Nature-Inclusive Design: a catalogue for offshore wind infrastructure

Witteveen + Bos

WAGENINGEN UNIVERSITY & RESEARCH

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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	

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.

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.

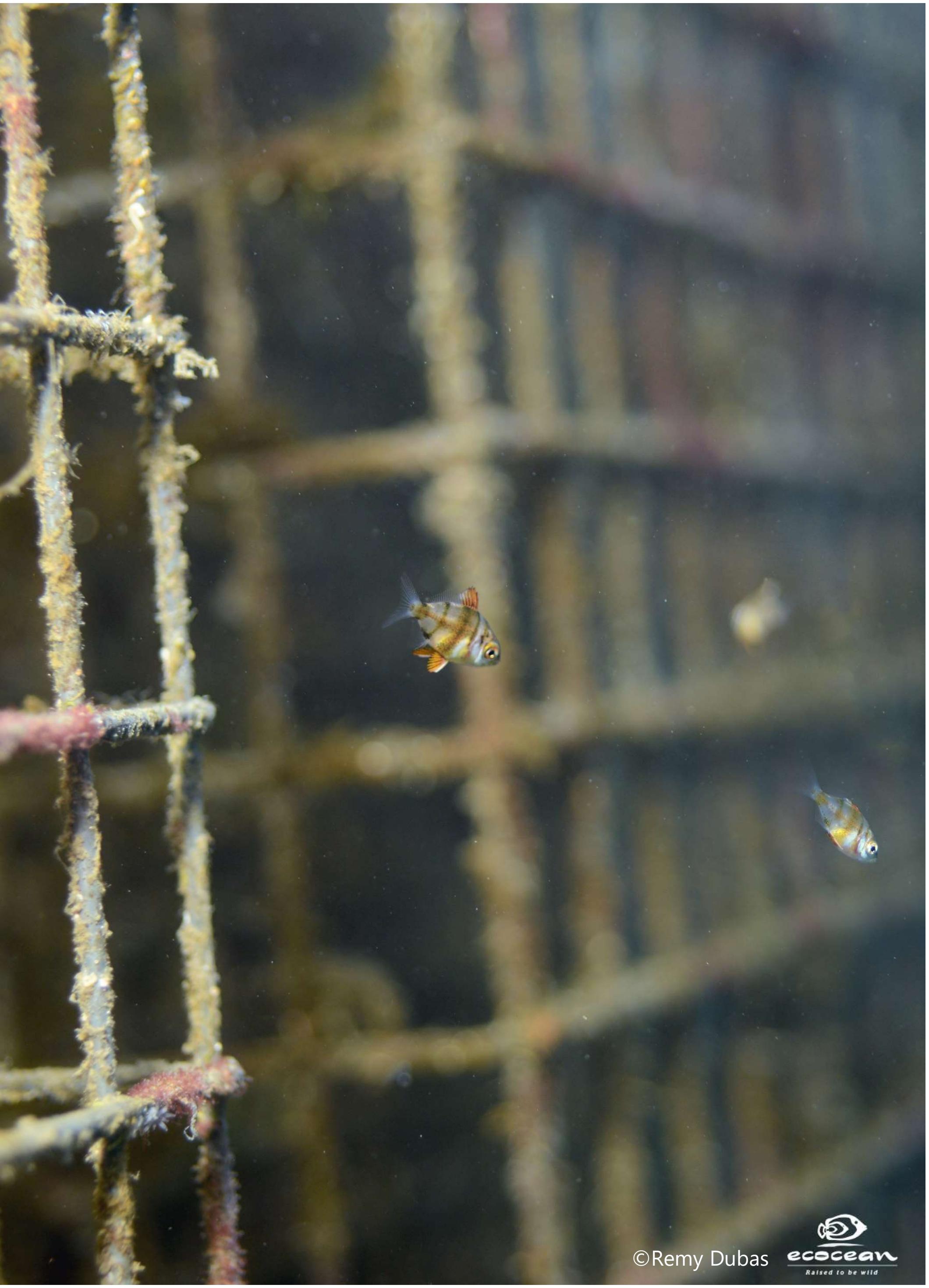
			Policy-relevant species			Commercial species	
			Atlantic cod	Poor cod	European flat oyster	Edible crab	European lobster
1	Add-on options	Biohut®	N	N			
		Cod hotel (Cotel)	S/N	S/N			
2	Optimized scour protection layer	Additional rock layer	S/N	S/N	As	S/N	S/N
		Adapted grading armour layer	N	N	As	S/N	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

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

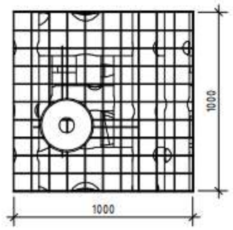
Atlantic cod *Gadus morhua*
Poor cod *Trisopterus minutus*

Add-on options Cod hotel (Cotel)

