The LCoECO is a function of the CapEx (installation and unit costs), OpEx (monitoring), and when applicable the decommissioning costs, divided by the ecological benefits yielded from the solution. This is schematically presented in Figure 6.1 The LCoECO would be different per target species.

Figure 6.1. Schematic overview of Levelized Cost of ECOlogy (LCoECO) calculation, * including design adaptation in case of attached NID, ** in case the attached NID requires extra turbine maintenance, *** only if standalone NID needs to be removed at the end of its lifetime.



When the assessment methods to determine the ecological benefits improve and monitoring results become available, new values can be entered into this formula, i.e. calculation methods remains in use, while input data are replaced when new monitoring results become available.

Future proofing
In the near future, a number of the NID options mentioned in this catalogue may have been further developed and tested in pilot projects in the North Sea, and new NID options may emerge. We recommend incorporating such information in an update of this catalogue, including feedback on the usability of the catalogue from the stakeholders.

7

REFERENCES

Agus B, Mereu M, Cannas R, Cau A, Coluccia E, Follesa MC, Cuccu D (2018) Age determination of *Loligo vulgaris* and *Loligo forbesii* using eye lens analysis. Zoomorphology 137:63-70

Bannister RCA, Howard AE (1991) A large-scale experiment to enhance a stock of lobster (*Homarus gammarus* L.) on the English east coast. ICES Mar Sci Symp 192:99-170

Bennett DB (1995) Factors in the life history of the edible crab (*Cancer pagurus* L.) that influence modelling and management. ICES mar Sei Symp 199:89-98

BIM European lobster – handling and quality guide. Ireland's Seefood Development Agency (BIM). http://www.bim.ie/media/bim/content/downloads/BIM,Lobster,Handling,and,Quality,Guide.pdf

Bouma S, Lengkeek W (2012) Benthic communities on hard substrates of the offshore wind farm Egmond aan Zee (OWEZ) Including results of samples collected in scour holes (http://www.noordzeewind.nl/wp-content/uploads/2012/10/OWEZ_R_266_T1_20120206_hard_substrate.pdf). Bureau Waardenburg. Report OWEZ_R_266_T1_20120206_hard_substrate.

Bos OG, Gittenberger A, De Boois IJ, Van Asch M, Van der Wal JT, Cremer J, Van der Hoorn B, Pieterse S (2016) Soortenlijst Nederlandse Noordzee. Wageningen Marine Research, Den Helder (http://edepot.wur.nl/401117). Wageningen Marine Research.

Brevé NWP (2010) Kennisdocument Atlantische kabeljauw Gadus morhua Linneaus, 1758. Kennisdocument 33. Sportvisserij Nederland.

Bureau Waardenburg (2020). Options for biodiversity enhancement in offshore wind farms. Knowledge base for the implementation of the Rich North Sea Programme. Bureau Waardenburg report nr 19-0153, Bureau Waardenburg, Culemborg.

Christianen MJA, Lengkeek W, Bergsma JH, Coolen JWP, Didderen K, Dorenbosch M, Driessen FMF, Kamermans P, Reuchlin-Hugenholtz E, Sas H, Smaal A, van den Wijngaard KA, van der Have TM (2018) Return of the native facilitated by the invasive? Population composition, substrate preferences and epibenthic species richness of a recently discovered shellfish reef with native European flat oysters (Ostrea edulis) in the North Sea. Mar Biol Res 0:1–8.

Coolen JWP, Van Der Weide B, Cuperus J, Blomberg M, Van Moorsel GWNM, Faasse MA, Bos OG, Degraer S, Lindeboom HJ (2018) Benthic biodiversity on old platforms, young wind farms, and rocky reefs (https://doi.org/10.1093/icesjms/fsy092). ICES Journal of Marine Science

Didderen K, Lengkeek W, Kamermans P, Deden B, Reuchlin-Hugenholtz E. (2019a) Pilot to actively restore native oyster reefs in the North Sea. Comprehensive report to share lessons learned in 2018. Report 19-013. Bureau Waardenburg, Culemborg. WWF, Zeist.

Didderen K, van der Have TM, Bergsma JH, van der Jagt H, Lengkeek W, Kamermans P, van den Brink A, Maathuis M, Sas H (2019b) Shellfish bed restoration pilots Voordelta, Netherlands Annual report 2018, ARK Report

Galparsoro I, Borja Á, Bald J, Liria P, Chust G (2009) Predicting suitable habitat for the European lobster (*Homarus gammarus*), on the Basque continental shelf (Bay of Biscay), using Ecological-Niche Factor Analysis. Ecological Modelling 220:556-567

Hal R van (2014) Demersal Fish Monitoring Princess Amalia Wind Farm (http://library.wur.nl/WebQuery/wurpubs/fulltext/380372). IMARES. Report C125/14

Heessen HJL, Daan N, Ellis JR (eds) (2015) Fish Atlas of the Celtic Sea, North Sea, and Baltic Sea. Wageningen Academic Publishers, Wageningen

Hunter E, Buckley AA, Stewart C, Metcalfe JD (2005) Migratory behaviour of the thornback ray, *Raja clavata*, in the southern North Sea. Journal of the Marine Biological Association of the United Kingdom 85:1095-1105

ICES (2017) Report of the Working Group on the Biology and Life History of Crabs (WGCRAB), 1–3 November 2016, Aberdeen, Scotland, UK. ICES CM 2016/SSGEPD:10. 78 pp (http://ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/SSGEPD/2016/01%20WGCRAB%20-%20Report%20of%20the%20Working%20Group%20on%20the%20Biology%20and%20Life%20History%20of%20Crabs.pdf).

ICES (2019) ICES Advice on fishing opportunities, catch, and effort. Greater North Sea Ecoregion. Published 28 June 2019. Cod (*Gadus morhua*) in Subarea 4, Division 7.d, and Subdivision 20 (North Sea, eastern English Channel, Skagerrak) (http://ices.dk/sites/pub/Publication%20Reports/Advice/2019/2019/cod.27.47d20.pdf).

Kristensen LD, Støttrup JG, Svendsen JC, Stenberg C, Højbjerg Hansen OK, Grønkjær P (2017) Behavioural changes of Atlantic cod (Gadus morhua) after marine boulder reef restoration: Implications for coastal habitat management and Natura 2000 areas. Fisheries Management and Ecology 24:353-360 (https://doi.org/10.1111/fme.12235)

Krone & Schröder (2011). Wrecks as artificial lobster habitats in the German Bight. Helgoland Marine Research, 65, 11-16.

Krone R, Dederer G, Kanstinger P, Krämer P, Schneider C, Schmalenbach I (2017) Mobile demersal megafauna at common offshore wind turbine foundations in the German Bight (North Sea) two years after deployment - increased production rate of *Cancer pagurus*. Marine Environmental Research 123:53-61

Krone R, Gutow L, Brey T, Dannheim J, Schroeder A (2013) Mobile demersal megafauna at artificial structures in the German Bight - Likely effects of offshore wind farm development, Vol 125

Lawton, P. and K. L. Lavalli (1995). Chapter 4 - Postlarval, Juvenile, Adolescent, and Adult Ecology. Biology of the Lobster. J. R. Factor. San Diego, Academic Press: 47-88

Lengkeek W, Didderen K, Dorenbosch M, Bouma S, Waardenburg HW (2013) Biodiversiteit van kunstmatige substraten. Een inventarisatie van 10 scheepswrakken op het NCP. Bureau Waardenburg. Report 13-226

Lengkeek W, Didderen K, Teunis M, Driessen F, Coolen JWP, Bos OG, Vergouwen SA, Raaijmakers T, De Vries MB, Van Koningsveld M (2017) Eco-friendly design of scour protection: potential enhancement of ecological functioning in offshore wind farms : Towards an implementation guide and experimental set-up (http://edepot.wur.nl/411374). Bureau Waardenburg. Report 17-001

Leonhard SB, Pedersen J (2006) Benthic communities at Horns Rev before, during and after construction of Horns Rev Offshore Wind farm. Final report. Annual Report 2005 (https://tethys.pnnl.gov/publications/benthic-communities-horns-rev-during-and-after-construction-horns-rev-offshore-wind). Bio/consult as.

Magnussen E, Magnussen MD (2009) Ecology of poor-cod (*Trisopterus minutus*) on the Faroe Bank. Mar Biol Res 5:133–142.

Mascaro M, Seed R (2001) Foraging behavior of juvenile *Carcinus maenas* (L .) and *Cancer pagurus* L . Mar Ecol Prog Ser 139:1135–1145.

Masefield R (2017) Edible crab (*Cancer pagurus*). Cefas Stock Status Report 2017. The Shellfish Team 2017.

Mercer JP, Bannister RCA, van der Meeren GI, Debuse V, Mazzoni D, Lovewell S, Browne R, Linnane A, Ball B (2002) An overview of the LEAR (Lobster Ecology and Recruitment) project: results of field and experimental studies on the juvenile ecology of Homarus gammarus in cobble. Marine and Freshwater Research 52:1291-1301

Min IenW, Min LNV (2018) Marine Strategy (part 1). Update of current environmental status, good environmental status, environmental targets and indicators 2018-2024 (https://www.noordzeeloket.nl/publish/pages/158924/marine_strategy_part_1_main_document_2018_-_2024.pdf).

Netherlands Enterprise Agency (2019) Project and Site Description Hollandse Kust (zuid) Wind Farm Zone, Wind Farm Sites III and IV; Appendix A: Applicable Law. Utrecht, the Netherlands.

OSPAR Commission (2008) List of Threatened and/or Declining Species and Habitats (OSPAR Agreement 2008-06). (https://www.ospar.org/documents?d=32794).

OSPAR Commission (2014) Background Document for Atlantic cod (*Gadus morhua)*.
Prodöhl PA, Jørstad KE, Triantafyllidis A, Katsares V, Triantaphyllidis C (2007) European lobster - *Homarus gammarus*. Genimpact final scientific report. Norway.
Reubens JT, Pasotti F, Degraer S, Vincx M (2013) Residency, site fidelity and habitat use of Atlantic cod (*Gadus morhua*) at an offshore wind farm using acoustic telemetry. Marine Environmental Research 90:128-135
Rozemeijer MJC, Van de Wolfshaar KE (2019) Desktop study on autecology and productivity of European lobster (*Homarus gammarus*, L) in offshore wind farms (https://doi.org/10.18174/466861). Wageningen Marine Research. Report C109/18
Ruijgrok E, van Druten E, , Bulder BH (2019) Cost Evaluation of North Sea Offshore Wind Post 2030. A report by Witteveen+Bos and ECN/TNO on behalf of the North Sea Wind Power Hub Consortium.
Ruiz A. (2008) *Trisopterus minutus* Poor cod. In Tyler-Walters H. and Hiscock K. (eds) Marine Life Information Network: Biology and Sensitivity Key Information Reviews, [on-line]. Plymouth: Marine Biological Association of the United Kingdom. [cited 20-02-2020]. Available from: https://www.marlin.ac.uk/species/detail/2171
Sas H, Kamermans P, van der Have T, Lengkeek W, Smaal A. (2016). Shellfish reef restoration pilots, Voordelta, The Netherlands. Annual report 2016, 20-12-2016. http://edepot.wur.nl/405730
Sas H, Kamermans P, van der Have T, Christianen M. et al (2018) Shellfish reef restoration pilots Voordelta The Netherlands, Annual report 2017.
Sas H, K Didderen, T van der Have, P Kamermans, K van den Wijngaard, E Reuchlin (2019) Recommendations for flat oyster restoration in the North Sea Synthesis of lessons learned from the Dutch Voordelta experiments, with additional observations from flat oyster pilots in Borkum Reef and Gemini wind farm, modelling exercises and literature. ARK report
Sheehy, MRJ, Bannister RC A, Wickins JF, Shelton PMJ (1999). New perspectives on the growth and longevity of the European lobster (Homarus gammarus). Canadian Journal of Fisheries and Aquatic Sciences 56(10): 1904-1915.
Smaal AC, Kamermans P, Kleissen F, Van Duren L, Van der Have. T. (2017). Flat oysters on offshore wind farms: opportunities for the development of flat oyster populations on existing and planned wind farms in the Dutch section of the North Sea. WMR Report C052/17. Yerseke, the Netherlands: Wageningen Marine Research. https://edepot.wur.nl/418092
Smaal AC, Kamermans P, Van der Have TM, Engelsma MY, Sas H (2015) Feasibility of Flat Oyster (*Ostrea edulis* L.) restoration in the Dutch part of the North Sea (http://edepot.wur.nl/335033). IMARES. Report C028/15
Schmalenbach I, Mehrtens F. Janke M, Buchholz F (2011). Landings of European lobster (*Homarus gammarus*) and edible crab (*Cancer pagurus*) from 1615 to 2009, Helgoland, North Sea. Supplement to: Schmalenbach, I et al. (2011): A mark-recapture study of hatchery-reared juvenile European lobsters, *Homarus gammarus*, released at the rocky island of Helgoland (German Bight, North Sea) from 2000 to 2009. Fisheries Research, 108(1), 22-30, https://doi.org/10.1016/j.fishres.2010.11.016, PANGAEA.
Stenberg C, Dahl K, Lundsteen S, Andersen ON (2015) Ecological benefits from restoring a marine cavernous boulder reef in Kattegat. DTU Aqua report no. 289-2015, Denmark.
Tangelder, M, Goudswaard PC,Es Yv (2015). Bepaling zware metalen in kreeften op nieuwe vooroevers in de Oosterschelde. IJmuiden, IMARES Wageningen UR.
Tamis JE, Van der Wal JT,Bos OG (2017). Quickscan potentiële natuurwaarden in bestaande Nederlandse offshorewindparken. WMR-rapport C025/17. Den Helder: Wageningen Marine Research. http://library.wur.nl/WebQuery/wurpubs/fulltext/411385.
Van Duren LA, Gittenberger A, Smaal AC, Van Koningsveld M, Osinga R, Cado van der Lelij JA, De Vries MB (2017). Rich Reefs in the North Sea Exploring the possibilities of promoting the establishment of natural reefs and colonisation of artificial hard substrate. Delft, the Netherlands: Deltares http://publications.deltares.nl/1221293_000_Eng.pdf
Van der Have TM, Van der Zee E (2016). Terugkeer van de platte oester in de Waddenzee. Verkenning naar een mogelijk herstel van platte oesterbanken in de Waddenzee. Bureau Waardenburg en Altenburg & Wymenga Rapportnr. 16-091, Culemborg i.o.v. Programma naar een Rijke Waddenzee. https://rijkewaddenzee.nl/wp-content/uploads/2016/10/Terugkeer_Platte_Oester_Wadddenzee_DEFINITIEF-1.pdf

van der Kooij J, Engelhard GH, Righton DA (2016) Climate change and squid range expansion in the North Sea. Journal of Biogeography 43:2285-2298 (https://doi.org/10.1111/jbi.12847)

Vanagt T, Faasse M (2014) Development of hard substratum fauna in the Princess Amalia Wind Farm: Monitoring six years after construction (http://www.ecoast.be/content/documents/2013009_PAWP_hardsub_rapport_final_april_2014.pdf). eCOAST. eCOAST report 2013009

Winter HV, Aarts GM, Keeken OA van (2010) Residence time and behaviour of sole and cod in the Offshore Wind farm Egmond aan Zee (OWEZ). IMARES Wageningen UR. (https://library.wur.nl/WebQuery/wurpubs/422187)

Wright SR, Lynam CP, Righton DA, Metcalfe J, Hunter E, Riley A, Garcia L, Posen P, Hyder K (2018) Structure in a sea of sand: fish abundance in relation to man-made structures in the North Sea. ICES Journal of Marine Science

8 LIST OF ABBREVIATIONS

CapEx	Capital expenditure
CL	Carapace length
Cotel	Cod hotel
CW	Carapace width
EEZ	Exclusive Economic Zone
HKnw	Hollandse Kust (noordwest)
HKw	Hollandse Kust (west)
HKz	Hollandse Kust (zuidwest)
ICES	International Council for the Exploration of the Sea
IJver	IJmuiden Ver
LCC	Life Cycle Cost
Ministry of EZK	Ministry of Economic Affairs and Climate Policy
Ministry of LNV	Ministry of Agriculture, Nature and Food quality
MSFD	Marine Strategy Framework Directive
LCC	Lifetime Cycle Cost
NID	Nature-Inclusive Design
OSPAR	Oslo/Paris convention for the Protection of the Marine Environment of the North-East Atlantic
OpEx	Operational Expenditure
OWEZ	Offshore Wind farm Egmond aan Zee
OWF	Offshore Wind Farm
PAWP	Princess Amalia Wind Farm
RVO	Netherlands Enterprise Agency
RWS	Rijkswaterstaat
TNW	Ten noorden van de Waddeneilanden
WMR	Wageningen Marine Research

Appendices

APPENDIX: SUMMARY MEMO FROM THE EXPERT SESSIONS ON NATURE-INCLUSIVE BUILDING

MEMORANDUM

Subject	A summary of expert interviews
Project	A catalogue of NID measures for offshore wind development
Client	Ministry of Agriculture, Nature and Food Quality (LNV)
Project code	114266
Status	Final version
Date	23 October 2019
Reference	114266/19-017.159
Author(s)	Mrs I. Prusina PhD
Checked by	O. Bos PhD
Approved by	Mrs A. Hermans MSc
Initials	
Appendices	List of interview questions
To	Interviewees pool
Copy	LNV E. Knegtering

1 INTRODUCTION

To support the permitting requirements for future plot decisions, the ministry of Agriculture, Nature and Food Quality had commissioned Wageningen Marine Research (WMR) and Witteveen+Bos (W+B) to compile a catalogue with proven concepts or ecologically promising nature inclusive design (NID) measures. The aim of the NID catalogue is twofold: 1) to fulfil the national goals of the European Habitats Directive and the Birds Directive, as well as the Marine Strategy Framework Directive and OSPAR guidelines; 2) to support the industry in implementing NID in the development of offshore wind.

In order to ensure the most cost-efficient and feasible options with the highest ecological benefits both industry representatives and ecological experts were consulted. In developing the catalogue three steps were taken: (1) making an inventory of possible NID measures, (2) consulting with the experts through the interviews and (3) summarizing input and conducting an interdisciplinary quality control.

2 THE EXPERT CONSULTATIONS

In order to ensure the ecological and technical feasibility of the proposed measures, the end users of the catalogue were actively involved in the development by means of expert consultations. During August and September 2019, nineteen individually held consultations (interviews) were conducted with a group of selected end users (see table 2.1). The interviewees included various industry players, from wind developers and contractors to specific suppliers. Representatives of knowledge institutes were consulted to determine the link between ecological and technical considerations. Moreover, specific technical, financial and ecological aspects were also discussed with a number of experts in Witteveen+Bos and Wageningen Marine Research.

Table 2.1 List of end users contributing to the expert interviews

Type of end user	Name of the company
Wind developer	Ørsted
	Eneco
	Vattenfall
	Gemini
Contractor	Van Oord
	Boskalis
Knowledge institute	Deltares
	TU Delft
	Wageningen University and Research
Consultancy	Bureau Waardenburg
Product supplier	Kyowa Filter Unit
	Yaeger Mare Solutions GmbH
	Ecocean
	ECOncrete
	ARCMarine

To ensure all interviews are conducted objectively and in the same manner, a standardized list of questions was used (see Appendix I). A list of NID measures discussed during the consultations included:

1 Optimized scour protection layer; additional rocks as a 3rd layer, or adapted rock grading in the standard armour layer.
2 Habitat pipes; steel or concrete pipes on the scour protection layer.
3 Oyster gabions; steel cage filled with rocks and shells on the scour protection layer.
4 Reef balls and layered cake; added on the scour protection layer.
5 3D printed reef units; added on the scour protection layer.
6 Bags filled with rocks (filter units); used for cable protection and cable crossings or alternative for scour protection.
7 Fish hotel; steel cage with tubes, welded on the monopile/jacket.
8 Biohut; steel cage with rocks, welded on the monopile/jacket.