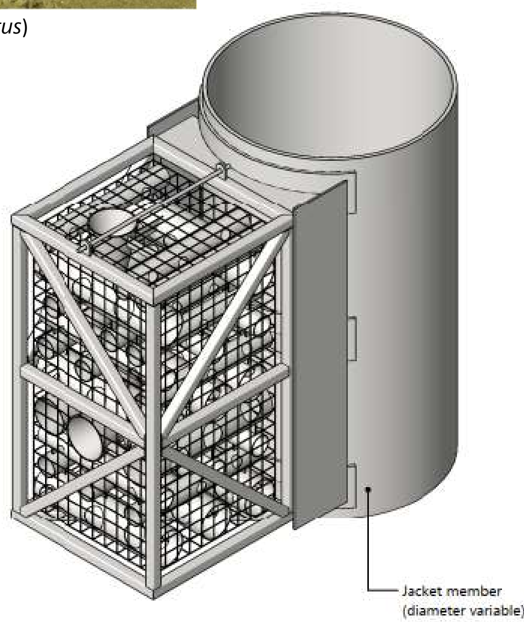
Policy-relevant species

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

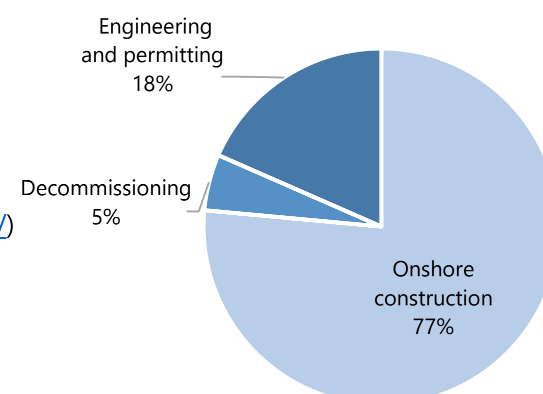
Saddle: height 2.3 m x width 1.2 m
Structural frame: height 2 m x width 1 m x 1 m
Steel gabion basket: height 2 m x width 1 m x 1 m
Mesh size: larger than 5 cm x 5 cm and smaller than 10 cm x 10 cm
Perforated tubes of 1 to 2 m with varying diameters (e.g. from 13 cm to 25 cm)
Perforations on the tubes 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



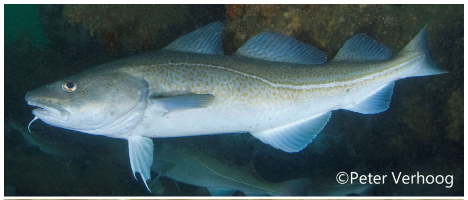
Design

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

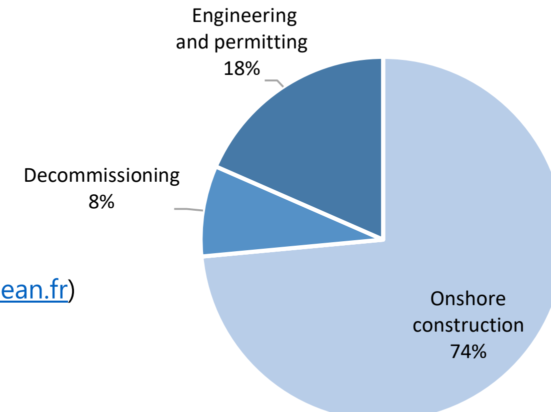
**Detailed structural design is required to withstand the governing loads of a Biohut modification for a jacket.*

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.

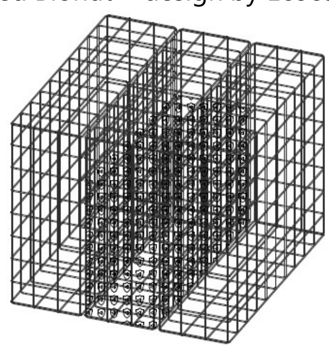
Costs (as per modification above)

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



Design

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



3D VIEW BIOHUT
Scale 1:10

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

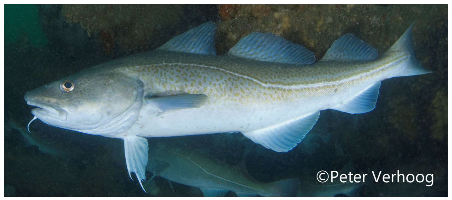
Made location specific, depending on the morphodynamic conditions. When adjusting (sections of) the scour protection, the maximum boulder size should be considered to allow pile driving for installation of the monopile. Internal stability of armour layer in relation to larger rock grading used to increase 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



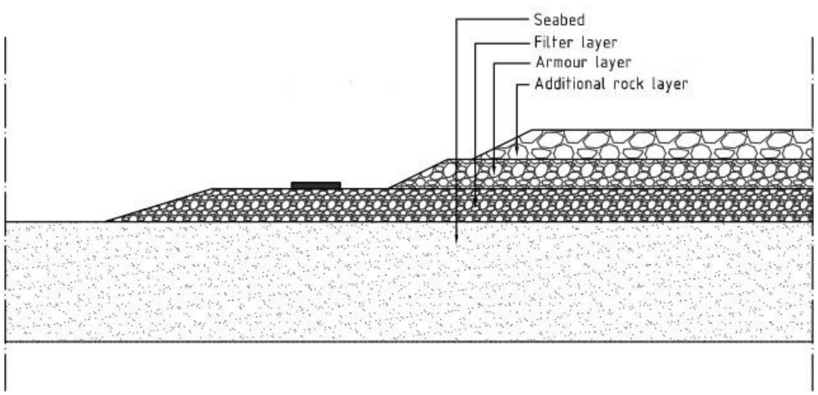
Atlantic cod (*Gadus morhua*)

Juvenile poor cod (*Trisopterus minutus*)

Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)