3 SUMMARY OF EXPERT INTERVIEWS

In the sections below a summary of the main conclusions and topics of interest are listed for (1) general experience with NID, (2) the role of the government in stimulating NID, (3) technological and ecological aspects of specific NID solutions and (4) other points of attention.

3.1 Experience with nature inclusive building

All interviewees in the context of their respective companies have experience with nature inclusive building. This relates to either their corporate social responsibility or fulfilling permitting requirements. A number of pilot projects are being executed or are recently initiated to address the knowledge gaps on nature restoration possibilities. The focus of the current pilots is on restoring European flat oyster reefs using the scour protection, loose shell material or adding oyster gabions. The stability of a number of NID measures is being tested under the various hydrodynamic conditions as part of the joint industry effort (JIP HaSPro).

Concern was expressed that non proven concepts bring uncertainties and risks to the standardized offshore practice, translating into an increase of the overall project cost. This resulted in a wish to separate NID from the assets, and merely using the space in between the assets. Clear defined target species and (proven) relation with produced ecological benefits is required for the industry to conduct a cost-benefit analysis and reduce risk and cost associated with NID. The impact of each NID solution on the standardized design of the asset is also pointed out as a crucial element.

3.2 Government's role in nature inclusive building

The general attitude from industry representatives towards NID requirements is welcoming. The majority of the experts agreed that if NID measure is to be implemented, it requires a permitting obligation. A good form of strategic incentives are contractual forms as BPKV/EMVI. These forms allow for creativity and innovation. There were some questions on the way NID has been stimulated to date by the relevant governmental bodies. Concerns mentioned are specifically related to the current HK(n) plot decision, where the requirements are believed to be:

- Focusing only on the design of scour protection layer.
- Not elaborating on the ecological benefits and the required scale.
- Not providing evidence of proven concepts at the required scale; and
- Not stimulating freedom of choice (lacking flexibility and preventing creativity).

Several other points of attention were raised in regards to policy and NID requirements, these will be addressed in the last section of this memo.

3.3 Technological and ecological considerations

The table below summarizes the main comments on selected NID measures received from the interviewees.

Table 3.1 Summary of the main points discussed for selected NID measures

NID measure	Comments
Optimized scour protection layer	**Advantage** - Use of natural material (rocks). - Relative to the scale of a wind farm, required scale to make an impact. - Integration of measure in existing work method. **Technical consideration** - Placement of larger boulders can prevent pile driving. - Integration of larger rocks in the armour layer could increase stability. - Rocks to be used to stabilize free span cables/free span cables should not be covered with rocks. - Required rock size (grading) and rock density should be indicated. - Currently only rocks are part of the standardized scour protection layer (1 or 2 layer), every new element (e.g. filter units, reef cubes etc.) has to be tested and specifically designed for local conditions. **Ecological consideration** - Adapted scour protection layer should be species-specific. - Use eco-friendly material as much as possible. - Consider seeding to increase the ecological success (e.g. oysters, lobsters) as is done in Gemini. - More randomized patterns in the armour layer in a form of underwater landscaping could have significant ecological benefit. - Shells placed on top of the armour layer can create stable layer and create a calcareous element (but, the cavity size is limited). **Risks** - The stability of the individually added rocks on the armour cannot be evaluated. - Larger rocks will have bigger loads and potentially impact the stability of the layer itself. - Post monopile installation can damage the coating of the monopile. - Post monopile installation can damage the free span cables. - Larger rocks can prevent pilling.

	- Specific crevice size does not guarantee targeted ecological benefit (source of ecological material). **Costs** - Increase in cost due to additional vessel mobilization and additional rock material. - Cost and the depth (there is a limitation) due to navigation (maintenance). - Cost estimation should include both material but also mobilization costs.
Optimised cable protection	**Advantage** - Consider adapting already standardized cable protection measures (e.g. matrasses). - Rock bags follow the seabed and adjust to the ripples on the seafloor making them more stable. - Relative to the scale of a wind farm. **Technical consideration** - Cable heating effect. - Cable maintenance requires space. - Complex units require additional installation method. **Ecological consideration** - Same as previous. **Risks** - The stability of the individually added units on the cables has to be ensured. - The installation of units (cubes, cages) can damage the cable. - Cable maintenance requires pulling out the top layer on the cables. **Costs** - The additional installation methods increase the cost. - Increase in cost due to additional vessel mobilization and additional material. - Include both material but also mobilization costs.
Standalone artificial reefs	**Advantage** - Use of optimized material type (eco-friendly but robust). - Relative to the scale of a wind farm. - Not impacting structural integrity of an asset if placed from the asset. - Less to impact the critical path of a project (mobilisation) if placed after the installation of the asset. **Technical consideration** - Stability of the units has to be ensured (not washed away). - Stability can be adapted to the conditions by adapting shapes, position, material density placement of the units BUT it requires knowledge on the local conditions. - Consider using autochthonous material as much as possible. - If units are to be placed on the scour protection layer they should not impact the functionality of the scour protection. - The interlocking is important for stability, e.g. pipes do not have a lot of interlocking but other shapes (with barbs) could be used to increase the contact area. - 3D structures recommended instead of the 2D - The closer the units are placed to the monopile or a jacket, the higher the loads on the structure - consider sufficiently spacing units from the cables. **Ecological consideration** - Opportunity to create more complex habitat. - Optimized material type to increase ecological success. - Consider adjusting reef ball shapes with multiple holes to a solid shape with dead end holes (better predator protection). - Use oyster shells that are Bonamia-free. **Risks** - Not using allochthonous material (steel and concrete). - Small and local impact and not up to a conservation scale. **Costs** - Include both material but also mobilization costs.

Add-on units	**Advantage** - Integral part of a structure. - No additional installation method. **Technical consideration** - The stability calculated to withstand expected load (including marine growth). - Pile driving force. - Transport of monopiles is extra challenging. **Ecological consideration** - Species-specific design. - Mesh size fitting the species requirements. **Risks** - Pile driving force. - Potential impact on the structural integrity (monopile). - Hydrodynamic load of the unit on the structure. - Increased current velocity (how much current velocity can e.g. cod tolerate?). - Positive effect is limited to the scale of a structure, it does not scale up. **Costs** - Include both material but also mobilization costs. - Increased cost due to changes in transportation (e.g. stacking of monopiles).

3.4 Updating the catalogue

During the consultations, it became evident that NID measures should be categorised based on the interface with the primary process e.g. standalone or placed on a part of the structure (jacket, monopile, scour protection, cable). This resulted in changing the initial list of eight (8) NID measures to 4 categories or types of NID measures. In table 4.1 four categories are presented followed by selected NID measures per category.

Table 4.1 List of categories with listed NID measures

NID category	Specific NID measure
1 Optimized scour protection layer	Additional rock layer Adapted grading armour layer Seeding the scour protection layer
2 Optimized cable protection layer	Filter Unit® Basalt bags ECO Mats® Reef cube® filter bag™ Reef cube® mattresses™ Prefab collar SCP
3 Standalone units (artificial reefs)	Habitat pipes Fish hotel (WUR) Reefball® and Layer cakes Reefcube® 3D printed units Rock patches ECO armour block® Biorock™ Oyster gabions Biohut® Cotel Eotel Sqotel
4 Add on units (integral part of the asset)	Biohut® Cotel Eotel Sqotel

3.5 Points of attention

During the expert sessions several topics were addressed related to the policy and requirements as part of the government’s efforts to regulate the use of the future offshore windfarms.

Co-use

Policy-wise there is a discrepancy between the efforts for nature restoration and implementing co-use in offshore wind farms (e.g. small scale fisheries, protein production, seaweed farming). It is recommended to have an integral policy where two efforts are interlinked. This specifically relates to the area within a wind farm but outside the safety zone of a wind turbine (50 m).

Decommissioning

If a NID measure is made with natural (possibly biodegradable), non-leaking materials and they are proven effective its removal as part of the decommissioning process should be open for discussion. What is the expected life time of a NID solution?

Maintenance and nature conservation

Regulation is required for managing NID measures when maintenance or repair activities of an asset is required.

Strategic monitoring

A strategic monitoring program driven by the government could be considered to obtain the required scale for robust monitoring results. Moreover, strategic funding for monitoring would allow for combined monitoring efforts and therefore reduce costs, increase quality by standardisation, experience and sample size and allow for comparability of the results.

APPENDIX: INTERVIEW QUESTIONS

Subject	Ecology experts Species experts of research institutes and universities	Industry experts Concession and grid owners
1.General	Can you briefly indicate who you are and what your background is?	Can you briefly indicate who you are and what your background is?
2. General	a. What is your (company) experience with nature inclusive building? b. What do you think of the form/manner in which this is stimulated from the relevant governmental bodies?	a. What is your (company) experience with nature inclusive building? b. What do you think of the form/manner in which this is stimulated from the relevant governmental bodies?
3. General	a. Providing the general description, do you agree with the described ecological benefits? b. What additions do you see for this design?	
4. Location	Do you see any hindrance in applying this design at the chosen wind location, considering the factors already described in this fact sheet?	Do you see any hindrance in applying this design at the chosen wind location, considering the factors already described in this fact sheet?
5. Applicability	a. Do you agree with the environmental factors that are identified as crucial for the ecological functionality of the design? b. Do you see any addition, and if yes, what?	a. Do you see a different applicability of the design in regard to the project phases (planning, execution, operation)?
		b. For which asset do you see a direct applicability of this design? c. For which asset do you consider this design to be a no-go?
6. Technical consideration	a. Do you agree with the technical considerations described for this design? b. What additional technical consideration should be taken into account during construction and/or operation?	a. Do you agree with the technical considerations described for this design? b. What additional technical consideration should be taken into account during construction and/or operation?
	c. Do you agree with the ecological functional requirements described for this design? d. What additional requirements should be taken into account?	
7. Risk	a. Do you agree with the ecological risk described for this design? b. What additional ecological risk should be taken into account for this design?	a. Do you agree with the risk described for this design? What additional risks (e.g. technical, planning, financial, interphase, operational, functional) should be taken into account during construction and/or operation?
		b. What interface risk of the described design do you see with the standard/current design used for your asset?
8. Monitoring	a. Do you agree with the monitoring requirements? b. What is the minimum monitoring requirement setup?	How does the listed monitoring requirements fit your standard monitoring practice?
9. Example projects	Are you aware of any projects where this design has been used?	Are you aware of any projects where this design has been used?

Subject	Ecology experts Species experts of research institutes and universities	Industry experts Concession and grid owners
10. General	Given the reviewed aspects above, which aspect would you consider most critical for a successful implementation? a. In terms of location, applicability, technical, risk and monitoring? b. Which of the solutions do you consider most viable for short term implementation (to 2023/2030)? c. And in the longer term (post 2030)?	Given the reviewed aspects above, which aspect would you consider most critical for a successful implementation? a. In terms of location, applicability, technical, risk and monitoring? b. Which of the solutions do you consider most viable for short term implementation (to 2023/2030)? c. And in the longer term (post 2030)?
11. Catalogue	a. How would the catalogue be most useful to you? b. Do you miss any solution (e.g. for other species than mentioned here)?	a. How would the catalogue be most useful to you? b. Do you miss any solution (other than mentioned here)?
12. Other	Do you have any other remarks?	Do you have any other remarks?

II

APPENDIX: DETAILED LIFE CYCLE COST CALCULATIONS FOR NID OPTIONS

PROJECT: NID CATALOGUE FOR OWF

ESTIMATE CLASS: CLASS 5 CONCEPT SCREENING

Scope description and basis of estimate

Methodology and assumptions:

- Deterministic estimate of investment costs (§ 7.1 lid 2.4 en 2.5)
- Factsheets "20190613 Dummy factsheets NID LNV v0.2.xlsx" date 26-07-2019
- Unit rates based on substantial amount, > 60 sets (reduced effect of fixed costs like engineering and fabrication process)
- Quantities (dimensions and number of elements) are assumed and of utmost importance for the total costs. Please very.

60 monopiles with either:

  - stand-alone solutions: 2 elements per pile
  - area solutions: 20% of scour protection area, based on ø30 m

#	Name	Investment costs (excl. VAT)		
BK1.1	Biohut®	€	3.672	1 set, of 1 pcs
BK1.2	Cotel	€	3.180	1 set, of 1 pcs
BK2.2	Additional rock layer	€	19.080	1 set, of 1 pcs
BK2.4	Habitat pipes	€	4.253	1 set, of 2 pcs
BK2.5	Fish hotel	€	3.180	1 set, of 1 pcs
BK2.6	Reef ball® and Layer cakes	€	6.559	1 set, of 2 pcs
BK2.7	Reef cube® 1 m³/pcs	€	6.296	1 set, of 2 pcs
BK2.8	Reef cube® bag	€	11.130	1 set, of 2 pcs
BK2.9	3D printed units	€	8.546	1 set, of 2 pcs
BK2.10	ECO armour block®	€	8.347	1 set, of 2 pcs
BK2.11	Oyster gabions	€	9.341	1 set, of 2 pcs
BK2.12	Biohut®	€	3.672	1 set, of 1 pcs
BK2.13	Rock bags (filter unit or basalt bag)	€	5.048	1 set, of 2 pcs
BK2.14	ECO Mats®	€	10.931	1 set, of 2 pcs
BK2.15	Reef cube ® mat	€	16.894	1 set, of 2 pcs
BK2.16	Filter unit	€	3.061	1 set, of 2 pcs
BK92	Interlocking unit 1 m³/pcs	€	5.962	1 set, of 2 pcs
BK93	Oyster and rock gabions	€	7.354	1 set, of 2 pcs

Exclusions:

Construction costs

- Explosives / archeology

Life Cycle Costs (§ 7.1 lid 2.1)

- Operate and maintain (e.g. monitoring, surveys, inspections etc.)
- Replacements
- Interest
- Demolishing (end of life cycle)

Colofon

Project leader:	mw I. Prusina Phd
Project director:	drs. M. Klinge
Estimate standard:	CROW Publicatie 137 (2010) [genoemde § nummers refereren hiernaar]
Estimate model number:	W+B SSK-2010 Rekenmodel 3.05a (22-06-2017)