ADDITIONAL ROCK LAYER

Specifications

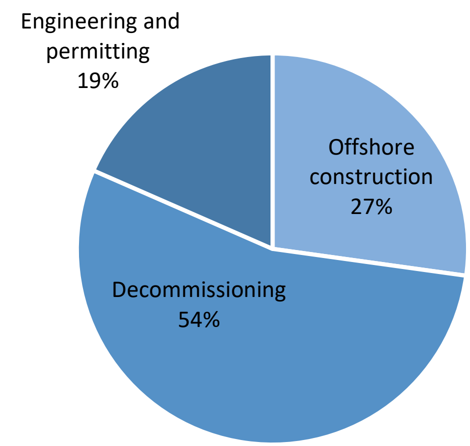
Minimum surface to be covered is 20% of the total scour protection layer. Additional layer of rocks with adjusted grading of e.g. 40-200 kg placed at the standard scour protection layer. crevices minimum of 10 cm to a maximum of 30 cm in diameter and a minimum of 20 cm to a maximum of 50 cm deep. Design 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

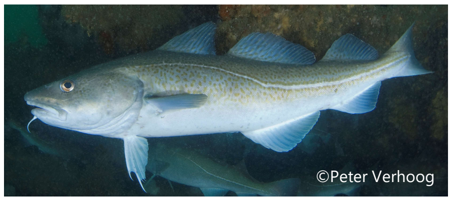


Supplier

Quarry suppliers

Optimized scour protection layer Adapted grading armour layer

Policy-relevant species



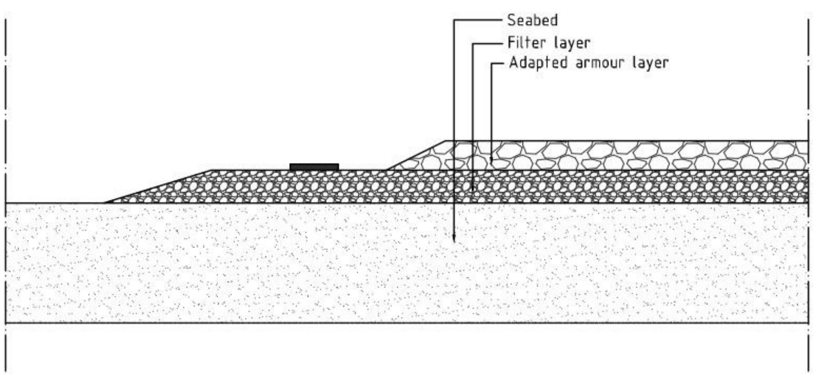
Atlantic cod (*Gadus morhua*)

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.

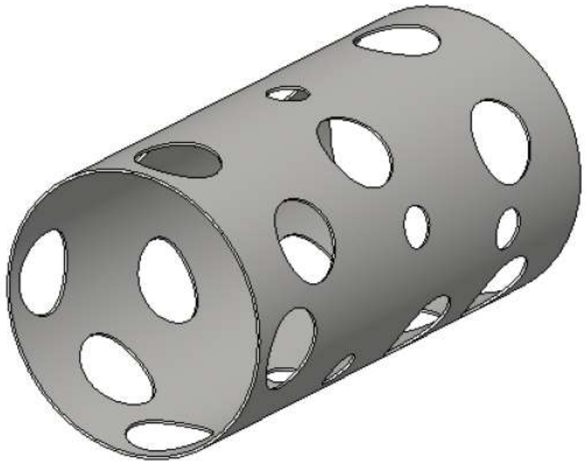
Costs

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

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.

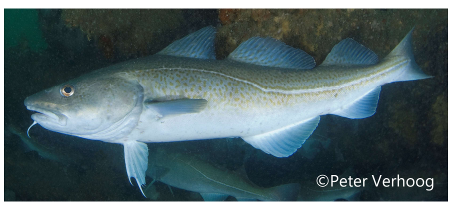
Suggested design

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.

Policy-relevant species



Atlantic cod (*Gadus morhua*)

Poor cod (*Trisopterus minutus*)

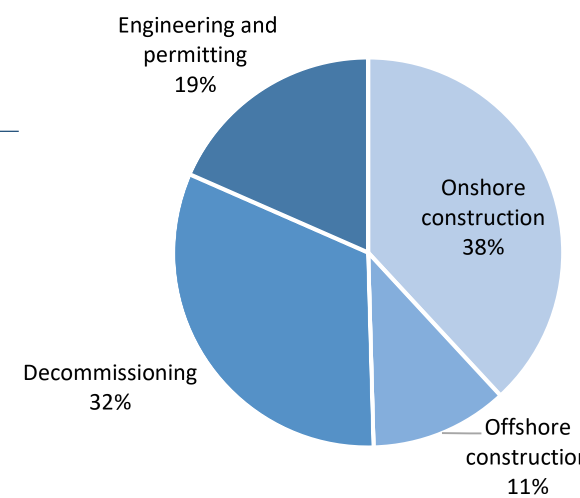
Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)

Costs

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



Supplier

n.a.