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Biohut®	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
11							
	INVESTMENT COSTS	1,00					
10	**Onshore activities**						
101120	Supply and install steel mesh in frame 1x1x2 m, with tubes	1,00	pcs	€	1.000,00	€	1.000,00
101130	Supply and install rock	3,30	ton	€	50,00	€	165,00
101140	Pile driving risk mitigation measure: offshore connection system	1,00	pcs	€	500,00	€	500,00
	Total Onshore activities			**€**	**1.665,00**		
30	**Offshore activities decommissioning (after 20 years)**						
301110	Removal of steel mesh in frame 1x1x2 m	1,00	pcs	€	100,00	€	100,00
301120	Removal and transport of rock	3,30	ton	€	25,00	€	82,50
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**182,50**		
	Direct costs					**€**	**1.848**
NTD111	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	1.848	€	185
	Direct costs incl. allowance					**€**	**2.032**
IK116	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	2.032	€	41
IK117	Site facilities	1,0%		€	2.032	€	20
IK119	Site organisation (eg. foreman, site managers)	10,0%		€	2.032	€	203
IK1110	General costs	8,0%		€	2.296	€	184
IK1111	Profit	3,0%		€	2.480	€	74
IK1112	Risk	2,0%		€	2.480	€	50
	Indirect costs ('contractors overhead')	28%				**€**	**572**
VZBK	**Costs foreseen**					**€**	**2.604**
RBK	**Contingency**	15%				**€**	**391**
BK1.1	**Construction costs Biohut®**					**€**	**2.995**
VK11	**Real estate Biohut®**					**€**	**-**
EK111	Detailed engineering contractor	2,0%		€	2.604	€	52
EK112	Engineering consultancies (design)	6,0%		€	2.604	€	156
EK113	Client's organisation (tendering, permitting)	10,0%		€	2.604	€	260
EK114	Site supervision, site management	4,0%		€	2.604	€	104
EK11	**Engineering Biohut®**	22%				**€**	**573**
OK111	Remaining costs (e.g. permits, insurances)	4,0%		€	2.604	€	104
OBK11	**Remaining costs Biohut®**	4%				**€**	**104**
INV11	**Total investment costs Biohut®**					**€**	**3.672**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Cotel	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
12							
	INVESTMENT COSTS	1,00					
10	**Onshore activities**						
101220	Supply and install steel mesh in frame 1x1x2 m, with tubes	1,00	pcs	€	1.000,00	€	1.000,00
101240	Pile driving risk mitigation measure: offshore connection system	1,00	pcs	€	500,00	€	500,00
	Total Onshore activities			**€**	**1.500,00**		
30	**Offshore activities decommissioning (after 20 years)**						
301210	Removal of steel mesh in frame 1x1x2 m	1,00	pcs	€	100,00	€	100,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**100,00**		
	Direct costs					**€**	**1.600**
NTD121	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	1.600	€	160
	Direct costs incl. allowance					**€**	**1.760**
IK126	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	1.760	€	35
IK127	Site facilities	1,0%		€	1.760	€	18
IK129	Site organisation (eg. foreman, site managers)	10,0%		€	1.760	€	176
IK1210	General costs	8,0%		€	1.989	€	159
IK1211	Profit	3,0%		€	2.148	€	64
IK1212	Risk	2,0%		€	2.148	€	43
	Indirect costs ('contractors overhead')	28%				**€**	**495**
VZBK	**Costs foreseen**					**€**	**2.255**
RBK	**Contingency**	15%				**€**	**338**
BK1.2	**Construction costs Cotel**					**€**	**2.594**
VK12	**Real estate Cotel**					**€**	**-**
EK121	Detailed engineering contractor	2,0%		€	2.255	€	45
EK122	Engineering consultancies (design)	6,0%		€	2.255	€	135
EK123	Client's organisation (tendering, permitting)	10,0%		€	2.255	€	226
EK124	Site supervision, site management	4,0%		€	2.255	€	90
EK12	**Engineering Cotel**	22%				**€**	**496**
OK121	Remaining costs (e.g. permits, insurances)	4,0%		€	2.255	€	90
OBK12	**Remaining costs Cotel**	4%				**€**	**90**
INV12	**Total investment costs Cotel**					**€**	**3.180**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Additional rock layer	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
22							
	INVESTMENT COSTS	1,00					
20	**Offshore activities**						
202240	Supply and inst. rock 15-300 kg on top of scour prot. (20% ø30x0,5 m)	1,00	pcs	€	3.200,00	€	3.200,00
	Total Offshore activities			**€**	**3.200,00**		
30	**Offshore activities decommissioning (after 20 years)**						
302270	Removal and transport rock 15-300 kg on top of scour prot. (20% ø30x0,5 m)	1,00	pcs	€	6.400,00	€	6.400,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**6.400,00**		
	Direct costs					**€**	**9.600**
NTD221	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	9.600	€	960
	Direct costs incl. allowance					**€**	**10.560**
IK226	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	10.560	€	211
IK227	Site facilities	1,0%		€	10.560	€	106
IK229	Site organisation (eg. foreman, site managers)	10,0%		€	10.560	€	1.056
IK2210	General costs	8,0%		€	11.933	€	955
IK2211	Profit	3,0%		€	12.887	€	387
IK2212	Risk	2,0%		€	12.887	€	258
	Indirect costs ('contractors overhead')	28%				**€**	**2.972**
VZBK	**Costs foreseen**					**€**	**13.532**
RBK	**Contingency**	15%				**€**	**2.030**
BK2.2	**Construction costs Additional rock layer**					**€**	**15.562**
VK22	**Real estate Additional rock layer**					**€**	**-**
EK221	Detailed engineering contractor	2,0%		€	13.532	€	271
EK222	Engineering consultancies (design)	6,0%		€	13.532	€	812
EK223	Client's organisation (tendering, permitting)	10,0%		€	13.532	€	1.353
EK224	Site supervision, site management	4,0%		€	13.532	€	541
EK22	**Engineering Additional rock layer**	22%				**€**	**2.977**
OK221	Remaining costs (e.g. permits, insurances)	4,0%		€	13.532	€	541
OBK22	**Remaining costs Additional rock layer**	4%				**€**	**541**
INV22	**Total investment costs Additional rock layer**					**€**	**19.080**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Habitat pipes	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
24							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
102470	Supply and prefab concrete habitat pipes ø1000 mm, T-shaped 1x1 m	2,00	pcs	€	500,00	€	1.000,00
	Total Onshore activities			**€**	**1.000,00**		
20	**Offshore activities**						
202430	Transport and placement of habitat pipes	2,00	pcs	€	150,00	€	300,00
	Total Offshore activities			**€**	**300,00**		
30	**Offshore activities decommissioning (after 20 years)**						
302460	Removal and transport of habitat pipes	2,00	pcs	€	420,00	€	840,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**840,00**		
	Direct costs					**€**	**2.140**
NTD241	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	2.140	€	214
	Direct costs incl. allowance					**€**	**2.354**
IK246	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	2.354	€	47
IK247	Site facilities	1,0%		€	2.354	€	24
IK249	Site organisation (eg. foreman, site managers)	10,0%		€	2.354	€	235
IK2410	General costs	8,0%		€	2.660	€	213
IK2411	Profit	3,0%		€	2.873	€	86
IK2412	Risk	2,0%		€	2.873	€	57
	Indirect costs ('contractors overhead')	28%				**€**	**662**
VZBK	**Costs foreseen**					**€**	**3.016**
RBK	**Contingency**	15%				**€**	**452**
BK2.4	**Construction costs Habitat pipes**					**€**	**3.469**
VK24	**Real estate Habitat pipes**					**€**	**-**
EK241	Detailed engineering contractor	2,0%		€	3.016	€	60
EK242	Engineering consultancies (design)	6,0%		€	3.016	€	181
EK243	Client's organisation (tendering, permitting)	10,0%		€	3.016	€	302
EK244	Site supervision, site management	4,0%		€	3.016	€	121
EK24	**Engineering Habitat pipes**	22%				**€**	**664**
OK241	Remaining costs (e.g. permits, insurances)	4,0%		€	3.016	€	121
OBK24	**Remaining costs Habitat pipes**	4%				**€**	**121**
INV24	**Total investment costs Habitat pipes**					**€**	**4.253**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Fish hotel	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
25							
	INVESTMENT COSTS	1,00					
10	**Onshore activities**						
102520	Supply and install steel mesh in frame 1x1x2 m, with tubes	1,00	pcs	€	1.000,00	€	1.000,00
102540	Pile driving risk mitigation measure: offshore connection system	1,00	pcs	€	500,00	€	500,00
	Total Onshore activities			**€**	**1.500,00**		
30	**Offshore activities decommissioning (after 20 years)**						
302510	Removal of steel mesh in frame 1x1x2 m	1,00	pcs	€	100,00	€	100,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**100,00**		
	Direct costs					**€**	**1.600**
NTD251	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	1.600	€	160
	Direct costs incl. allowance					**€**	**1.760**
IK256	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	1.760	€	35
IK257	Site facilities	1,0%		€	1.760	€	18
IK259	Site organisation (eg. foreman, site managers)	10,0%		€	1.760	€	176
IK2510	General costs	8,0%		€	1.989	€	159
IK2511	Profit	3,0%		€	2.148	€	64
IK2512	Risk	2,0%		€	2.148	€	43
	Indirect costs ('contractors overhead')	28%				**€**	**495**
VZBK	**Costs foreseen**					**€**	**2.255**
RBK	**Contingency**	15%				**€**	**338**
BK2.5	**Construction costs Fish hotel**					**€**	**2.594**
VK25	**Real estate Fish hotel**					**€**	**-**
EK251	Detailed engineering contractor	2,0%		€	2.255	€	45
EK252	Engineering consultancies (design)	6,0%		€	2.255	€	135
EK253	Client's organisation (tendering, permitting)	10,0%		€	2.255	€	226
EK254	Site supervision, site management	4,0%		€	2.255	€	90
EK25	**Engineering Fish hotel**	22%				**€**	**496**
OK251	Remaining costs (e.g. permits, insurances)	4,0%		€	2.255	€	90
OBK25	**Remaining costs Fish hotel**	4%				**€**	**90**
INV25	**Total investment costs Fish hotel**					**€**	**3.180**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Reef ball® and Layer cakes	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
26							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
102660	Supply and prefab concrete reef balls ø1890x1300 mm, weight 2268 kg	2,00	pcs	€	500,00	€	1.000,00
	Total Onshore activities			**€**	**1.000,00**		
20	**Offshore activities**						
202790	Transport and placement of elements	2,00	pcs	€	500,00	€	1.000,00
	Total Offshore activities			**€**	**1.000,00**		
30	**Offshore activities decommissioning (after 20 years)**						
302730	Removal and transport of elements	2,00	pcs	€	650,00	€	1.300,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**1.300,00**		
	Direct costs					**€**	**3.300**
NTD261	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	3.300	€	330
	Direct costs incl. allowance					**€**	**3.630**
IK266	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	3.630	€	73
IK267	Site facilities	1,0%		€	3.630	€	36
IK269	Site organisation (eg. foreman, site managers)	10,0%		€	3.630	€	363
IK2610	General costs	8,0%		€	4.102	€	328
IK2611	Profit	3,0%		€	4.430	€	133
IK2612	Risk	2,0%		€	4.430	€	89
	Indirect costs ('contractors overhead')	28%				**€**	**1.022**
VZBK	**Costs foreseen**					**€**	**4.652**
RBK	**Contingency**	15%				**€**	**698**
BK2.6	**Construction costs Reef ball® and Layer cakes**					**€**	**5.349**
VK26	**Real estate Reef ball® and Layer cakes**					**€**	**-**
EK261	Detailed engineering contractor	2,0%		€	4.652	€	93
EK262	Engineering consultancies (design)	6,0%		€	4.652	€	279
EK263	Client's organisation (tendering, permitting)	10,0%		€	4.652	€	465
EK264	Site supervision, site management	4,0%		€	4.652	€	186
EK26	**Engineering Reef ball® and Layer cakes**	22%				**€**	**1.023**
OK261	Remaining costs (e.g. permits, insurances)	4,0%		€	4.652	€	186
OBK26	**Remaining costs Reef ball® and Layer cakes**	4%				**€**	**186**
INV26	**Total investment costs Reef ball® and Layer cakes**					**€**	**6.559**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Reef cube® 1 m³/pcs	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
27							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
102870	Supply reef cubes 1 m³/pcs	2,00	pcs	€	384,00	€	768,00
102860	Onshore transport (from factory to port)	2,00	pcs	€	50,00	€	100,00
	Total Onshore activities			**€**	**868,00**		
20	**Offshore activities**						
202890	Transport and placement of elements	2,00	pcs	€	500,00	€	1.000,00
	Total Offshore activities			**€**	**1.000,00**		
30	**Offshore activities decommissioning (after 20 years)**						
302830	Removal and transport of elements	2,00	pcs	€	650,00	€	1.300,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**1.300,00**		
	Direct costs					**€**	**3.168**
NTD271	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	3.168	€	317
	Direct costs incl. allowance					**€**	**3.485**
IK276	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	3.485	€	70
IK277	Site facilities	1,0%		€	3.485	€	35
IK279	Site organisation (eg. foreman, site managers)	10,0%		€	3.485	€	348
IK2710	General costs	8,0%		€	3.938	€	315
IK2711	Profit	3,0%		€	4.253	€	128
IK2712	Risk	2,0%		€	4.253	€	85
	Indirect costs ('contractors overhead')	28%				**€**	**981**
VZBK	**Costs foreseen**					**€**	**4.465**
RBK	**Contingency**	15%				**€**	**670**
BK2.7	**Construction costs Reef cube® 1 m³/pcs**					**€**	**5.135**
VK27	**Real estate Reef cube® 1 m³/pcs**					**€**	**-**
EK271	Detailed engineering contractor	2,0%		€	4.465	€	89
EK272	Engineering consultancies (design)	6,0%		€	4.465	€	268
EK273	Client's organisation (tendering, permitting)	10,0%		€	4.465	€	447
EK274	Site supervision, site management	4,0%		€	4.465	€	179
EK27	**Engineering Reef cube® 1 m³/pcs**	22%				**€**	**982**
OK271	Remaining costs (e.g. permits, insurances)	4,0%		€	4.465	€	179
OBK27	**Remaining costs Reef cube® 1 m³/pcs**	4%				**€**	**179**
INV27	**Total investment costs Reef cube® 1 m³/pcs**					**€**	**6.296**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Reef cube® bag	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
28							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
102940	Supply reef cubes 0,5 m/pcs	20,00	pcs	€	60,00	€	1.200,00
102950	Supply steel bag and place reef cubes	2,00	pcs	€	1.000,00	€	2.000,00
102960	Onshore transport (from factory to port)	2,00	pcs	€	50,00	€	100,00
	Total Onshore activities			**€**	**3.300,00**		
20	**Offshore activities**						
202990	Transport and placement of elements	2,00	pcs	€	500,00	€	1.000,00
	Total Offshore activities			**€**	**1.000,00**		
30	**Offshore activities decommissioning (after 20 years)**						
302930	Removal and transport of elements	2,00	pcs	€	650,00	€	1.300,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**1.300,00**		
	Direct costs					**€**	**5.600**
NTD281	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	5.600	€	560
	Direct costs incl. allowance					**€**	**6.160**
IK286	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	6.160	€	123
IK287	Site facilities	1,0%		€	6.160	€	62
IK289	Site organisation (eg. foreman, site managers)	10,0%		€	6.160	€	616
IK2810	General costs	8,0%		€	6.961	€	557
IK2811	Profit	3,0%		€	7.518	€	226
IK2812	Risk	2,0%		€	7.518	€	150
	Indirect costs ('contractors overhead')	28%				**€**	**1.734**
VZBK	**Costs foreseen**					**€**	**7.894**
RBK	**Contingency**	15%				**€**	**1.184**
BK2.8	**Construction costs Reef cube® bag**					**€**	**9.078**
VK28	**Real estate Reef cube® bag**					**€**	**-**
EK281	Detailed engineering contractor	2,0%		€	7.894	€	158
EK282	Engineering consultancies (design)	6,0%		€	7.894	€	474
EK283	Client's organisation (tendering, permitting)	10,0%		€	7.894	€	789
EK284	Site supervision, site management	4,0%		€	7.894	€	316
EK28	**Engineering Reef cube® bag**	22%				**€**	**1.737**
OK281	Remaining costs (e.g. permits, insurances)	4,0%		€	7.894	€	316
OBK28	**Remaining costs Reef cube® bag**	4%				**€**	**316**
INV28	**Total investment costs Reef cube® bag**					**€**	**11.130**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	3D printed units	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
29							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
103000	Supply and prefab 3DCP unit ø1500x1300 mm, weight 1000 kg	2,00	pcs	€	1.000,00	€	2.000,00
	Total Onshore activities			**€**	**2.000,00**		
20	**Offshore activities**						
202980	Transport and placement of 3DCP units	2,00	pcs	€	500,00	€	1.000,00
	Total Offshore activities			**€**	**1.000,00**		
30	**Offshore activities decommissioning (after 20 years)**						
303010	Removal and transport of 3DCP units	2,00	pcs	€	650,00	€	1.300,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**1.300,00**		
	Direct costs					**€**	**4.300**
NTD291	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	4.300	€	430
	Direct costs incl. allowance					**€**	**4.730**
IK296	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	4.730	€	95
IK297	Site facilities	1,0%		€	4.730	€	47
IK299	Site organisation (eg. foreman, site managers)	10,0%		€	4.730	€	473
IK2910	General costs	8,0%		€	5.345	€	428
IK2911	Profit	3,0%		€	5.772	€	173
IK2912	Risk	2,0%		€	5.772	€	115
	Indirect costs ('contractors overhead')	28%				**€**	**1.331**
VZBK	**Costs foreseen**					**€**	**6.061**
RBK	**Contingency**	15%				**€**	**909**
BK2.9	**Construction costs 3D printed units**					**€**	**6.970**
VK29	**Real estate 3D printed units**					**€**	**-**
EK291	Detailed engineering contractor	2,0%		€	6.061	€	121
EK292	Engineering consultancies (design)	6,0%		€	6.061	€	364
EK293	Client's organisation (tendering, permitting)	10,0%		€	6.061	€	606
EK294	Site supervision, site management	4,0%		€	6.061	€	242
EK29	**Engineering 3D printed units**	22%				**€**	**1.333**
OK291	Remaining costs (e.g. permits, insurances)	4,0%		€	6.061	€	242
OBK29	**Remaining costs 3D printed units**	4%				**€**	**242**
INV29	**Total investment costs 3D printed units**					**€**	**8.546**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	ECO armour block®	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit	unit rate	total
30					
	INVESTMENT COSTS	2,00			
10	**Onshore activities**				
103110	Supply Eco Armour block	2,00	pcs	€ 850,00	€ 1.700,00
103170	Onshore transport (from factory to port)	2,00	pcs	€ 100,00	€ 200,00
	Total Onshore activities			**€ 1.900,00**	
20	**Offshore activities**				
203190	Transport and placement of elements	2,00	pcs	€ 500,00	€ 1.000,00
	Total Offshore activities			**€ 1.000,00**	
30	**Offshore activities decommissioning (after 20 years)**				
303130	Removal and transport of elements	2,00	pcs	€ 650,00	€ 1.300,00
	Totaal Offshore activities decommissioning (after 20 years)			**€ 1.300,00**	
	Direct costs				**€ 4.200**
NTD301	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€ 4.200	€ 420
	Direct costs incl. allowance				**€ 4.620**
IK306	Non-reoccurring costs (e.g. mob/demob)	2,0%		€ 4.620	€ 92
IK307	Site facilities	1,0%		€ 4.620	€ 46
IK309	Site organisation (eg. foreman, site managers)	10,0%		€ 4.620	€ 462
IK3010	General costs	8,0%		€ 5.221	€ 418
IK3011	Profit	3,0%		€ 5.638	€ 169
IK3012	Risk	2,0%		€ 5.638	€ 113
	Indirect costs ('contractors overhead')	28%			**€ 1.300**
VZBK	**Costs foreseen**				**€ 5.920**
RBK	**Contingency**	15%			**€ 888**
BK2.10	**Construction costs ECO armour block®**				**€ 6.808**
VK30	**Real estate ECO armour block®**				**€ -**
EK301	Detailed engineering contractor	2,0%		€ 5.920	€ 118
EK302	Engineering consultancies (design)	6,0%		€ 5.920	€ 355
EK303	Client's organisation (tendering, permitting)	10,0%		€ 5.920	€ 592
EK304	Site supervision, site management	4,0%		€ 5.920	€ 237
EK30	**Engineering ECO armour block®**	22%			**€ 1.302**
OK301	Remaining costs (e.g. permits, insurances)	4,0%		€ 5.920	€ 237
OBK30	**Remaining costs ECO armour block®**	4%			**€ 237**
INV30	**Total investment costs ECO armour block®**				**€ 8.347**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Oyster gabions	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
31							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
103190	Supply and prefab steel gabions 1,5x2,0x0,4 m (with ballast and oyster shell)	2,00	pcs	€	1.200,00	€	2.400,00
	Total Onshore activities			**€**	**2.400,00**		
20	**Offshore activities**						
203170	Transport and placement of gabions	2,00	pcs	€	500,00	€	1.000,00
	Total Offshore activities			**€**	**1.000,00**		
30	**Offshore activities decommissioning (after 20 years)**						
303200	Removal and transport of gabions	2,00	pcs	€	650,00	€	1.300,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**1.300,00**		
	Direct costs					**€**	**4.700**
NTD311	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	4.700	€	470
	Direct costs incl. allowance					**€**	**5.170**
IK316	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	5.170	€	103
IK317	Site facilities	1,0%		€	5.170	€	52
IK319	Site organisation (eg. foreman, site managers)	10,0%		€	5.170	€	517
IK3110	General costs	8,0%		€	5.842	€	467
IK3111	Profit	3,0%		€	6.309	€	189
IK3112	Risk	2,0%		€	6.309	€	126
	Indirect costs ('contractors overhead')	28%				**€**	**1.455**
VZBK	**Costs foreseen**					**€**	**6.625**
RBK	**Contingency**	15%				**€**	**994**
BK2.11	**Construction costs Oyster gabions**					**€**	**7.619**
VK31	**Real estate Oyster gabions**					**€**	**-**
EK311	Detailed engineering contractor	2,0%		€	6.625	€	132
EK312	Engineering consultancies (design)	6,0%		€	6.625	€	397
EK313	Client's organisation (tendering, permitting)	10,0%		€	6.625	€	662
EK314	Site supervision, site management	4,0%		€	6.625	€	265
EK31	**Engineering Oyster gabions**	22%				**€**	**1.457**
OK311	Remaining costs (e.g. permits, insurances)	4,0%		€	6.625	€	265
OBK31	**Remaining costs Oyster gabions**	4%				**€**	**265**
INV31	**Total investment costs Oyster gabions**					**€**	**9.341**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Biohut®	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
32							
	INVESTMENT COSTS	1,00					
10	**Onshore activities**						
103220	Supply and install steel mesh in frame 1x1x2 m, with tubes	1,00	pcs	€	1.000,00	€	1.000,00
103230	Supply and install rock	3,30	ton	€	50,00	€	165,00
103240	Pile driving risk mitigation measure: offshore connection system	1,00	pcs	€	500,00	€	500,00
	Total Onshore activities			**€**	**1.665,00**		
30	**Offshore activities decommissioning (after 20 years)**						
303210	Removal of steel mesh in frame 1x1x2 m	1,00	pcs	€	100,00	€	100,00
303220	Removal and transport of rock	3,30	ton	€	25,00	€	82,50
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**182,50**		
	Direct costs					**€**	**1.848**
NTD321	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	1.848	€	185
	Direct costs incl. allowance					**€**	**2.032**
IK326	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	2.032	€	41
IK327	Site facilities	1,0%		€	2.032	€	20
IK329	Site organisation (eg. foreman, site managers)	10,0%		€	2.032	€	203
IK3210	General costs	8,0%		€	2.296	€	184
IK3211	Profit	3,0%		€	2.480	€	74
IK3212	Risk	2,0%		€	2.480	€	50
	Indirect costs ('contractors overhead')	28%				**€**	**572**
VZBK	**Costs foreseen**					**€**	**2.604**
RBK	**Contingency**	15%				**€**	**391**
BK2.12	**Construction costs Biohut®**					**€**	**2.995**
VK32	**Real estate Biohut®**					**€**	**-**
EK321	Detailed engineering contractor	2,0%		€	2.604	€	52
EK322	Engineering consultancies (design)	6,0%		€	2.604	€	156
EK323	Client's organisation (tendering, permitting)	10,0%		€	2.604	€	260
EK324	Site supervision, site management	4,0%		€	2.604	€	104
EK32	**Engineering Biohut®**	22%				**€**	**573**
OK321	Remaining costs (e.g. permits, insurances)	4,0%		€	2.604	€	104
OBK32	**Remaining costs Biohut®**	4%				**€**	**104**
INV32	**Total investment costs Biohut®**					**€**	**3.672**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Rock bags (filter unit or basalt bag)	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
33							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
103460	Supply and prefab rock bag, filled with rock	2,00	pcs	€	500,00	€	1.000,00
	Total Onshore activities			**€**	**1.000,00**		
20	**Offshore activities**						
203320	Transport and placement of reef balls	2,00	pcs	€	300,00	€	600,00
	Total Offshore activities			**€**	**600,00**		
30	**Offshore activities decommissioning (after 20 years)**						
303350	Removal and transport of reef balls	2,00	pcs	€	470,00	€	940,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**940,00**		
	Direct costs					**€**	**2.540**
NTD331	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	2.540	€	254
	Direct costs incl. allowance					**€**	**2.794**
IK336	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	2.794	€	56
IK337	Site facilities	1,0%		€	2.794	€	28
IK339	Site organisation (eg. foreman, site managers)	10,0%		€	2.794	€	279
IK3310	General costs	8,0%		€	3.157	€	253
IK3311	Profit	3,0%		€	3.410	€	102
IK3312	Risk	2,0%		€	3.410	€	68
	Indirect costs ('contractors overhead')	28%				**€**	**786**
VZBK	**Costs foreseen**					**€**	**3.580**
RBK	**Contingency**	15%				**€**	**537**
BK2.13	**Construction costs Rock bags (filter unit or basalt bag)**					**€**	**4.117**
VK33	**Real estate Rock bags (filter unit or basalt bag)**					**€**	**-**
EK331	Detailed engineering contractor	2,0%		€	3.580	€	72
EK332	Engineering consultancies (design)	6,0%		€	3.580	€	215
EK333	Client's organisation (tendering, permitting)	10,0%		€	3.580	€	358
EK334	Site supervision, site management	4,0%		€	3.580	€	143
EK33	**Engineering Rock bags (filter unit or basalt bag)**	22%				**€**	**788**
OK331	Remaining costs (e.g. permits, insurances)	4,0%		€	3.580	€	143
OBK33	**Remaining costs Rock bags (filter unit or basalt bag)**	4%				**€**	**143**
INV33	**Total investment costs Rock bags (filter unit or basalt bag)**					**€**	**5.048**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	ECO Mats®	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
34							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
103520	Supply Eco mat	2,00	pcs	€	1.500,00	€	3.000,00
103570	Onshore transport (from factory to port)	2,00	pcs	€	100,00	€	200,00
	Total Onshore activities			**€**	**3.200,00**		
20	**Offshore activities**						
203590	Transport and placement of elements	2,00	pcs	€	500,00	€	1.000,00
	Total Offshore activities			**€**	**1.000,00**		
30	**Offshore activities decommissioning (after 20 years)**						
303530	Removal and transport of elements	2,00	pcs	€	650,00	€	1.300,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**1.300,00**		
	Direct costs					**€**	**5.500**
NTD341	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	5.500	€	550
	Direct costs incl. allowance					**€**	**6.050**
IK346	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	6.050	€	121
IK347	Site facilities	1,0%		€	6.050	€	61
IK349	Site organisation (eg. foreman, site managers)	10,0%		€	6.050	€	605
IK3410	General costs	8,0%		€	6.837	€	547
IK3411	Profit	3,0%		€	7.383	€	222
IK3412	Risk	2,0%		€	7.383	€	148
	Indirect costs ('contractors overhead')	28%				**€**	**1.703**
VZBK	**Costs foreseen**					**€**	**7.753**
RBK	**Contingency**	15%				**€**	**1.163**
BK2.14	**Construction costs ECO Mats®**					**€**	**8.915**
VK34	**Real estate ECO Mats®**					**€**	**-**
EK341	Detailed engineering contractor	2,0%		€	7.753	€	155
EK342	Engineering consultancies (design)	6,0%		€	7.753	€	465
EK343	Client's organisation (tendering, permitting)	10,0%		€	7.753	€	775
EK344	Site supervision, site management	4,0%		€	7.753	€	310
EK34	**Engineering ECO Mats®**	22%				**€**	**1.706**
OK341	Remaining costs (e.g. permits, insurances)	4,0%		€	7.753	€	310
OBK34	**Remaining costs ECO Mats®**	4%				**€**	**310**
INV34	**Total investment costs ECO Mats®**					**€**	**10.931**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Reef cube ® mat	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
35							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
103640	Supply reef cubes 0,5 m/pcs	100,00	pcs	€	60,00	€	6.000,00
103670	Onshore transport (from factory to port)	2,00	pcs	€	100,00	€	200,00
	Total Onshore activities			**€**	**6.200,00**		
20	**Offshore activities**						
203690	Transport and placement of elements	2,00	pcs	€	500,00	€	1.000,00
	Total Offshore activities			**€**	**1.000,00**		
30	**Offshore activities decommissioning (after 20 years)**						
303630	Removal and transport of elements	2,00	pcs	€	650,00	€	1.300,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**1.300,00**		
	Direct costs					**€**	**8.500**
NTD351	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	8.500	€	850
	Direct costs incl. allowance					**€**	**9.350**
IK356	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	9.350	€	187
IK357	Site facilities	1,0%		€	9.350	€	94
IK359	Site organisation (eg. foreman, site managers)	10,0%		€	9.350	€	935
IK3510	General costs	8,0%		€	10.566	€	845
IK3511	Profit	3,0%		€	11.411	€	342
IK3512	Risk	2,0%		€	11.411	€	228
	Indirect costs ('contractors overhead')	28%				**€**	**2.631**
VZBK	**Costs foreseen**					**€**	**11.981**
RBK	**Contingency**	15%				**€**	**1.797**
BK2.15	**Construction costs Reef cube ® mat**					**€**	**13.778**
VK35	**Real estate Reef cube ® mat**					**€**	**-**
EK351	Detailed engineering contractor	2,0%		€	11.981	€	240
EK352	Engineering consultancies (design)	6,0%		€	11.981	€	719
EK353	Client's organisation (tendering, permitting)	10,0%		€	11.981	€	1.198
EK354	Site supervision, site management	4,0%		€	11.981	€	479
EK35	**Engineering Reef cube ® mat**	22%				**€**	**2.636**
OK351	Remaining costs (e.g. permits, insurances)	4,0%		€	11.981	€	479
OBK35	**Remaining costs Reef cube ® mat**	4%				**€**	**479**
INV35	**Total investment costs Reef cube ® mat**					**€**	**16.894**

code	description	quantity	unit		unit rate		total
36							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
103650	Supply and prefab steel mesh ø800x250 mm, filled with rock 15-300 kg	2,00	pcs	€	100,00	€	200,00
	Total Onshore activities			**€**	**200,00**		
20	**Offshore activities**						
203610	Transport and placement of filter unit	2,00	pcs	€	250,00	€	500,00
	Total Offshore activities			**€**	**500,00**		
30	**Offshore activities decommissioning (after 20 years)**						
303640	Removal and transport of filter unit	2,00	pcs	€	420,00	€	840,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**840,00**		
	Direct costs					**€**	**1.540**
NTD361	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	1.540	€	154
	Direct costs incl. allowance					**€**	**1.694**
IK366	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	1.694	€	34
IK367	Site facilities	1,0%		€	1.694	€	17
IK369	Site organisation (eg. foreman, site managers)	10,0%		€	1.694	€	169
IK3610	General costs	8,0%		€	1.914	€	153
IK3611	Profit	3,0%		€	2.067	€	62
IK3612	Risk	2,0%		€	2.067	€	41
	Indirect costs ('contractors overhead')	28%				**€**	**477**
VZBK	**Costs foreseen**					**€**	**2.171**
RBK	**Contingency**	15%				**€**	**326**
BK2.16	**Construction costs Filter unit**					**€**	**2.496**
VK36	**Real estate Filter unit**					**€**	**-**
EK361	Detailed engineering contractor	2,0%		€	2.171	€	43
EK362	Engineering consultancies (design)	6,0%		€	2.171	€	130
EK363	Client's organisation (tendering, permitting)	10,0%		€	2.171	€	217
EK364	Site supervision, site management	4,0%		€	2.171	€	87
EK36	**Engineering Filter unit**	22%				**€**	**478**
OK361	Remaining costs (e.g. permits, insurances)	4,0%		€	2.171	€	87
OBK36	**Remaining costs Filter unit**	4%				**€**	**87**
INV36	**Total investment costs Filter unit**					**€**	**3.061**

Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Interlocking unit 1 m³/pcs	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
92							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
109330	Supply interlocking unit 1 m³/pcs	2,00	pcs	€	350,00	€	700,00
	Total Onshore activities			**€**	**700,00**		
20	**Offshore activities**						
209390	Transport and placement of elements	2,00	pcs	€	500,00	€	1.000,00
	Total Offshore activities			**€**	**1.000,00**		
30	**Offshore activities decommissioning (after 20 years)**						
309330	Removal and transport of elements	2,00	pcs	€	650,00	€	1.300,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**1.300,00**		
	Direct costs					**€**	**3.000**
NTD921	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	3.000	€	300
	Direct costs incl. allowance					**€**	**3.300**
IK926	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	3.300	€	66
IK927	Site facilities	1,0%		€	3.300	€	33
IK929	Site organisation (eg. foreman, site managers)	10,0%		€	3.300	€	330
IK9210	General costs	8,0%		€	3.729	€	298
IK9211	Profit	3,0%		€	4.027	€	121
IK9212	Risk	2,0%		€	4.027	€	81
	Indirect costs ('contractors overhead')	28%				**€**	**929**
VZBK	**Costs foreseen**					**€**	**4.229**
RBK	**Contingency**	15%				**€**	**634**
BK92	**Construction costs Interlocking unit 1 m³/pcs**					**€**	**4.863**
VK92	**Real estate Interlocking unit 1 m³/pcs**					**€**	**-**
EK921	Detailed engineering contractor	2,0%		€	4.229	€	85
EK922	Engineering consultancies (design)	6,0%		€	4.229	€	254
EK923	Client's organisation (tendering, permitting)	10,0%		€	4.229	€	423
EK924	Site supervision, site management	4,0%		€	4.229	€	169
EK92	**Engineering Interlocking unit 1 m³/pcs**	22%				**€**	**930**
OK921	Remaining costs (e.g. permits, insurances)	4,0%		€	4.229	€	169
OBK92	**Remaining costs Interlocking unit 1 m³/pcs**	4%				**€**	**169**
INV92	**Total investment costs Interlocking unit 1 m³/pcs**					**€**	**5.962**

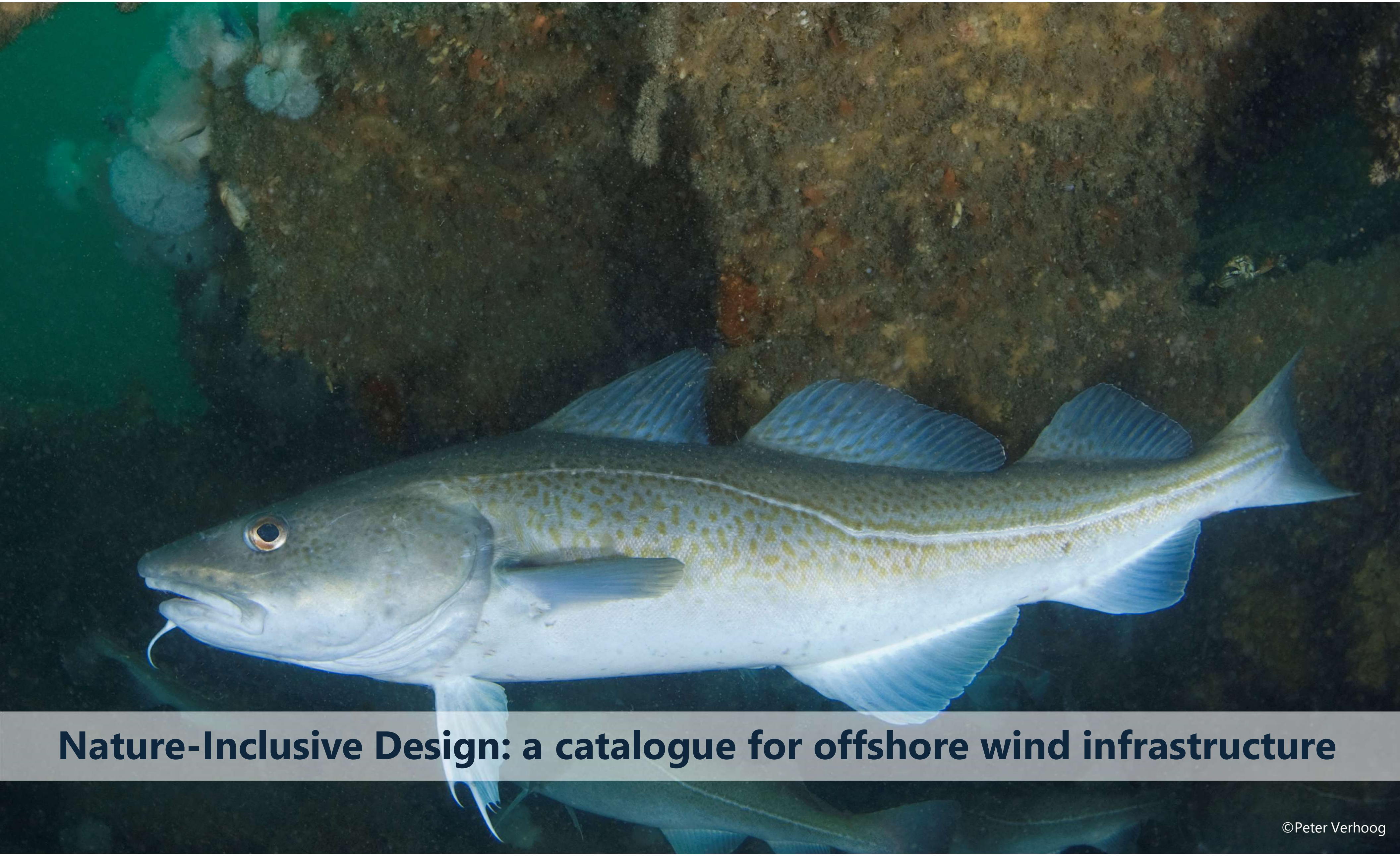
Client:	Ministerie van Landbouw Natuur en Voedselkwaliteit	Price level:	Q4-2019	Date:	21-2-2020
Project:	NID catalogue for OWF	Version:	02	Project code:	114266
Sub-item:	Oyster and rock gabions	Status:	Final	Author:	E. Schulte MSc.

code	description	quantity	unit		unit rate		total
93							
	INVESTMENT COSTS	2,00					
10	**Onshore activities**						
109380	Supply and prefab steel gabions 1,5x2,0x0,4 m (with ballast, rock and oyster shell	2,00	pcs	€	700,00	€	1.400,00
	Total Onshore activities			**€**	**1.400,00**		
20	**Offshore activities**						
209370	Transport and placement of gabions	2,00	pcs	€	500,00	€	1.000,00
	Total Offshore activities			**€**	**1.000,00**		
30	**Offshore activities decommissioning (after 20 years)**						
309400	Removal and transport of gabions	2,00	pcs	€	650,00	€	1.300,00
	Totaal Offshore activities decommissioning (after 20 years)			**€**	**1.300,00**		
	Direct costs					**€**	**3.700**
NTD931	Additional items (e.g. bolts and nuts, cuts&losses)	10,0%		€	3.700	€	370
	Direct costs incl. allowance					**€**	**4.070**
IK936	Non-reoccurring costs (e.g. mob/demob)	2,0%		€	4.070	€	81
IK937	Site facilities	1,0%		€	4.070	€	41
IK939	Site organisation (eg. foreman, site managers)	10,0%		€	4.070	€	407
IK9310	General costs	8,0%		€	4.599	€	368
IK9311	Profit	3,0%		€	4.967	€	149
IK9312	Risk	2,0%		€	4.967	€	99
	Indirect costs ('contractors overhead')	28%				**€**	**1.145**
VZBK	**Costs foreseen**					**€**	**5.215**
RBK	**Contingency**	15%				**€**	**782**
BK93	**Construction costs Oyster and rock gabions**					**€**	**5.998**
VK93	**Real estate Oyster and rock gabions**					**€**	**-**
EK931	Detailed engineering contractor	2,0%		€	5.215	€	104
EK932	Engineering consultancies (design)	6,0%		€	5.215	€	313
EK933	Client's organisation (tendering, permitting)	10,0%		€	5.215	€	522
EK934	Site supervision, site management	4,0%		€	5.215	€	209
EK93	**Engineering Oyster and rock gabions**	22%				**€**	**1.147**
OK931	Remaining costs (e.g. permits, insurances)	4,0%		€	5.215	€	209
OBK93	**Remaining costs Oyster and rock gabions**	4%				**€**	**209**
INV93	**Total investment costs Oyster and rock gabions**					**€**	**7.354**

III

APPENDIX: NATURE-INCLUSIVE DESIGN CATALOGUE

Nature-Inclusive Design: a catalogue for offshore wind infrastructure



©Peter Verhoog

Witteveen + Bos

Wageningen University & Research

February 2020

Witteveen+Bos

Project	Nature-Inclusive Design: a catalogue for offshore wind infrastructure
Client	The Ministry of Agriculture, Nature and Food Quality
Document	Nature-Inclusive Design catalogue for offshore wind infrastructure
Status	Final version 02
Date	23 June 2020
Reference	114266/20-009.700
Project code	114266
Project Leader	I. Prusina PhD
Project Director	M. Klinge MSc
Author(s)	Witteveen+Bos: I. Prusina PhD, A. Hermans MSc, Just van der Endt MSc; Wageningen Marine Research: O. G. Bos PhD
Checked by	M. Klinge MSc
Approved by	M. Klinge MSc
Initials	Marcel Klinge Digitally signed by Marcel Klinge Date: 2020.06.23 16:35:51 +02'00'

Witteveen+Bos Raadgevende ingenieurs B.V. | Leeuwenbrug 8 | P.O. Box 233 | 7400 AE Deventer | The Netherlands | +31 570 69 79 11 | www.witteveenbos.com | CoC 38020751

PREFACE

The Ministry of Agriculture, Nature and Food Quality (LNV) aims to stimulate enhancement of ecological functioning of the North Sea during the development of offshore wind projects in the Netherlands. One of the tools available is to include nature regulations in wind farm site decisions and related permitting.

According to the current regulations, the permit holder must make demonstrable efforts to design and build the wind farm in such a way that it actively enhances the sea's ecosystem, helping to foster conservation efforts and goals relating to sustainable use of species and habitats that occur naturally in the Netherlands (RVO 2019).

To support the regulations for future wind farm site decisions or related instruments, LNV has commissioned Witteveen+Bos (W+B) and Wageningen Marine Research (WMR) to compile a catalogue with technically proven concepts and ecologically promising *Nature-Inclusive Design* options.

This catalogue is part of a technical report in which the supporting technical and ecological information can be found.

Nature-Inclusive Design: a catalogue for offshore wind infrastructure

Witteveen+Bos
Wageningen Marine Research

Starting points and constraints

- NID options should contribute to ecological functioning of the indigenous species of the Dutch North Sea, with a focus on strengthening species and habitats that need a development towards recovery (e.g. species listed in the EU Habitats Directive, Dutch action plan for the recovery of vulnerable species, Dutch red lists, OSPAR List of Threatened and/or Declining Species and Habitats).
- Simultaneously supporting the spread of non-indigenous as a result of NID is undesirable.
- Possibilities for NID options beneficial for commercial species (co-use) can be considered.
- NID options should be ready-to-use, they at least have been successfully applied elsewhere in a pilot project or have been assessed as ecologically promising and practically applicable; this should be substantiated, by literature references and or expert opinions.
- The scale to which NID options should contribute to the restoration of the native biodiversity in the ecosystem is not yet defined by the governmental bodies (local, national or international).
- In order to address the concept of the scale in relation to the ecological benefits of an NID option and its cost, the calculations in this catalogue are based on a reference offshore wind farm consisting of 60 monopiles and 2 substations.