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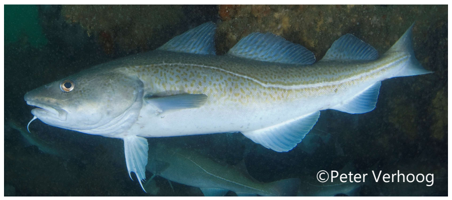
Optimized scour protection layer Fish hotel (WUR)

Policy-relevant species



Atlantic cod (*Gadus morhua*)

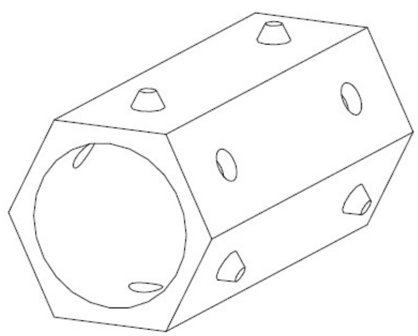
Juvenile poor cod (*Trisopterus minutus*)

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

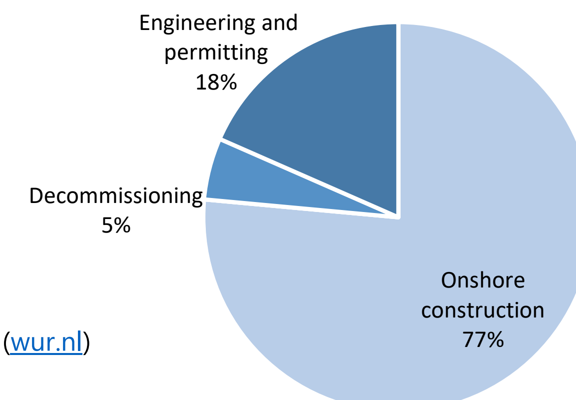
Length: 80 cm
Diameter: 36 cm
Small hole diameter: 10-15 cm
Minimum of tubes for a Fish hotels per location: 5

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

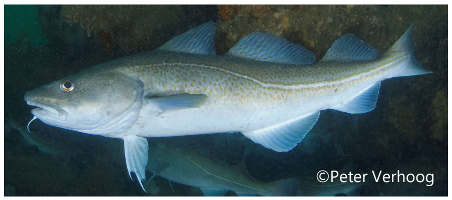


Supplier

Design by Wageningen University & Research (wur.nl)

Optimized scour protection layer Reefball® and Layer cakes

Policy-relevant species



Atlantic cod (*Gadus morhua*)

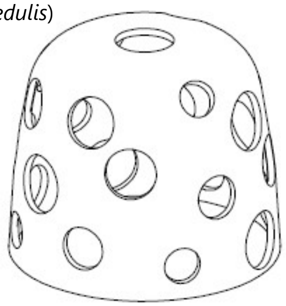
Juvenile poor cod (*Trisopterus minutus*)

European flat oyster (*Ostrea edulis*)

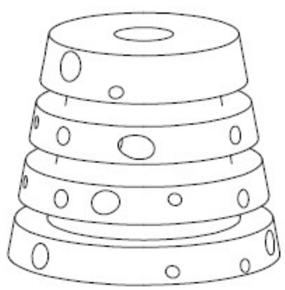
Commercial species

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

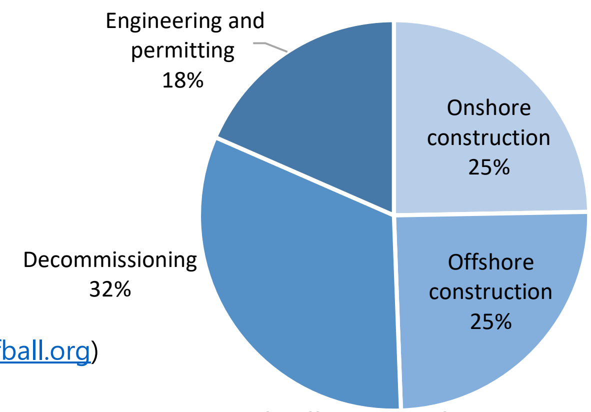
**design geometry can be modified to accommodate specific site conditions; suggested changes to the design include decrease in number of holes, including the top hole. The sizes of the holes should be adapted to accommodate the target species. Layered cake is preferred shape from the ecological perspective.*

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



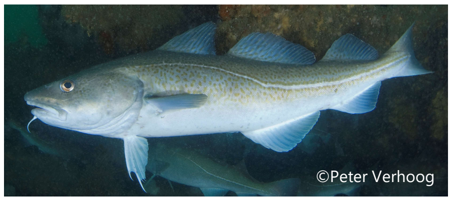
Supplier

Patented design by Reefball Foundation®(reefball.org)

Witteveen+Bos WAGENINGEN UNIVERSITY & RESEARCH

Optimized scour protection layer Reef cube®

Policy-relevant species



Atlantic cod (*Gadus morhua*)

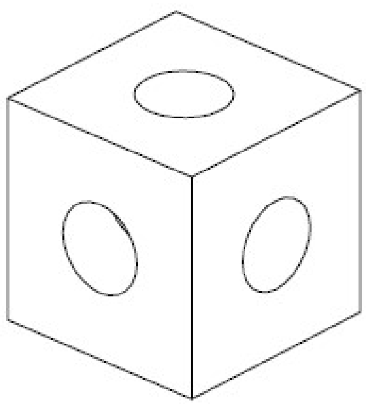
Juvenile poor cod (*Trisopterus minutus*)