Industry proofing

- Selected NID options were discussed with industry experts.
- The interviewees included various industry representatives, from wind developers and contractors to specific suppliers.
- Suppliers of selected NID structures/modules were consulted to get further insight into the product design and its ecological viability.
- Representatives of knowledge institutes were consulted to determine the link between ecological and technical considerations.
- Industry proofing ensured the feasibility (both ecological and technical) of NID options offered in the catalogue.
- NID options in the catalogue are ready-to-use with clear design guidelines and associated risks and costs.

How to use the catalogue?

- The **Nature-Inclusive Design catalogue** can be used in two ways - by *target species* or by *interface* with the offshore structure.
- The options in the catalogue are divided into three (3) different categories based on their interface with the infrastructure:

I. Add-on (on jackets)

II. Optimized scour protection layer

III. Optimized cable protection layer

- Per category, a selection of options are described based on the function they provide for the target species.

Target species – policy-relevant species

- The target species selected for this study have been used as input to conduct the inventory of the selected NID options.
- The policy-relevant species considered in this catalogue are listed in the table below:

Species	Relevance
Atlantic cod *Gadus morhua*	OSPAR species* Habitat Directive typical species of H1110C NL Red List (Near Threatened)
Poor cod *Trisopterus minutus*	NL Red list (Near Threatened)
European flat oyster *Ostrea edulis*	OSPAR species MSFD target**
Sharks and rays Elasmobranchs	OSPAR species MSFD target*** NL Red List: Starry ray: endangered

* OSPAR Commission (2008).

** Target D6T5 - return and recovery of biogenic reefs including flat oyster beds (Min IenW & Min LNV, 2018).

*** Target D1C2 - Improving the population abundance of sharks and rays in the North Sea and above all in the coastal zone (Min IW & Min LNV, 2018).

Target species – policy-relevant species

- Species that need hiding places, feeding area or nursery area and will profit from creating additional smaller and larger crevices: **Atlantic cod (*Gadus morhua*)** and **poor cod (*Trisopterus minutus*)** in different life stages.
- Atlantic cod is considered an umbrella species: measures taken to enhance habitat for this species will result in the enhancement of a suite of co-occurring species at the same time (Lengkeek et al., 2017). A variety of sizes of crevices will also result in hiding spaces for their prey species (crustaceans, worms, shellfish).
- Poor cod will also benefit from additional hiding places as the species schools near the bottom and preys on shrimp, worms, young crabs and juvenile fish, while on the other hand it serves as prey for larger predators such as seals.
- The **European flat oyster (*Ostrea edulis*)**, since it is a habitat engineer and it is considered an umbrella species in Lengkeek et al. (2017). It provides a biogenic reef structure that attracts many other species (Lengkeek et al., 2017).
- Although flat oysters do not require specific NID structures, they do require reintroduction of adults or introduction of juveniles as spat on shell. It is important that at the time of larval production, enough settlement material (e.g. dead mussel shells) are available for the larvae to settle on.

Target species – commercial species

- The following commercially interesting species were taken for further consideration, since their sustainable use in the context of co-use of wind farms for aquaculture gains a lot of attention:

Target Species	Relevance
Commercial species	
Atlantic cod *Gadus morhua*	Commercial species
European flat oyster *Ostrea edulis*	Commercial species
European lobster *Homarus gammarus*	Commercial species
Edible crab *Cancer paguras*	Commercial species
Cuttlefish and squid	Commercial species

- **Edible crab (*Cancer pagurus*)** and **European lobster (*Homarus gammarus*)** will profit from the creation of additional crevices and hiding places.

©Peter Verhoog

Target species – not included in the catalogue

- Based on the inventory of possible NID options and the uncertainties regarding how beneficial the structures will be for these species; the following species were not taken into further consideration in this catalogue:
- Shark and ray species;
- Cuttlefish and squid.

Options for these groups could be explored in the future.

Overview of Nature Inclusive Design measures

- The proven technology or ecologically promising NID options are organized in three categories based on the way they *interface with the offshore infrastructure* e.g. is an NID an integral part of the offshore substation, cable (crossing) or scour protection.

Category	Specific NID option
1. Add-on options*	Biohut® Cod hotel (Cotel)
2. Optimized scour protection layer	Additional rock layer Adapted grading armour layer Placing unit on or in the scour protection layer: – Habitat pipes – Fish hotel (WUR) – Reefball® and Layer cakes – Reef cube® – 3D printed units – ECO armour block® – Oyster gabions – Biohut®
3. Optimized cable protection layer	Filter Unit® Basalt bags ECO Mats® Reef cube bag™ Reef cube matt™

*at the current stage of the technical development, adding an additional element to the design of a monopile is undesirable in offshore conditions. This option is currently feasible for implementation on jacket constructions.

Overview of expected ecological functions of NID

- The NID options need to be beneficial to the target species in one or several stages of their life cycle. The following table gives an overview of the expected ecological functions of NID for target species.

			Policy-relevant species			Commercial species	
			Atlantic cod	Poor cod	European flat oyster	Edible crab	European lobster
1	Add-on options	Biohut®	N	N			
		Cod hotel (Cotel)	S/N	S/N			
2	Optimized scour protection layer	Additional rock layer	S/N	S/N	As	S/N	S/N
		Adapted grading armour layer	N	N	As	S/N	N
		Placing unit on or in the scour protection layer:					
		- Habitat pipes	S/N	S/N		S/N	S/N
		- Fish hotel (WUR)	S/N	S/N		S/N	S/N
		- Reefball® and Layer cakes	S/N	S/N	As	S/N	S/N
		- Reef cube®	N	N	As	S/N	S/N
		- 3D printed units	S/N	S/N	As	S/N	S/N
		- ECO armour block®	N	N	As	N	N
		- Oyster gabions	N	N	As	N	N
		- Biohut®	S/N	S/N		N	N
3	Optimized cable protection layer	Filter Unit®	N	N		N	N
		Basalt bags	N	N		N	N
		ECO Mats®			As		
		Reef cube bag™	N	N		N	N
		Reef cube matt ™	N	N	As	N	N

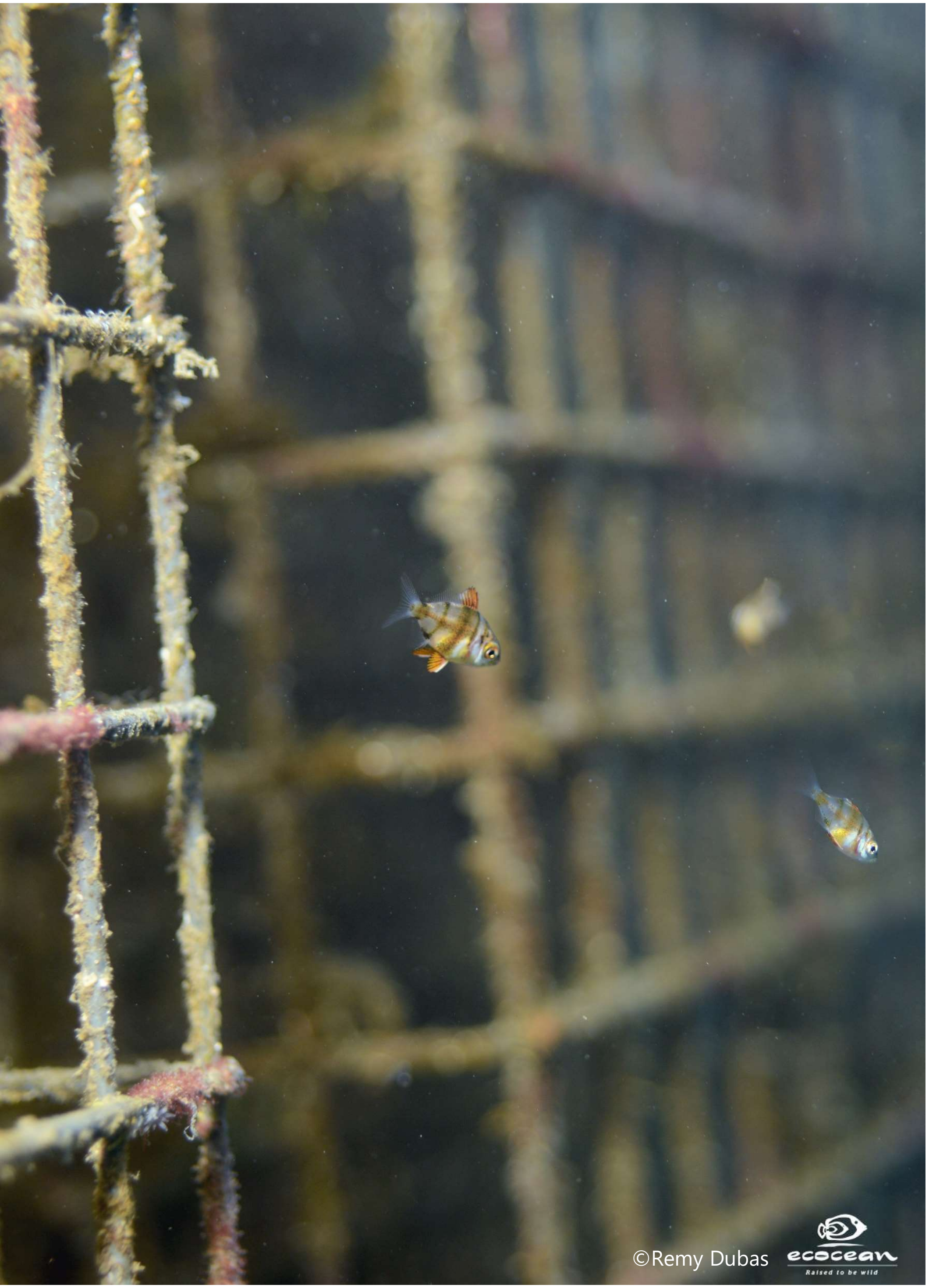
S- shelter (adults), N- nursery (larvae, juveniles), As- attachment substrate

Shuttershock

Cost calculations

- A deterministic estimate of investment costs was performed for each NID option in the catalogue.
- Costs of NID options in this catalogue are expressed per two NID elements. There are two exceptions; fish hotel (1 unit) and reef cubes (8 units).
- Quantities (dimensions and number of elements) are assumed and of utmost importance for the total costs (reduction effect of fixed costs such as engineering and fabrication process). If the quantity changes, so do the costs.
- The cost estimation calculations presented in this catalogue are based on a reference wind farm comprising of 60 monopiles with:
  - standalone solutions: 2 elements per monopile;
  - area solutions: 20 % of scour protection area, based on ø30 m.

  Due to the quantity of elements and surface, the costs are relatively low and serve to compare different solutions/techniques.
- The capital investment cost (CapEx) estimation included onshore and offshore activities, direct (material) and indirect costs (site organisation, mobilisation, facilities, risk), contingency, construction, engineering, permits and insurances.
- Operational expenditures (OpEx) such as monitoring are not included in the calculations (for the cost estimate of monitoring activities refer to the report of Bureau Waardenburg, 2020).
- The provided costs are excluding VAT.



Category 1: Add-on options

General description

NID units installed directly on an offshore jacket to accommodate target species. These options provide nursery and/or shelter for juveniles and attachment substrate for prey species. Add - on unit is to be adjusted to accommodate specific function for a target species, e.g. shelter for juvenile Atlantic cod.

Technical considerations

Adding unit to a jacket affects the hydrodynamic load of an asset. Calculations are to be done to prevent constructive failure. Pile driving force is to be considered when applicable, as well as on the filling material (shells, rock). Special attention should be given to the reliability of the integration of the NID with the structure to avoid potential damage of the primary structure itself.

Target species

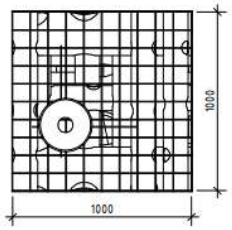
Atlantic cod *Gadus morhua*
Poor cod *Trisopterus minutus*

Add-on options Cod hotel (Cotel)

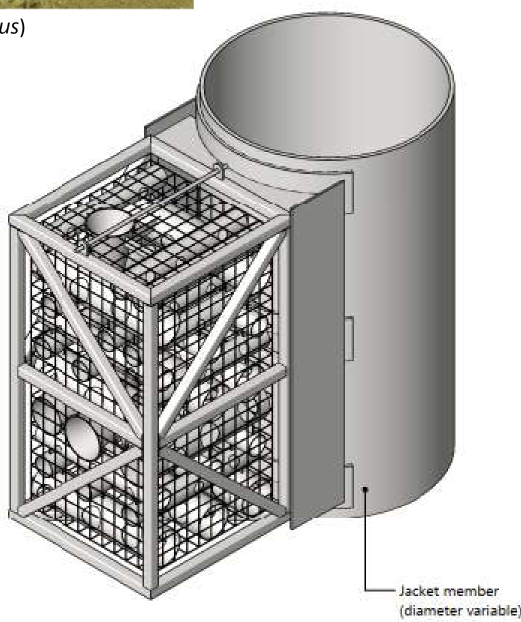
Policy-relevant species

Atlantic cod (*Gadus morhua*)

Poor cod (*Trisopterus minutus*)



TOP VIEW TYPE I
scale: 1 : 20



3D VIEW TYPE I

Specifications

A cod hotel consists of 3 main parts: the saddle connects the frame of the cod hotel to the jacket structure; the steel frame forms the structural casing; the ecological unit consists of a steel gabion basket filled with perforated steel tubes and monitoring funnels. The frame and the saddle to be designed to withstand the governing loads. The structural steel of the fish hotel (frame, saddles and double plates) is coated like the jacket structure.

Suggested design

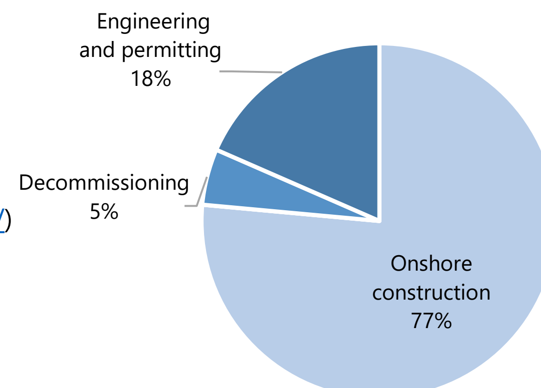
Saddle: height 2.3 m x width 1.2 m
Structural frame: height 2 m x width 1 m x 1 m
Steel gabion basket: height 2 m x width 1 m x 1 m
Mesh size: larger than 5 cm x 5 cm and smaller than 10 cm x 10 cm
Perforated tubes of 1 to 2 m with varying diameters (e.g. from 13 cm to 25 cm)
Perforations on the tubes larger than 7.5 cm and smaller than 15 cm
Adding funnel-shaped tubes (input funnel 30 cm, end funnel 10 cm) for eDNA sampling

Ecological benefits

A cod hotel is to accommodate primarily Atlantic cod. The perforated tubes with various diameters, provide shelter and foraging area. Cod hotel is expected to increase the biomass of Atlantic cod, as well as poor cod and associated prey species. There is no information on the production of cod in OWF. Assuming that an NID would be able to support 100 small cod each year to grow up to 30 cm then the production per NID option would be 100 x 0.347 kg = 34 kg of cod. This calculation requires validation through monitoring.

Costs

Onshore construction	€ 2,699
Offshore construction	€ 0
Decommissioning	€ 296
Engineering and permitting	€ 677



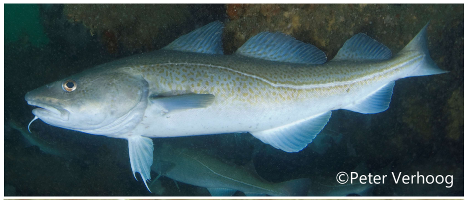
Design

Witteveen+Bos design (www.witteveenbos.com/)

Add-on options Biohut®

Policy-relevant species

Atlantic cod (*Gadus morhua*)



Poor cod (*Trisopterus minutus*)

Specifications

The Biohut is a system of 2-3 cages in succession. They can be modified and adjusted for placement on a jacket/or as a stand-alone unit. The middle cage should be filled with quarry rock.

Suggested changes* to the patented design

Cage frame: height 2 m x width 1 m x 1 m
Steel gabion basket: height 2 m x width 1 m x 1 m
Mesh size: 10 cm x 10 cm
Adding funnel-shaped tubes (input funnel 30 cm, end funnel 10 cm) for eDNA sampling

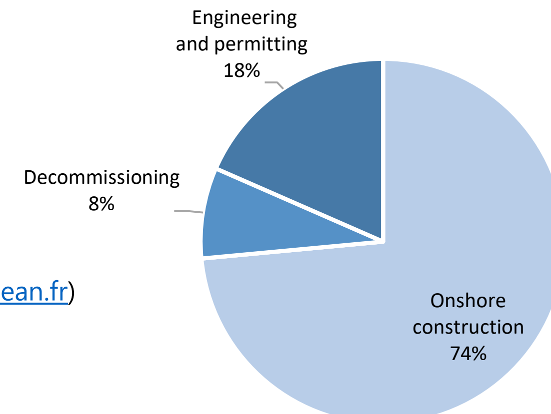
**Detailed structural design is required to withstand the governing loads of a Biohut modification for a jacket.*

Ecological benefits

A modified design of a Biohut to be used on offshore jackets is to accommodate primarily Atlantic cod, poor cod and associated prey species. The function is to act as a shelter and nursery area, serving to increase the biomass of the target species. See Cod hotel for estimation od production in a wind farm. This calculation requires validation through monitoring.

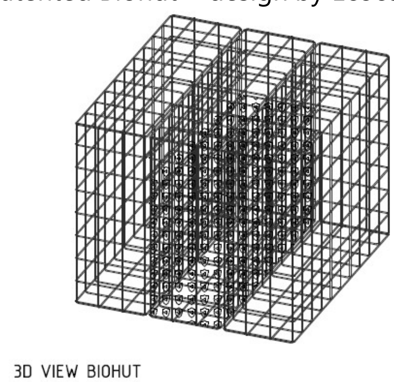
Costs (as per modification above)

Onshore construction	€ 2,431
Offshore construction	€ 0
Decommissioning	€ 162
Engineering and permitting	€ 586



Design

Patented Biohut® design by Ecocean (www.ecocean.fr)



Category 2: Optimized scour protection layer

General description

Optimizing scour protection layer with larger rock grading to create crevices to a maximum of 50 centimeters depth. Adjusted rock grading to minimally cover 20% of the total scour protection. Increasing rock grading allows variation in crevices' size and therefore accommodate different life stages of the target species. Additionally, different stand-alone units can be integrated on the scour protection layer to create additional habitat.

Technical considerations

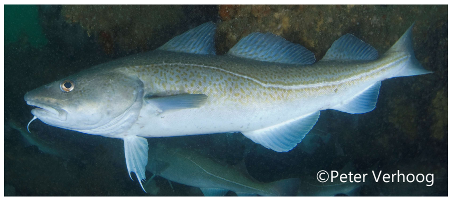
Made location specific, depending on the morphodynamic conditions. When adjusting (sections of) the scour protection, the maximum boulder size should be considered to allow pile driving for installation of the monopile. Internal stability of armour layer in relation to larger rock grading used to increase crevices sizes should be considered. When placing stand-alone units on the scour protection layer, the stability and interface of these NID units and the interface with the armour layer should be considered for hydraulic loads.

Target species

Juvenile cod *Gadus morhua*
Poor cod *Trisopterus minutus*
Flat oyster *Ostrea edulis*
Lobster *Homarus gammarus*
Edible crab *Cancer pagurus*

Optimized scour protection layer Additional rock layer

Policy-relevant species



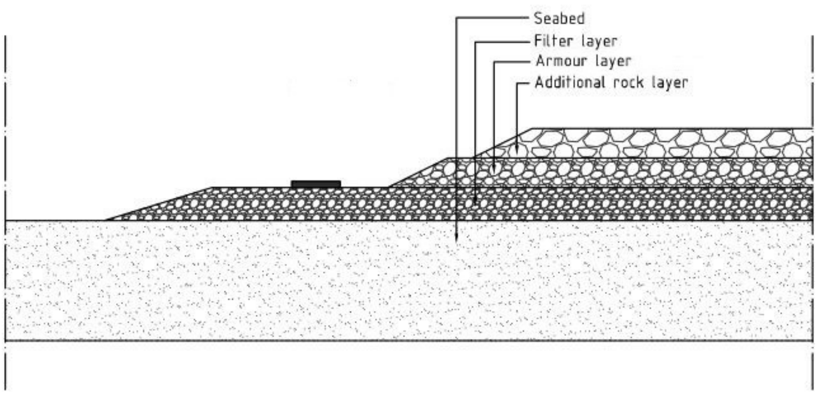
Atlantic cod (*Gadus morhua*)

Juvenile poor cod (*Trisopterus minutus*)

Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)



Specifications

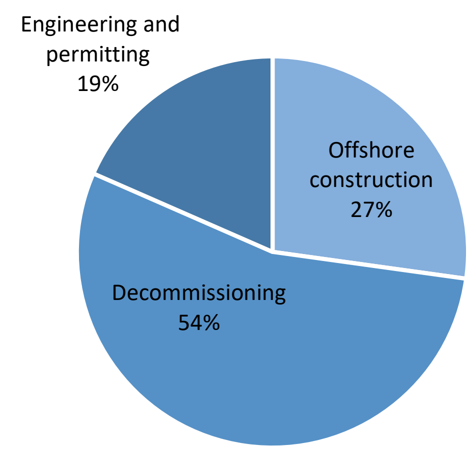
Minimum surface to be covered is 20% of the total scour protection layer. Additional layer of rocks with adjusted grading of e.g. 40-200 kg placed at the standard scour protection layer. crevices minimum of 10 cm to a maximum of 30 cm in diameter and a minimum of 20 cm to a maximum of 50 cm deep. Design conditions are to allow little or no movement of rocks.

Ecological benefits

Increase of biomass: If each monopile and its surrounding scour protection would produce 2 adult lobsters per year of 85 mm CL, the biomass production would be 2 * 0.410 kg = 0.820 kg per monopile. For an OWF of 60 monopiles this would be 120 lobsters (49.2 kg/y).
An additional rock layer could also provide shelter for juvenile cod. For this, no estimates have been made, since the number of hiding spaces/scour protection is not known. If the rock layer is seeded with European flat oyster (adults and/or spat on shell), it could be the starting point of an oyster reef.

Costs

Onshore construction	€ 0
Offshore construction	€ 5,187
Decommissioning	€ 10,374
Engineering and permitting	€ 3,518



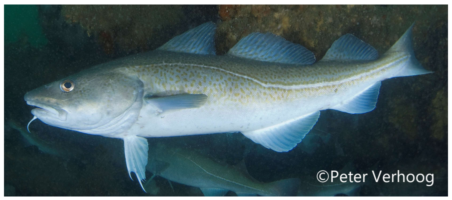
Supplier

Quarry suppliers

ADDITIONAL ROCK LAYER

Optimized scour protection layer Adapted grading armour layer

Policy-relevant species



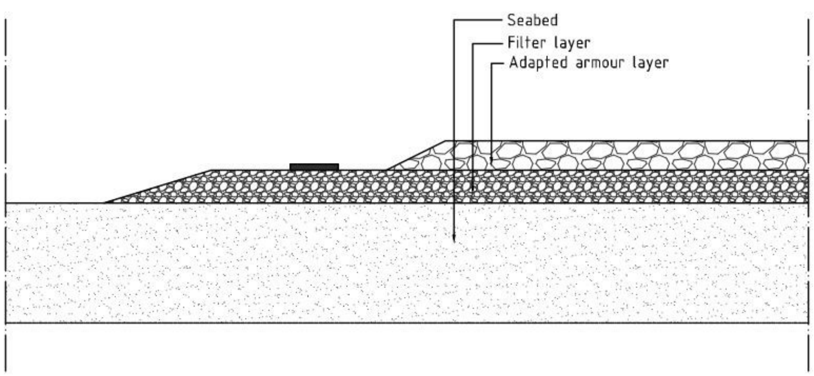
Atlantic cod (*Gadus morhua*)

Juvenile poor cod (*Trisopterus minutus*)

Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)



ADAPTED GRADING ARMOUR LAYER

Specifications

Minimum surface to be covered is 20% of the total scour protection layer. Optimized layer can replace the typical armour layer. Adaptation is done during design phase. Same technical specification as described for additional rock layer.

Ecological benefits

Grading is adapted to provide habitats for crab, lobster and juvenile cod. This increases biomass as it provides shelter for these species. See assumptions for additional rock layer.

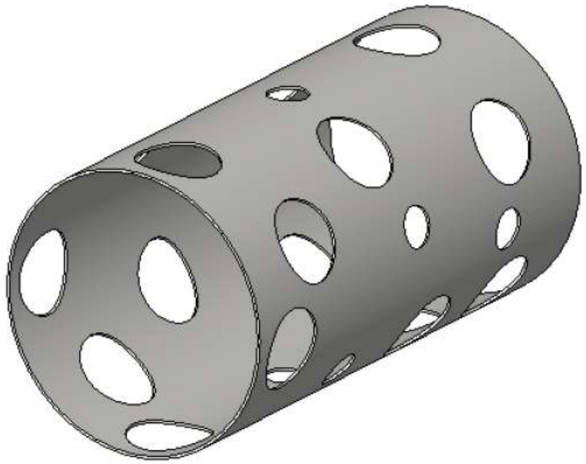
Costs

Additional cost are considered neglectable, since the armour layer is primarily adapted. This requires a design change but is not likely to result in a large increase in the construction cost. These cost are thus not provided.

Supplier

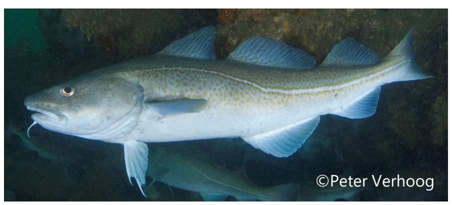
Quarry suppliers

Optimized scour protection layer Habitat pipes



Pipe 3D view

Policy-relevant species



Atlantic cod (*Gadus morhua*)

Poor cod (*Trisopterus minutus*)

Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)

Specifications

Steel pipes for which one of the pipe ends must always be accessible, and with at least four holes of at least 15 cm and at most 30 cm to guarantee water exchange. When placing habitat pipes on the scour protection, the stability and interface of these NID units and the interface with the armour layer should be considered for hydraulic loads. Therefore the pipes must be placed in T or X shape. This is preferred to more fragile and instable concrete pipes.

Suggested design

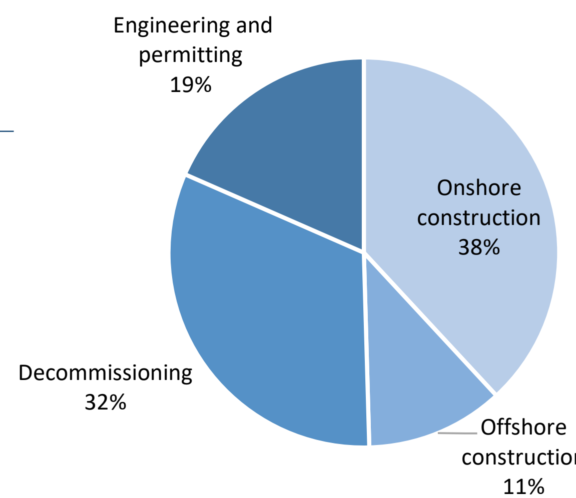
Length: 200 cm
Diameter: 100 cm
Number of holes: 25-50 (to enhance the effect on smaller mobile species (juvenile cod, crab)

Ecological benefits

Small holes allow for the movement of species in and out the pipes. The steel material allows for the settlement of other sessile species compared to for example concrete materials. However, steel is unsuitable for oyster settlement.

Costs

Onshore construction	€ 1,621
Offshore construction	€ 486
Decommissioning	€ 1,362
Engineering and permitting	€ 784



Supplier

n.a.

Optimized scour protection layer Fish hotel (WUR)

Policy-relevant species

Atlantic cod (*Gadus morhua*)

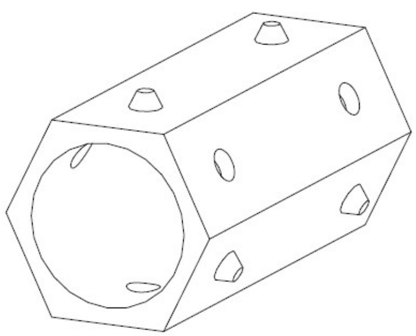
Juvenile poor cod (*Trisopterus minutus*)

Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)

Prof. Dr. Tinka Murk and Dr. Reindert Nijland (Wageningen University & Research) placed an artificial reef in the Haringvliet estuary to offer a hiding place for migratory fish.



3D VIEW FISH HOTEL (WUR)

Specifications

Concrete tubes which can be interlocked and stacked. Several tubes together forms a Fish Hotel. Structures can be stacked in different ways, allowing for a diverse design. The interlocking of the structures provides some stability for the artificial reef.

Design

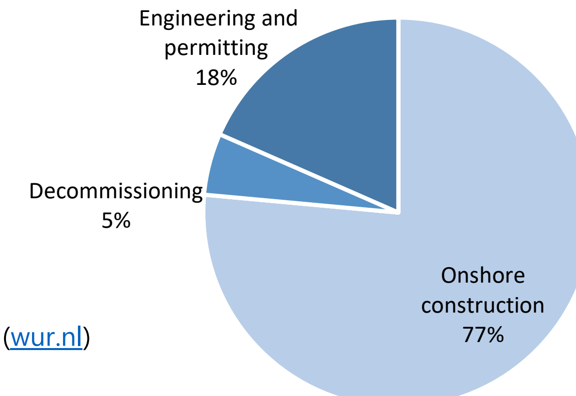
Length: 80 cm
Diameter: 36 cm
Small hole diameter: 10-15 cm
Minimum of tubes for a Fish hotels per location: 5

Ecological benefits

Cod hotels are primarily designed for cod. However, it also provides shelter for commercial species, like crab and lobster. Cod hotel is expected to increase the biomass of Atlantic cod, as well as poor cod and associated prey species. There is no information on the production of cod in OWF. The fish hotel shelters relatively large adults, which ensures a higher reproductive rate.

Costs

Onshore construction	€ 2,431
Offshore construction	€ 0
Decommissioning	€ 162
Engineering and permitting	€ 586



Supplier

Design by Wageningen University & Research (wur.nl)

Optimized scour protection layer Reefball® and Layer cakes

Policy-relevant species

Atlantic cod (*Gadus morhua*)

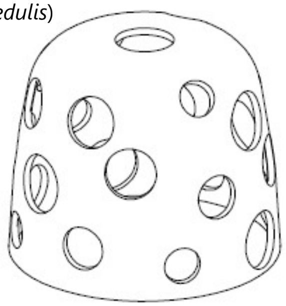
Juvenile poor cod (*Trisopterus minutus*)

European flat oyster (*Ostrea edulis*)

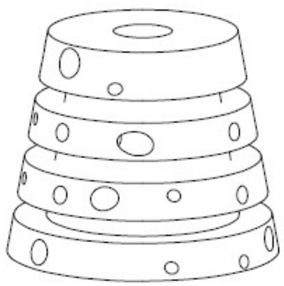
Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)



REEFBALL 3D VIEW



LAYER CAKES 3D VIEW

Specifications

Reef balls, either Goliath or Layered cake design, are reinforced concrete units. They are placed on the scour protection layer using a crane. They have interconnecting holes, aggregated exposed outside surface texture.

Design*

Height: 130 cm
Base diameter: 189 cm
Surface area 21 m^2
Weight: 2268 kg

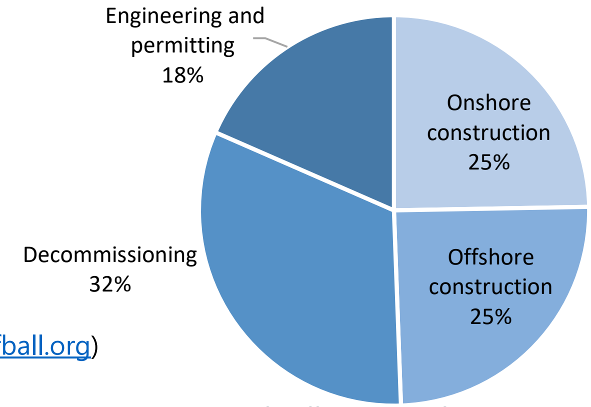
**design geometry can be modified to accommodate specific site conditions; suggested changes to the design include decrease in number of holes, including the top hole. The sizes of the holes should be adapted to accommodate the target species. Layered cake is preferred shape from the ecological perspective.*

Ecological benefits

The domed shaped structures create habitat serving as a shelter, feeding ground and/or nursery for target species. The layered structures are creating horizontal surface area and shelter for species such as lobsters and crabs, and growing habitat for oysters and other mollusks. The design provides a large surface area, in a relatively compact space. This ensures high food availability for target species.

Costs

Onshore construction	€ 1,621
Offshore construction	€ 1,621
Decommissioning	€ 2,107
Engineering and permitting	€ 1,209

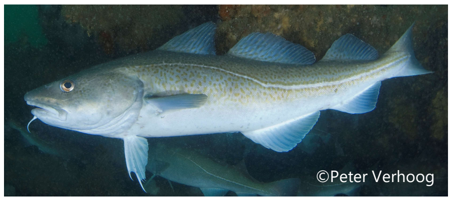


Supplier

Patented design by Reefball Foundation® (reefball.org)

Optimized scour protection layer Reef cube®

Policy-relevant species



Atlantic cod (*Gadus morhua*)

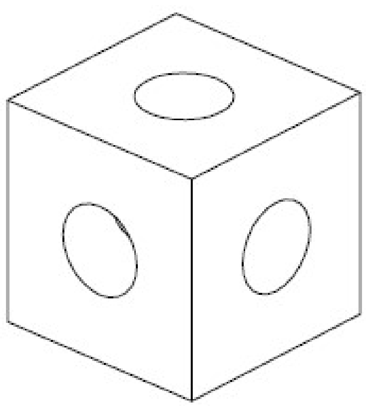
Juvenile poor cod (*Trisopterus minutus*)

European flat oyster (*Ostrea edulis*)

Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)



3D VIEW REEF CUBE

Specifications

Concrete structure which can be stacked and placed on seafloor. Structured can be placed individually or in groups. A large number (> 200) of structures could be placed around a monopile to create a reef structure. Modelling by the supplier suggests that the structures are relatively stable. Sizes can vary for different species.

Design (basic)

Dimensions: 50 cm x 50 cm x 50 cm
Hole diameter: 20 cm
Number of holes per cube: 6

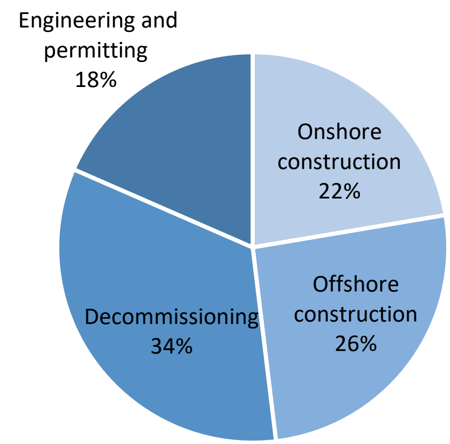
Ecological benefits

Structure with holes to provide shelter for small individuals. Observations show an increase in biodiversity one year after deployment. The Reef Cubes had already attracted serval mobile species, such as lobster and crab. The material is designed to enhance the settlement of European flat oysters on the structures.

Costs

Onshore construction	€ 1,407
Offshore construction	€ 1,621
Decommissioning	€ 2,107
Engineering and permitting	€ 1,161

Costs are based on 1 m^3 which consist of 8 units.



Supplier

Patented design by ARC Marine (arcmarine.co.uk)

Optimized scour protection layer 3D printed units

Policy-relevant species

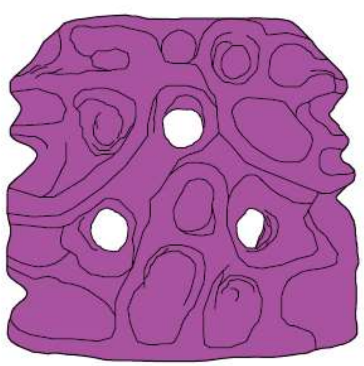
Atlantic cod (*Gadus morhua*)

European flat oyster (*Ostrea edulis*)

Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)



Schematic 3D view of one printed unit
(random shape)

Specifications

The 3D-printed units are made with sand and can be shaped in any desired shape. However, the units should be confinement within a 1.5 m^2 shape for efficient transport and placement. 3D printed units are placed on the outer rim of the scour protection post-installation using a crane. The structures are like Reef balls, with the added benefit that they can be designed in a great variety of shapes and have a lower environmental footprint.

Suggested design

Maximum base size: 1.5 m^2
Complex texture, randomly allocated holes fitting the size of target species.

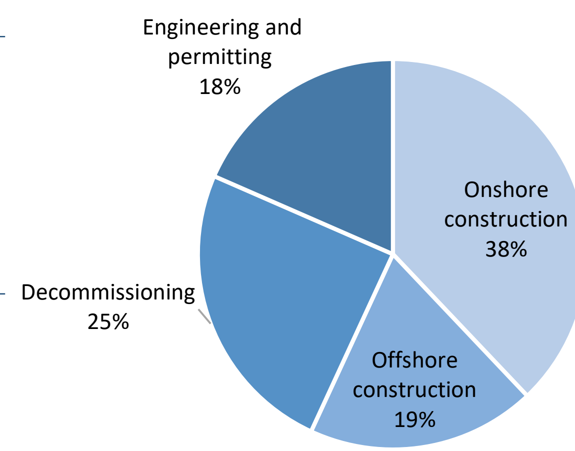
Ecological benefits

The 3D printed units will create a shelter habitat for a diversity of species and the shape can be altered to fit their needs. The structures provide habitat serving as a shelter, feeding ground and/or nursery for target species. The printed reefs are creating horizontal surface area for oysters and shelter for species such as lobsters and crabs. The design provides a large surface area in a relatively compact space. This ensures high food availability for target species.

Costs*

Onshore construction	€ 3,242
Offshore construction	€ 1,621
Decommissioning	€ 2,107
Engineering and permitting	€ 1,576

* This is an innovative technique; costs are highly dependent on its development

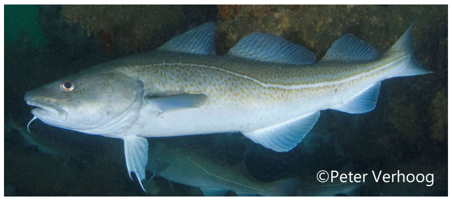


Supplier

n.a.

Optimized scour protection layer ECO Armour Block®

Policy-relevant species



Atlantic cod (*Gadus morhua*)

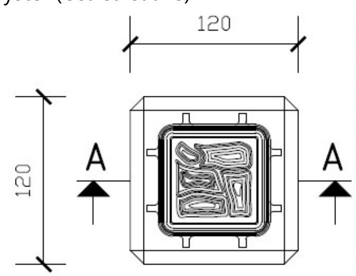
Juvenile poor cod (*Trisopterus minutus*)

European flat oyster (*Ostrea edulis*)

Commercial species

European lobster (*Homarus gammarus*)


Edible crab (*Cancer pagurus*)



FRONT VIEW ARMOUR BLOCK
Scale 1:25

Specifications

Concrete blocks with 10% ECO admix. This strengthens the concrete's compression forces and reduces the CO_2 footprint. It is also claimed to enhance settlement by sessile organisms. Can be lived from the top by a crane.