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

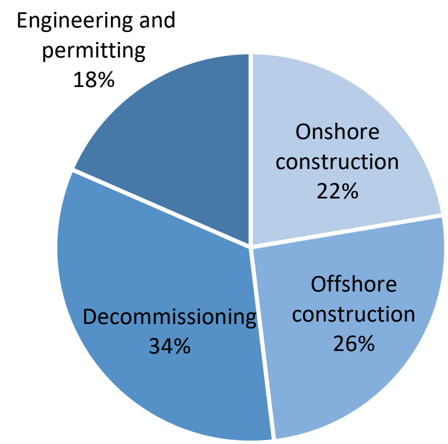
Ecological benefits

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

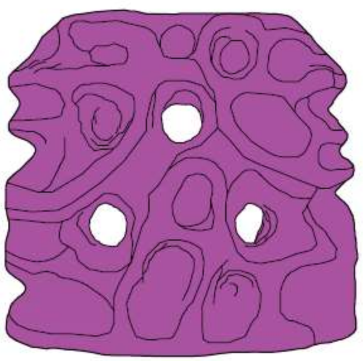
Atlantic cod (*Gadus morhua*)


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.

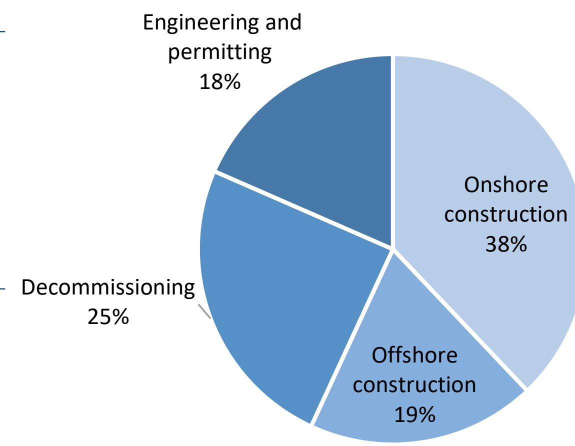
Ecological benefits

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

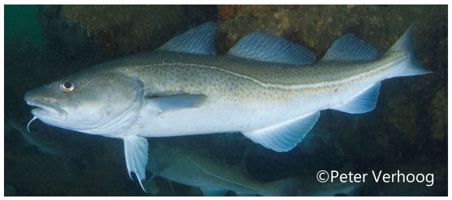


Supplier

n.a.

Optimized scour protection layer ECO Armour Block®

Policy-relevant species



Atlantic cod (*Gadus morhua*)

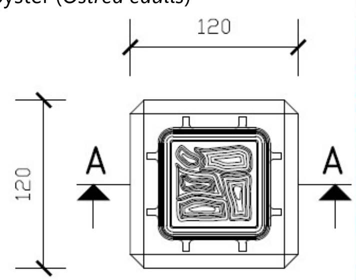
Juvenile poor cod (*Trisopterus minutus*)

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

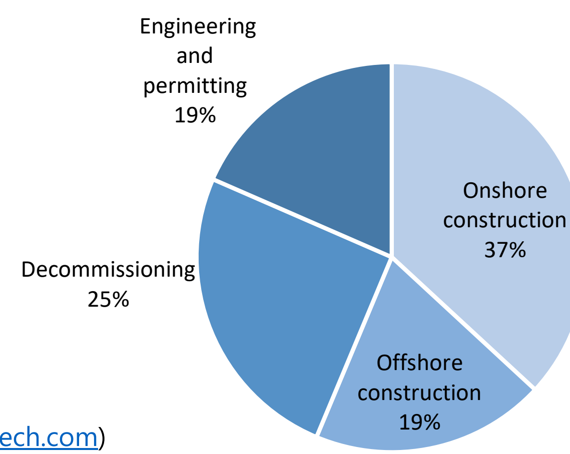
Height: 120 cm
Width: 120 cm
Depth: 120 cm

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

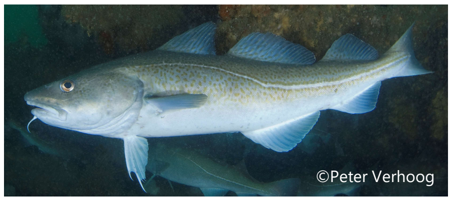


Supplier

Patented design by ECOncrete Tech (econcretetech.com)

Optimized scour protection layer Oyster gabions

Policy-relevant species



Atlantic cod (*Gadus morhua*)

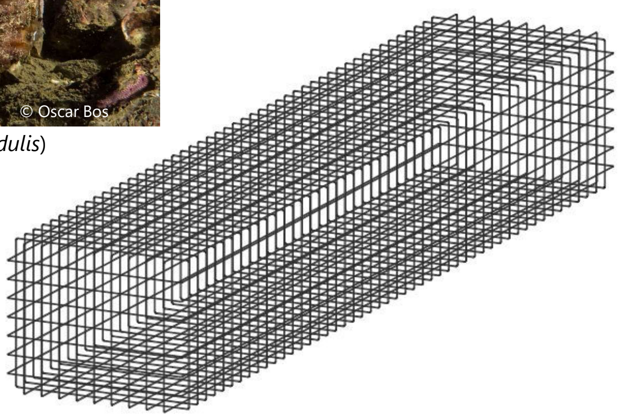
Juvenile poor cod (*Trisopterus minutus*)

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

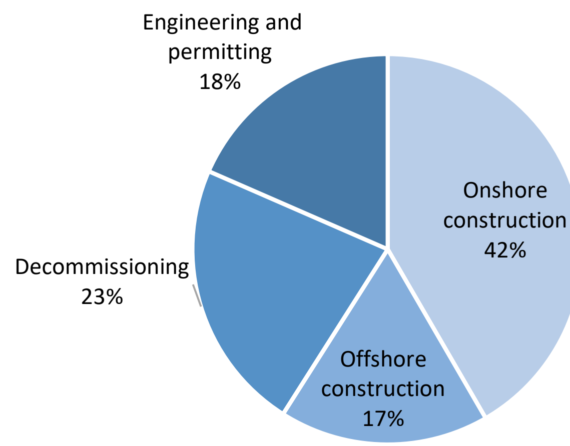
Length: 200 cm
Width: 150 cm
Hight: 40 cm
Mesh size: maximum 5 cm x 5 cm

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.