Design

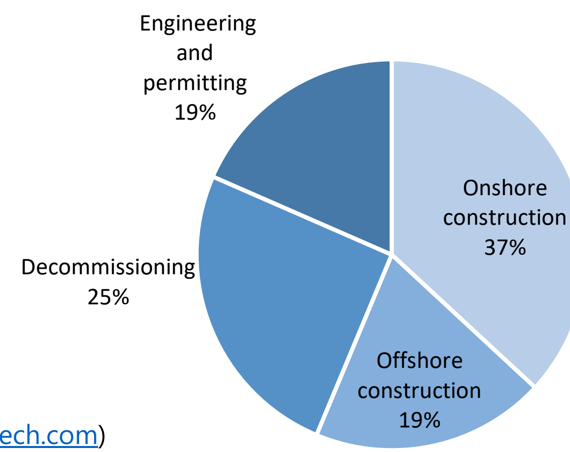
Height: 120 cm
Width: 120 cm
Depth: 120 cm

Ecological benefits

Structure with holes to provide shelter for small individuals. Allows for settlement of sessile organisms, like mollusc and oysters. The concreted mixture is adapted to enhance settlement. It is therefore expected that these structures will have a higher European flat oyster density compared to other NIDs.

Costs

Onshore construction	€ 3,080
Offshore construction	€ 1,621
Decommissioning	€ 2,107
Engineering and permitting	€ 1,539

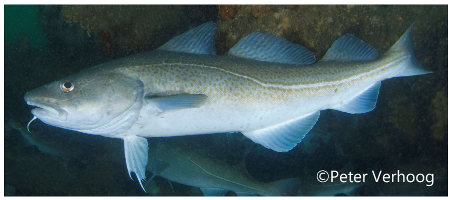


Supplier

Patented design by ECOncrete Tech (econcretetech.com)

Optimized scour protection layer Oyster gabions

Policy-relevant species



Atlantic cod (*Gadus morhua*)

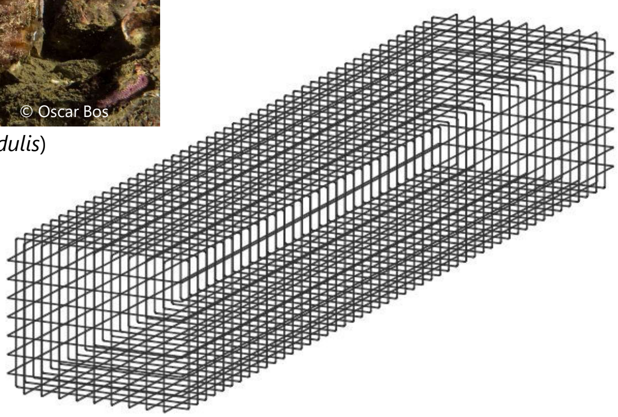
Juvenile poor cod (*Trisopterus minutus*)

European flat oyster (*Ostrea edulis*)

Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)



3D VIEW OYSTER GABION BASKET

Specifications

A mesh net cage placed directly on the armour layer of the scour protection, filled wit oyster shells. Mesh size not smaller than 5 cm x 5 cm to prevent shell from falling out. The structure is to be lowered with the crane and placed on the outer size of the armour layer of the scour protection.

Suggested design

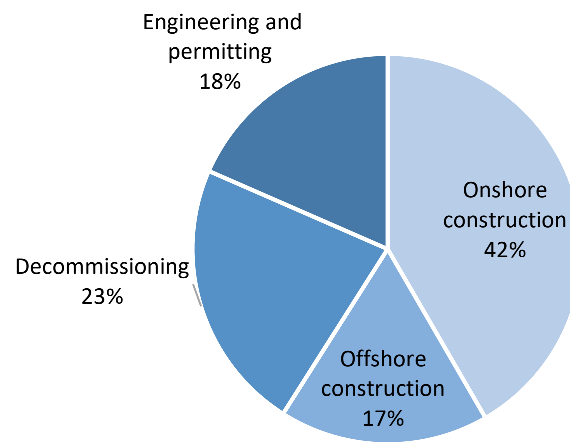
Length: 200 cm
Width: 150 cm
Hight: 40 cm
Mesh size: maximum 5 cm x 5 cm

Ecological benefits

The function of the oyster gabions is to create additional hard substrate suitable for oyster growth. However, it also creates shelter for small cod, crabs and lobsters. The function of the oyster gabions is to create additional hard substrate suitable for oyster growth. The species which will inhabit the gabions will provide nutrients to the target species

Costs

Onshore construction	€ 3,890
Offshore construction	€ 1,621
Decommissioning	€ 2,107
Engineering and permitting	€ 1,722



Supplier

n.a.

Category 3: Optimized cable protection

General description

Optimizing cable protection layer with hard substrate to provide shelter and nursery habitat for target species. Optimization can be made by adjusting currently used cable protection units. Several options available, depending on the standard practice and local conditions. Bags filled with quarry rocks with a well sorted grading and mesh size adjusted to accommodate target species. Matrasses with complex surface adjusted to accommodate target species.

Technical considerations

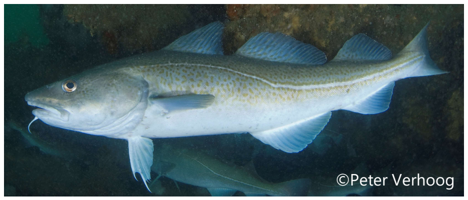
It is important that to note that these structure are an alternative form of cable protection. They should not deviate from this primarily function and thus be made location specific, depending on the morphodynamical conditions. The NID should be designed in such manner that no additional insulation of the cable is induced. Installation method depends on the chosen option. When designing an NID, it should be considered that maintenance can be carried out with a minimal amount of disruption to the NID, e.g. the ability to lift a cable mattress and place it adjacent to the cable during repairs and replacing it after completion.

Target species

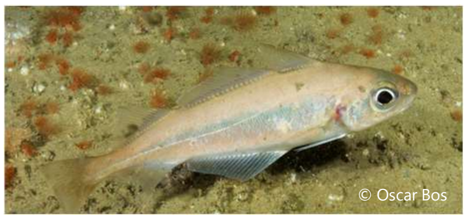
Juvenile cod *Gadus morhua*
Flat oyster *Ostrea edulis*
Lobster *Homarus gammarus*
Edible crab *Cancer pagurus*

Optimized cable protection Filter Unit®

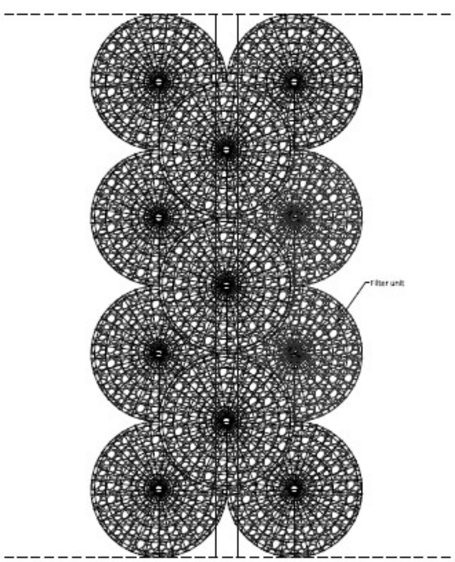
Policy-relevant species



Atlantic cod (*Gadus morhua*)



Poor cod (*Trisopterus minutus*)


TOP VIEW OF THE UNITS

Commercial species

European lobster (*Homarus gammarus*)


Edible crab (*Cancer pagurus*)

Specifications

Filter unit is a mesh net filled with rocks. They can be installed for a scour and/or cable protection or at cable crossings. Quarry rock with a well sorted grading of 40-200 kg. A polyester mesh is used.

Suggested design

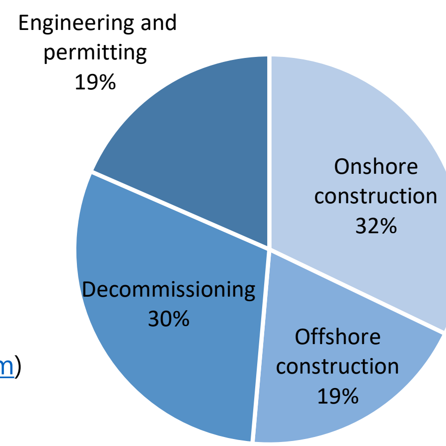
Grading: 40-200 kg
Crevice size of minimally 10 cm to 30 cm in diameter and 20 to 50 cm depth (to host juveniles of selected target species)

Ecological benefits

Filter units are usually placed for a structural function, but design should be optimized to fulfill ecological function as a habitat for juvenile fish and invertebrates. The surface of the filter units will be covered by diverse epifouling species. It thus not only provides shelter from predators, but also supports prey-predator interaction.

Costs

Onshore construction	€ 1,621
Offshore construction	€ 973
Decommissioning	€ 1,524
Engineering and permitting	€ 931

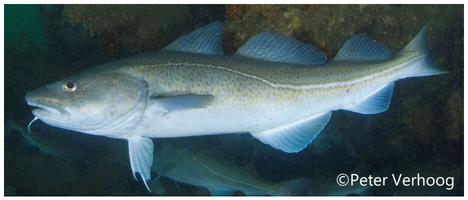


Supplier

Sumitomo Deutschland GmbH (sumitomo-filter-unit.com)

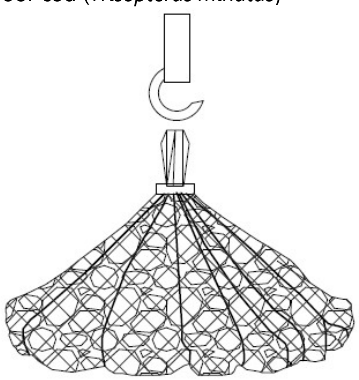
Optimized cable protection Basalt bags

Policy-relevant species



Atlantic cod (*Gadus morhua*)

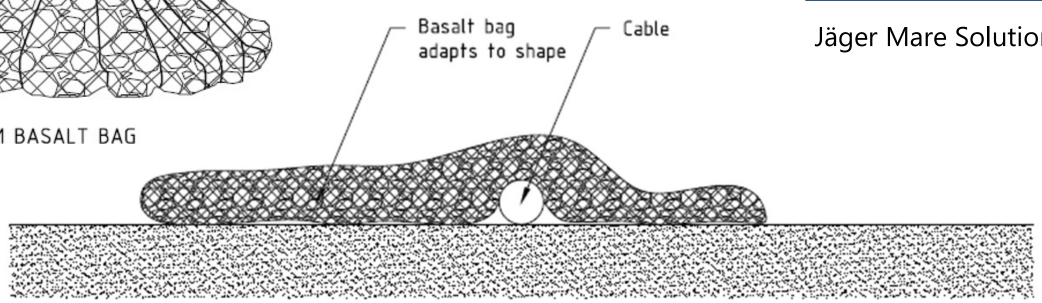
Poor cod (*Trisopterus minutus*)


MECHANISM BASALT BAG

Commercial species

European lobster (*Homarus gammarus*)


Edible crab (*Cancer pagurus*)



FRONT VIEW BASALT BAG

Specifications

Basalt bags are mesh nets filled with rocks which can lay on top of cables. They are slightly flexible in their structure. Quarry rock with a well sorted grading of 40-200 kg. A basalt mesh is used.

Suggested design

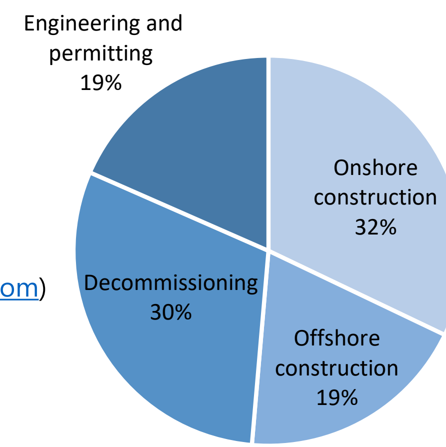
Grading: 40-200 kg
Crevice size of minimally 10 cm to 30 cm in diameter and 20 cm to 50 cm depth (to host juveniles of selected target species)
Additional benefit is a mesh made of basalt and therefore considered more ecologically friendly.

Ecological benefits

Basalt bags create crevices of varying sizes which provide shelter for juvenile Atlantic cod, edible crab and European lobster. Additionally, other species will inhabit the bags, creating an artificial reef. This increases both prey and predator biomass.

Costs

Onshore construction	€ 1,621
Offshore construction	€ 973
Decommissioning	€ 1,524
Engineering and permitting	€ 931



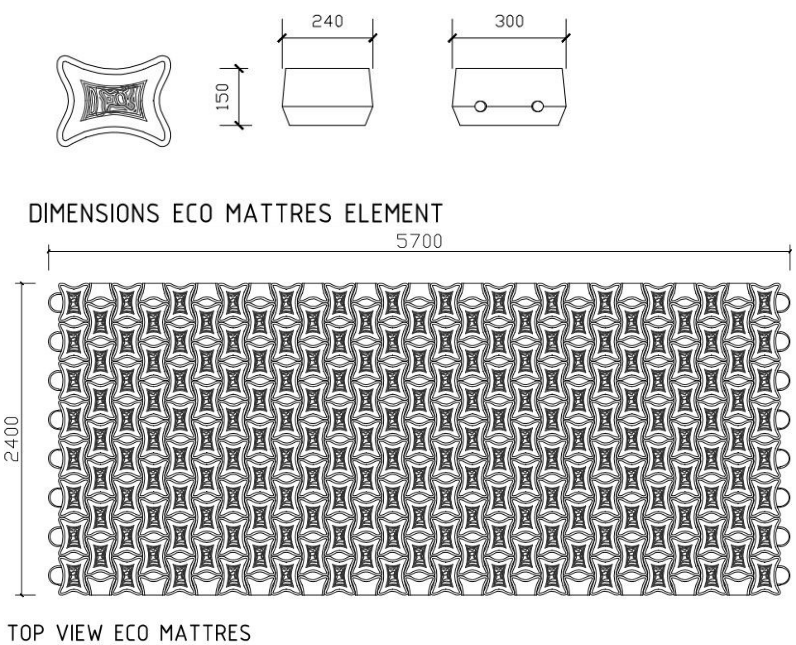
Supplier

Jäger Mare Solutions GmbH (jaeger-maresolutions.com)

Optimized cable protection ECO Mats®

Policy-relevant species

European flat oyster (*Ostrea edulis*)



Specifications

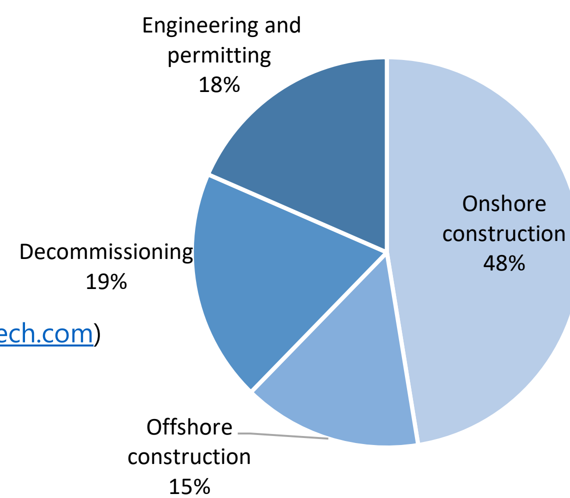
Mattresses which can be used for cable protection. The mattresses are comprised of separate concrete units. The units are links resulting in a flexible structure which can be placed on top of cables. ECOncrete®'s admix, added as ~10% of the cement content in the mix, strengthens the concrete's compression forces and reduces the CO_2 footprint. It is also claimed to enhance settlement by sessile organisms.

Ecological benefits

ECO mats provide substrates for a wide range of species and in particular the European flat oyster. This is attributed to the concrete mixture which is applied. As the mats are placed on top of other structures, they create holes of varying sizes.

Costs

Onshore construction	€ 5,187
Offshore construction	€ 1,621
Decommissioning	€ 2,107
Engineering and permitting	€ 2,016



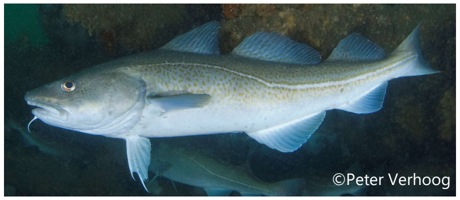
Supplier

Patented design by ECOncrete Tech (econcretetech.com)

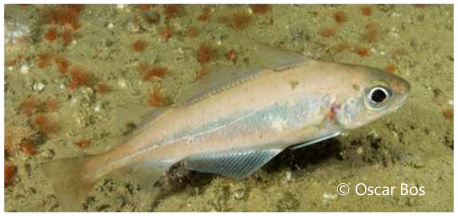
Witteveen Bos
WAGENINGEN UNIVERSITY & RESEARCH

Optimized cable protection Reef cube® bag™

Policy-relevant species



Atlantic cod (*Gadus morhua*)



Poor cod (*Trisopterus minutus*)

Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)

Specifications

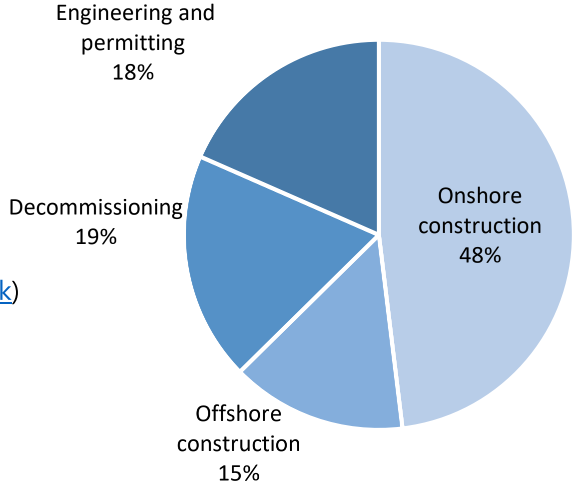
Reef cubes (see details for Reef Cubes) placed in a cage-like structure on top of cables to function as cable protection. Reef cube uses low carbon alkali activated materials. The cubes could provide a more homogenous structure compared to the filter unit and basalt bags.

Ecological benefits

Reef cube provides shelter for juvenile Atlantic cod, edible crab and European lobster. It also provides substrates for sessile species, which are predated on by larger organisms. This effect increases the biomass of the target species.

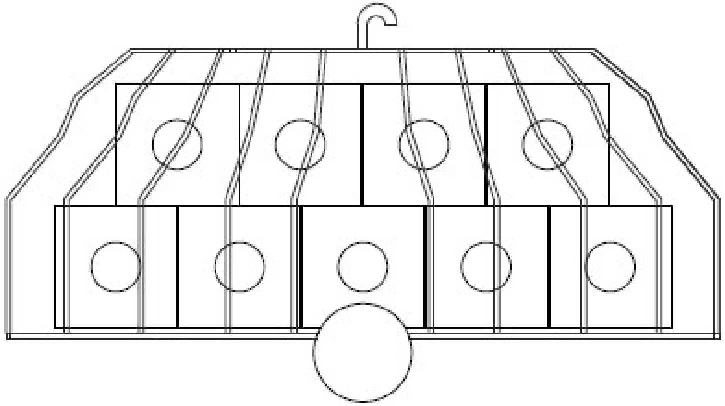
Costs

Onshore construction	€ 5,349
Offshore construction	€ 1,621
Decommissioning	€ 2,107
Engineering and permitting	€ 2,052

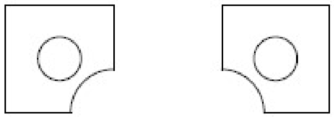


Supplier

Patented design by ARC Marine (arcmarine.co.uk)



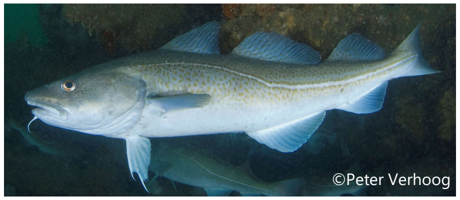
FRONT VIEW REEF CUBE FILTER BAGS (5X4)

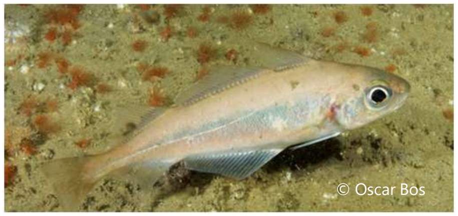


SPECIAL REEF CUBE FILTER BAGS (5X4)

Optimized cable protection Reef cube® matt™

Policy-relevant species


Atlantic cod (*Gadus morhua*)


Poor cod (*Trisopterus minutus*)


European flat oyster (*Ostrea edulis*)

Commercial species


European lobster (*Homarus gammarus*)


Edible crab (*Cancer pagurus*)

Specifications

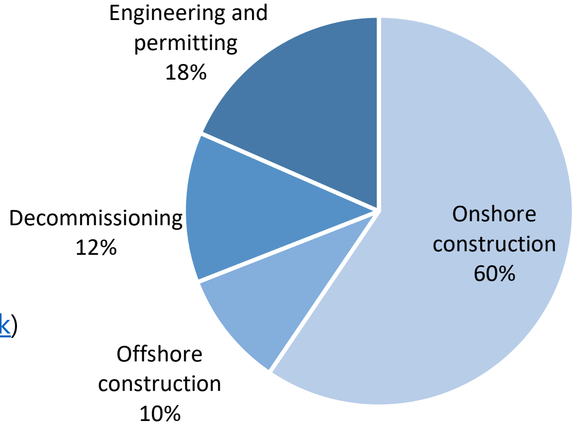
Flexible mattresses made of Reef cubes. Reef cube is a low carbon alkali activated material. See details under Reef cube.

Ecological benefits

Allows for the settlement of sessile organisms. These provide nutrients for edible crabs and European lobsters, increasing their biomass. Small individuals (juveniles) can also seek shelter in the smaller crevices created in and between the reef cubes.

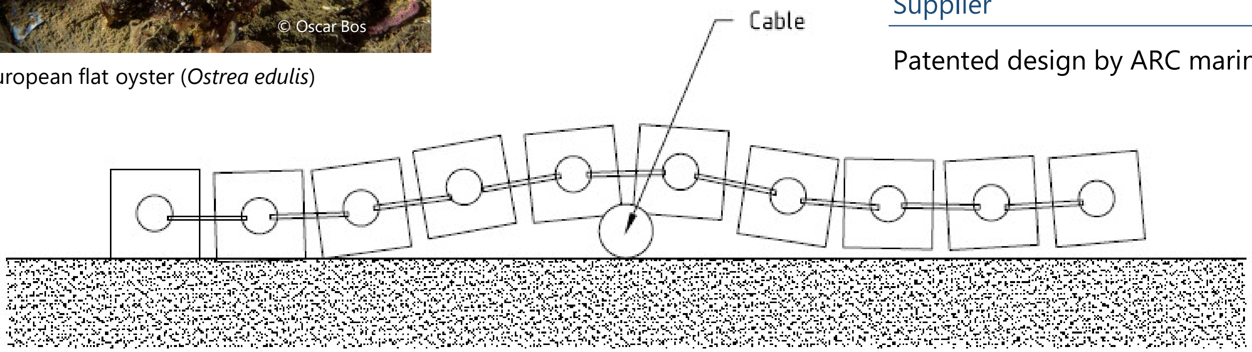
Costs

Onshore construction	€ 10,050
Offshore construction	€ 1,621
Decommissioning	€ 2,107
Engineering and permitting	€ 3,115



Supplier

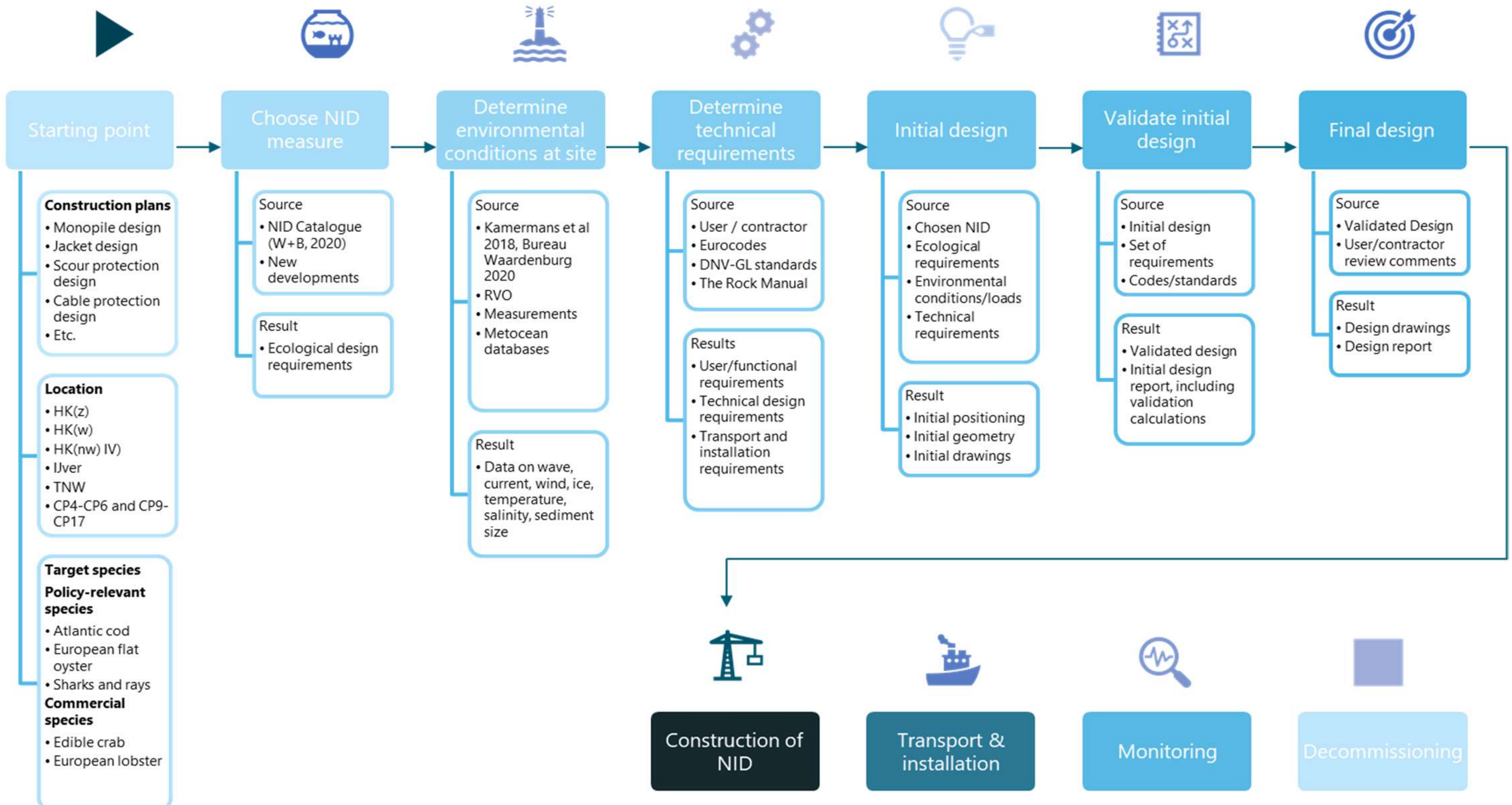
Patented design by ARC marine (arcmarine.co.uk)



FRONT VIEW REEF CUBE MATRESS

Nature Inclusive Design plan process

The NID options presented in this catalogue are by design an addition to or, alteration of the primary offshore structure. A detailed design process is required, showing for each step the *source* of the required information as well as the intended *result* from this step.



Witteveen+Bos WAGENINGEN UNIVERSITY & RESEARCH

Every NID option carries certain technical and ecological risks that have to be considered from an early phase (design) and monitored in the later phase (operational) in order to properly mitigate these risks and prevent negative consequences. During the expert consultations, the top five technical (T 1-5) and top five ecological (E 1-5) risks were identified.

#		Risk description	Cause	Consequences	Likelihood	Technical impact	Potential ecological impact	Risk	Mitigation measures
T-1	Technical	Structural failure of primary structure	Uncertainties in the environmental loads	(Temporary) loss of function	2 small	5 very high	1 neutral	Medium	Periodic inspection and scheduled maintenance
T-2	Technical	Structural failure of NID	Uncertainties in the environmental loads	Damaging primary structure	3 average	4 high	3 negative	High	Periodic inspection, repairments, removal of NID
T-3	Technical	Biofouling	Settlement of non-organisms on structures	Additional drag, blocking of habitat by non-target species	4 high	4 high	2 small negative	High	Account for in design, periodic inspection and removal of NID if required
T-4	Technical	Design failure in placement phase	Environmental circumstances different than expected, use of sub-optimal equipment	Damage to primary structure, improper placement	2 small	4 high	2 small negative	Medium	Correct weather window, detailed morphological survey, optimal equipment
T-5	Technical	Unforeseen costs	Uncertainties, lack of experience	Overdimensioning	4 high	1 neutral	1 neutral	Low	Interdisciplinary collaboration, contact regulatory bodies, financial buffer
E-1	Ecological	Lack of ecological success	Uncertainties, lack of experience, unpredictable environmental factors	Resources wasted and NID reputation damage	4 high	1 neutral	3 negative	Medium	No regret measure, define goals of pilot accordingly
E-2	Ecological	Settlement of non-indigenous species	(non specific) artificial structures	No or smaller population of indigenous (target) species	4 high	1 neutral	3 negative	Medium	Specify design for target species, stock enhancement of target species
E-3	Ecological	Competition between target species	Overlapping habitat, predation	Increased mortality target species	4 high	1 neutral	1 neutral	Low	Gain experience
E-4	Ecological	Absence of target species	Lack of stock population, unsuitable environment, lack of settlement cues from environment	Limited biological impact	4 high	1 neutral	1 neutral	Low	Site assessment, stock enhancement
E-5	Ecological	Food limitation for target species	Competition for food, limited biological activity	Decreased settlement success	3 average	1 neutral	3 negative	Medium	Site selection, baseline monitoring

Nature-Inclusive Design: a catalogue for offshore wind infrastructure

Witteveen+Bos
Wageningen Marine Research

Nature Inclusive Design references for selected NID options

Category	NID option	Top 5 references	Link
1. Add-on option	Biohut®	Bouchoucha et al. 2016	https://doi.org/10.3354/meps11641
		Mercader, Mercière, et al. 2017	https://doi.org/10.1016/j.ecoleng.2017.03.022
		Selfati et al. 2018	https://doi.org/10.1016/j.biocon.2018.01.013
		Mercader, Fontcuberta, et al. 2017	https://doi-org/10.1007/s12526-016-0498-x
		Lossent et al. 2018	https://doi.org/10.1121/1.5068272
	Cod hotel (cotel)	n.a. (first pilot in HKZ Beta substation)	
2. Optimized scour protection layer	Optimized scour protection	Rozemeijer et al. 2016	https://library.wur.nl/WebQuery/wurpubs/522329
		Rozemeijer & Van de Wolfshaar, 2019	https://doi.org/10.18174/466861
		Van Duren et al. 2017	http://publications.deltares.nl/1221293_000_Eng.pdf
		Lengkeek et al. 2017	https://edepot.wur.nl/411374
		Degraer, Brabant, Rumes, & Vigin, 2018	https://odnature.naturalsciences.be/downloads/mumm/windfarms/winmon_report_2018_final.pdf
	Habitat pipes	see site decision for HK(n) Wind Farm site V	https://www.rvo.nl/sites/default/files/2019/05/stcrt-2019-24545.pdf
	Reefball® and Layer cakes	Meesters, Smith, & Becking, 2013	https://library.wur.nl/WebQuery/wurpubs/fulltext/333153
		Folpp et al. 2013	https://doi.org/10.1371/journal.pone.0063505
		Vlaams Insituut voor de Zee, 2014	http://www.vliz.be/en/2014-04-23-artificial-reefs
		Dos Santos, Brotto, & Zalmon, 2010	https://doi.org/10.1016/j.jembe.2010.01.018
		Sisson & Shen, 2012	https://doi.org/10.21220/V5TB4S
	Reef cube®	Liu et al. 2012	https://doi.org/10.1080/19942060.2012.11015440
		Lindberg et al. 2006	https://doi.org/10.1890/1051-0761(2006)016[0731:DHSAPB]2.0.CO;
		COAST laboratory, 2018	https://www.plymouth.ac.uk/research/esif-funded-projects/arc-marine-a-case-studyhttps://doi.org/10.1007/s00338-018-1690-1
		Moustaka et al. 2018	
		Rifqi Fauzi et al. 2017	https://doi.org/10.12962/j23546026.y2017i6.3284
	3D printed units	see Reefball®	
	Eco armour block®	Dennis et al. 2018	https://doi.org/10.1016/j.ecoleng.2017.05.031
		Sella & Perkol-Finkel, 2015	https://doi.org/10.1016/j.ecoleng.2015.09.016
		Perkol-Finkel, et al. 2019	https://search.informit.com.au/documentSummary;dn=800571314459488;res=IELENG
		Abdo, Perkol-Finkel & Gonzalez, 2015	http://harborseals.org/wp-content/uploads/2015/03/150527_econceteresearchpaper_tahirah_abdo.pdf
	Cod hotel (Cotel)	see above	
3. Optimized cable protection layer	Rock/filter and basalt bags	see suppliers' brochures	https://rockbags.co.uk/wp-content/uploads/2018/02/Filter-Unit-Civil-Engineering-pamphlet-Ridgeway.pdf https://www.jaegergroup.com/en/products/green-products/marine-technology/scour-protection/
	Eco mats®	See Eco armour block®	
	Reef cube matt™	See Reef cube®	

Abdo T, Perkol-Finkel S, Gonzalez M (2015). The Effects of Different Types of Concrete Compositions on Benthic Organisms under an Ecodock. Marine Biology research programme, New York.

Bouchoucha M Darnaude AM, Gudefin A, Neveu R, Verdoit-Jarraya M, Boissery P, Lenfant P (2016). Potential use of marinas as nursery grounds by rocky fishes: insights from four *Diplodus* species in the Mediterranean. Marine Ecology Progress Series, 547, 193–209.

Degraer S, Brabant R, Rumes B, Vigin L (2018). Environmental impacts of offshore wind farms in the Belgian part of the North Sea: assessing and Managing Effect Spheres of Influence. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, 136 p.

Dennis HD, Evans AJ, Banner AJ, Moore, P. J. (2018). Reefcrete: Reducing the environmental footprint of concretes for eco-engineering marine structures. Ecological Engineering, 120, 668–678.

dos Santos LN, Brotto DS, Zalmon IR (2010). Fish responses to increasing distance from artificial reefs on the Southeastern Brazilian Coast. Journal of Experimental Marine Biology and Ecology, 386(1–2), 54–60.

Folpp H, Lowry M, Gregson M, Suthers IM (2013). Fish Assemblages on Estuarine Artificial Reefs: Natural Rocky-Reef Mimics or Discrete Assemblages? PLoS ONE, 8(6), e63505.

Lengkeek W, Didderen K, Teunis M, Driessen F (2017). Eco-friendly design of scour protection: potential enhancement of ecological functioning in offshore wind farms. Towards an implementation guide and experimental set-up (http://edepot.wur.nl/411374). Bureau Waardenburg. Report 17-001

Lindberg WJ, Frazer TK, Portier KM, Vose F, Loftin J, Murie DJ, … Hart MK (2006). Density-Dependent Habitat Selection And Performance By A Large Mobile Reef Fish. Ecological Applications, 16(2), 731–746.

Liu Y, Guan CT, Zhao YP, Cui Y, Dong GH (2012). Numerical Simulation and PIV Study of Unsteady Flow Around Hollow Cube Artificial Reef with Free Water Surface. Engineering Applications of Computational Fluid Mechanics, 6(4), 527–540.

Lossent J, Gudefin A, Gervaise C, Foncuberta A, Gilles L, Iorio LD (2018). Acoustic signature and footprint of artificial nurseries in harbors. The Journal of the Acoustical Society of America, 144(3), 1887–1887.

Meesters EHWG, Smith SR, Becking LE (2013). A review of coral reef restoration techniques. IMARES (Report / IMARES Wageningen UR C028/14).

Mercader M, Fontcuberta A, Mercière A, Saragoni G, Boissery P, Bérenger L, … Lenfant P (2017). Observation of juvenile dusky groupers (*Epinephelus marginatus*) in artificial habitats of North-Western Mediterranean harbors. Marine Biodiversity, 47(2), 371–372.

Mercader M, Mercière A, Saragoni G, Cheminée A, Crec'hriou R, Pastor J, … Lenfant P (2017). Small artificial habitats to enhance the nursery function for juvenile fish in a large commercial port of the Mediterranean. Ecological Engineering, 105, 78–86.

Moustaka M, Langlois TJ, Mclean D, Bond T, Fisher R, Fearns P, … Evans RD (2018). The effects of suspended sediment on coral reef fish assemblages and feeding guilds of north-west Australia. Coral Reefs, 37.

Perkol-Finkel S, Sella I, Rella A, Musella R, Moriarty D (2019). Bringing concrete to life: Harnessing biological processes for building resilient ports and coastal infrastructure. Engineers Australia. Australasian Coasts and Ports 2019 Conference: Hobart, 10-13 September 2019.

Rifqi Fauzi MA, Armono HD, Mustain M, Amalia AR (2017). Comparison Study of Various Type Artificial Reef Performance in Reducing Wave Height. IPTEK Journal of Proceedings Series, 3(6).

Rozemeijer MJC, Slijkerma, D, Bos OG, Röckmann C, Paijmans AJ, Kamermans P (2016). Bouwen met Noordzee-natuur Uitwerking Gebiedsagenda Noordzee 2050. Wageningen Marine Research (Wageningen Marine Research rapport C024/17).

Rozemeijer MJC, Van de Wolfshaar KE (2019) Desktop study on autecology and productivity of European lobster (*Homarus gammarus*, L) in offshore wind farms (https://doi.org/10.18174/466861). Wageningen Marine Research. Report C109/18.

Selfati M, El Ouamari N, Lenfant P, Fontcuberta A, Lecaillon G, Mesfioui A, … Bazairi H (2018). Promoting restoration of fish communities using artificial habitats in coastal marinas. Biological Conservation, 219, 89–95.

Sella I, Perkol-Finkel S (2015). Blue is the new green - Ecological enhancement of concrete based coastal and marine infrastructure. Ecological Engineering, 84, 260–272.

Sisson M, Shen J (2012). Modeling of Oyster Larval Connectivity for CBF in Support of NOAA'S Co. Retrieved February 24, 2020, from https://scholarworks.wm.edu/reports/1083/

Van Duren veld M, Osinga R, Cado van der Lelij JA, De Vries MB (2017). Rich Reefs in the North Sea Exploring the possibilities of promoting the establishment of natural reefs and colonisation of artificial hard substrate. Delft, the Netherlands: Deltares http://publications.deltares.nl/1221293_000_Eng.pdf