©ECOncrete Tech

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

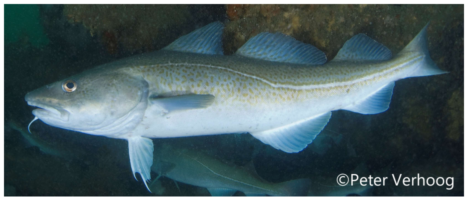
It is important that to note that these structure are an alternative form of cable protection. They should not deviate from this primarily function and thus be made location specific, depending on the morphodynamical conditions. The NID should be designed in such manner that no additional insulation 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

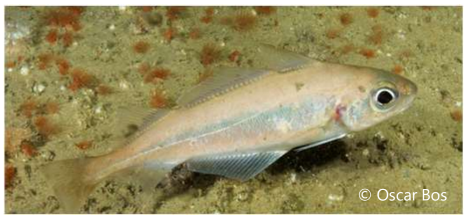
Juvenile cod *Gadus morhua*
Flat oyster *Ostrea edulis*
Lobster *Homarus gammarus*
Edible crab *Cancer pagurus*

Optimized cable protection Filter Unit®

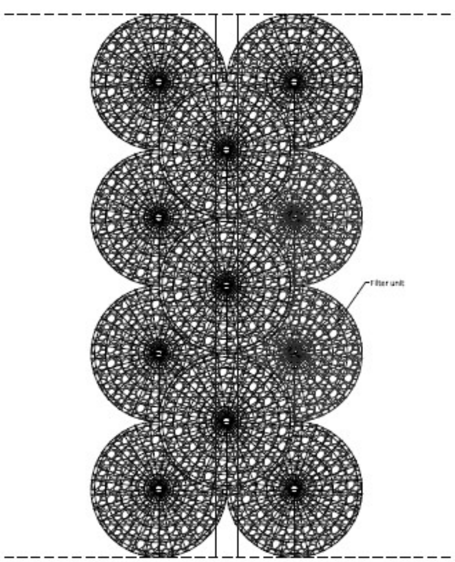
Policy-relevant species



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

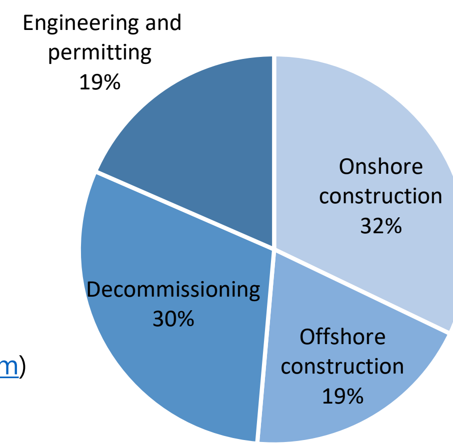
Grading: 40-200 kg
Crevice size of minimally 10 cm to 30 cm in diameter and 20 to 50 cm depth (to host juveniles of selected target species)

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

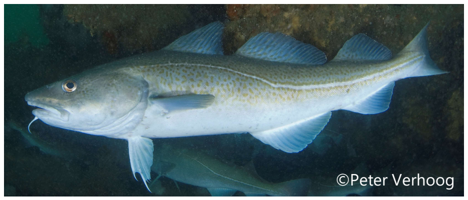


Supplier

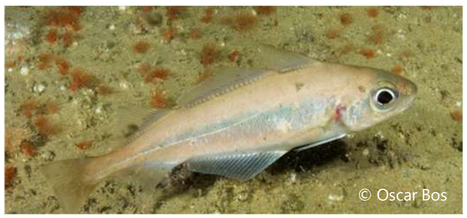
Sumitomo Deutschland GmbH (sumitomo-filter-unit.com)

Optimized cable protection Basalt bags

Policy-relevant species



Atlantic cod (*Gadus morhua*)

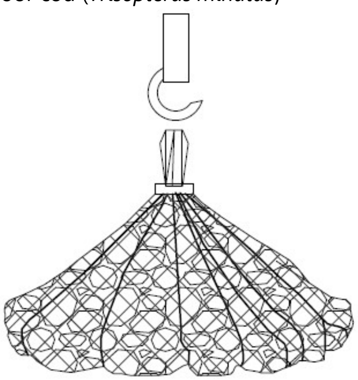


Poor cod (*Trisopterus minutus*)

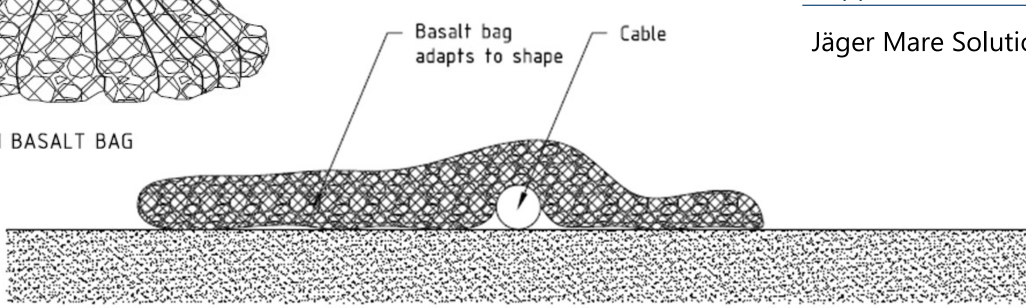
Commercial species

European lobster (*Homarus gammarus*)

Edible crab (*Cancer pagurus*)



MECHANISM BASALT BAG



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

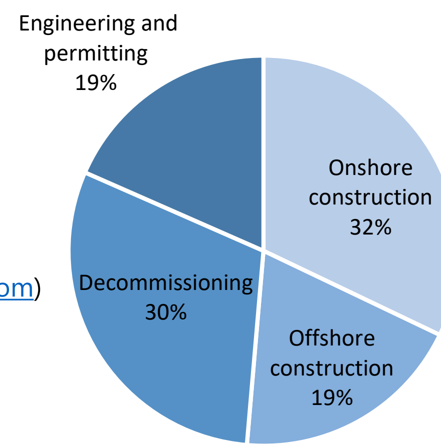
Grading: 40-200 kg
Crevice size of minimally 10 cm to 30 cm in diameter and 20 cm to 50 cm depth (to host juveniles of selected target species)
Additional benefit is a mesh made of basalt and therefore considered more ecologically friendly.

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



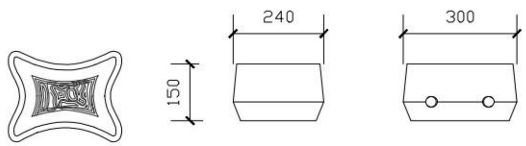
Supplier

Jäger Mare Solutions GmbH (jaeger-maresolutions.com)

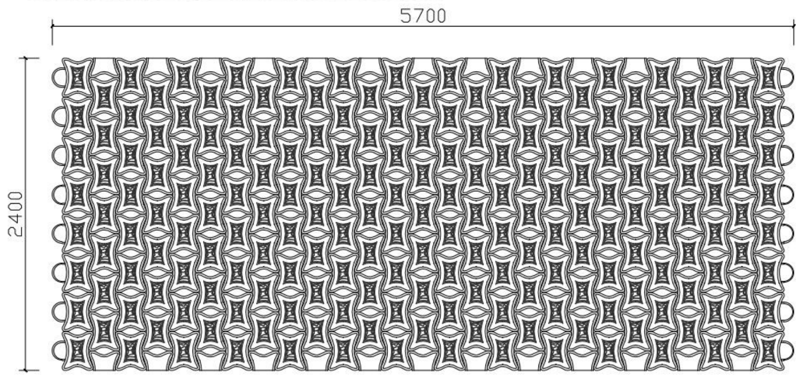
Optimized cable protection ECO Mats®

Policy-relevant species

European flat oyster (*Ostrea edulis*)



DIMENSIONS ECO MATTRES ELEMENT



TOP VIEW ECO MATTRES

Specifications

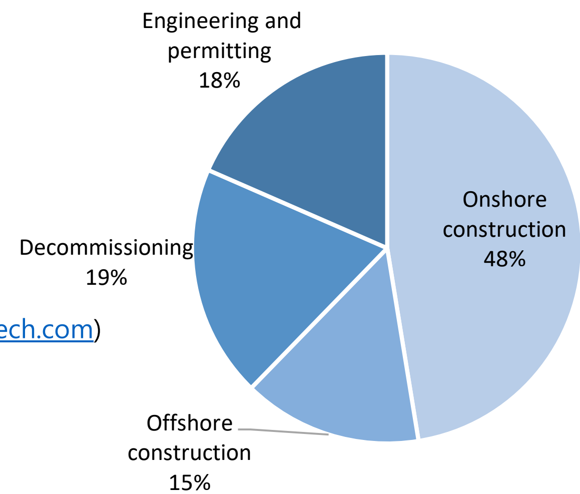
Mattresses which can be used for cable protection. The mattresses are comprised of separate concrete units. The units are links resulting in a flexible structure which can be placed on top of cables. ECOncrete®'s admix, added as ~10% of the cement content in the mix, strengthens the concrete's compression 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

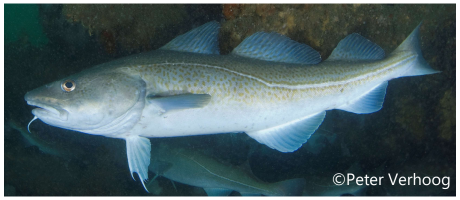


Supplier

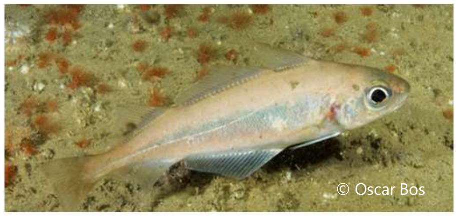
Patented design by ECOncrete Tech (econcretetech.com)

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

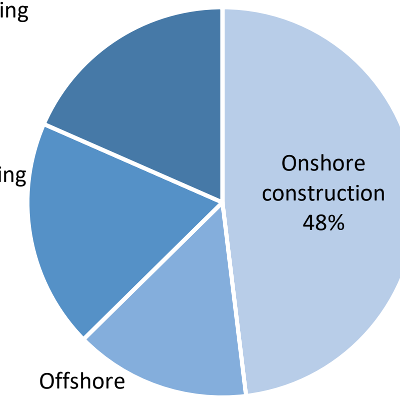
Reef cubes (see details for Reef Cubes) placed in a cage-like structure on top of cables to function as cable protection. Reef cube uses low carbon alkali activated materials. The cubes could provide a more homogenous structure compared to the filter unit and basalt bags.

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.

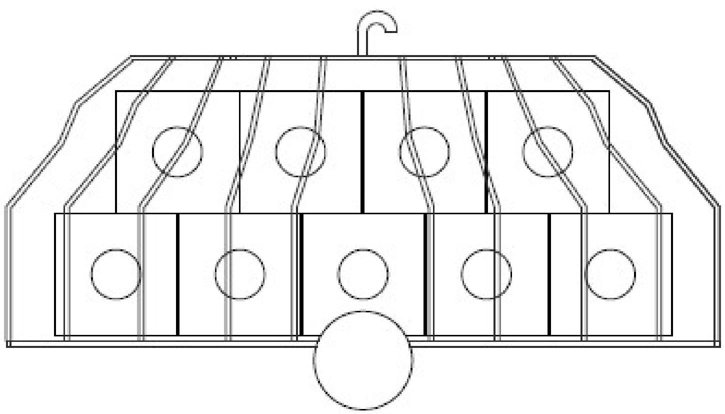
Costs

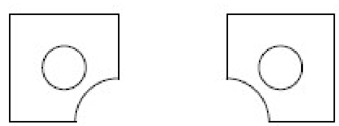
Onshore construction	€ 5,349
Offshore construction	€ 1,621
Decommissioning	€ 2,107
Engineering and permitting	€ 2,052



Supplier

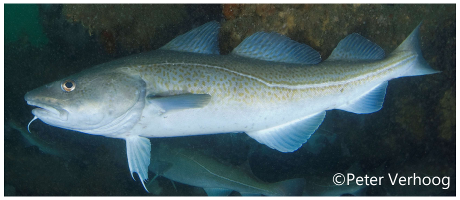
Patented design by ARC Marine (arcmarine.co.uk)


FRONT VIEW REEF CUBE FILTER BAGS (5X4)

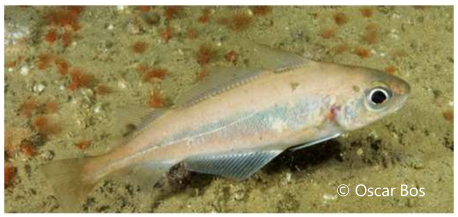

SPECIAL REEF CUBE FILTER BAGS (5X4)

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

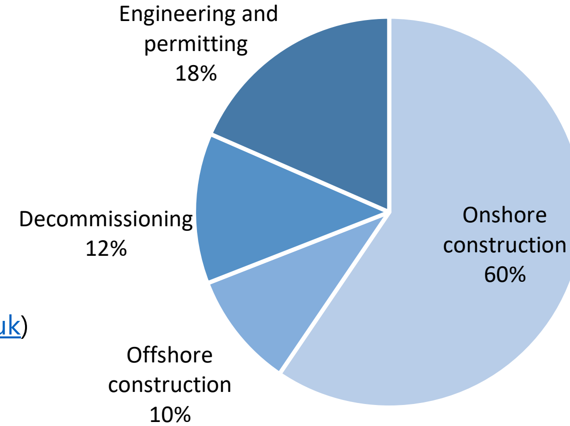
Flexible mattresses made of Reef cubes. Reef cube is a low carbon alkali activated material. See details under Reef cube.

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.

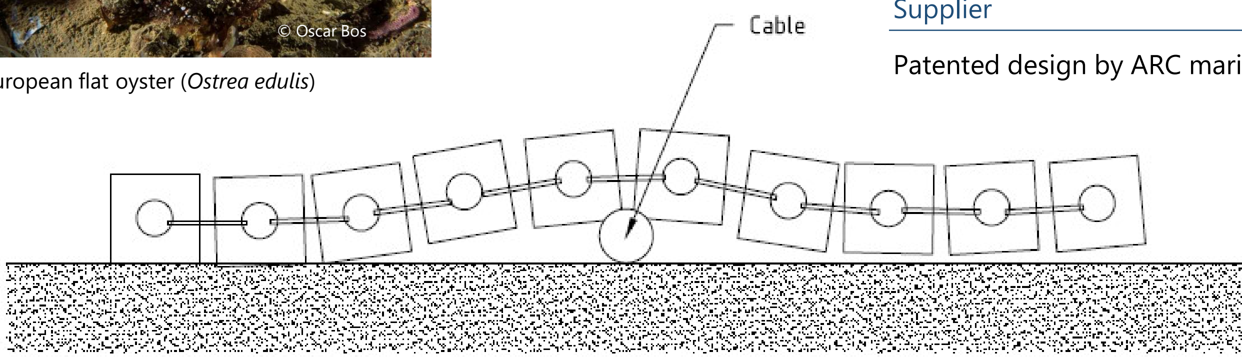
Costs

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



Supplier

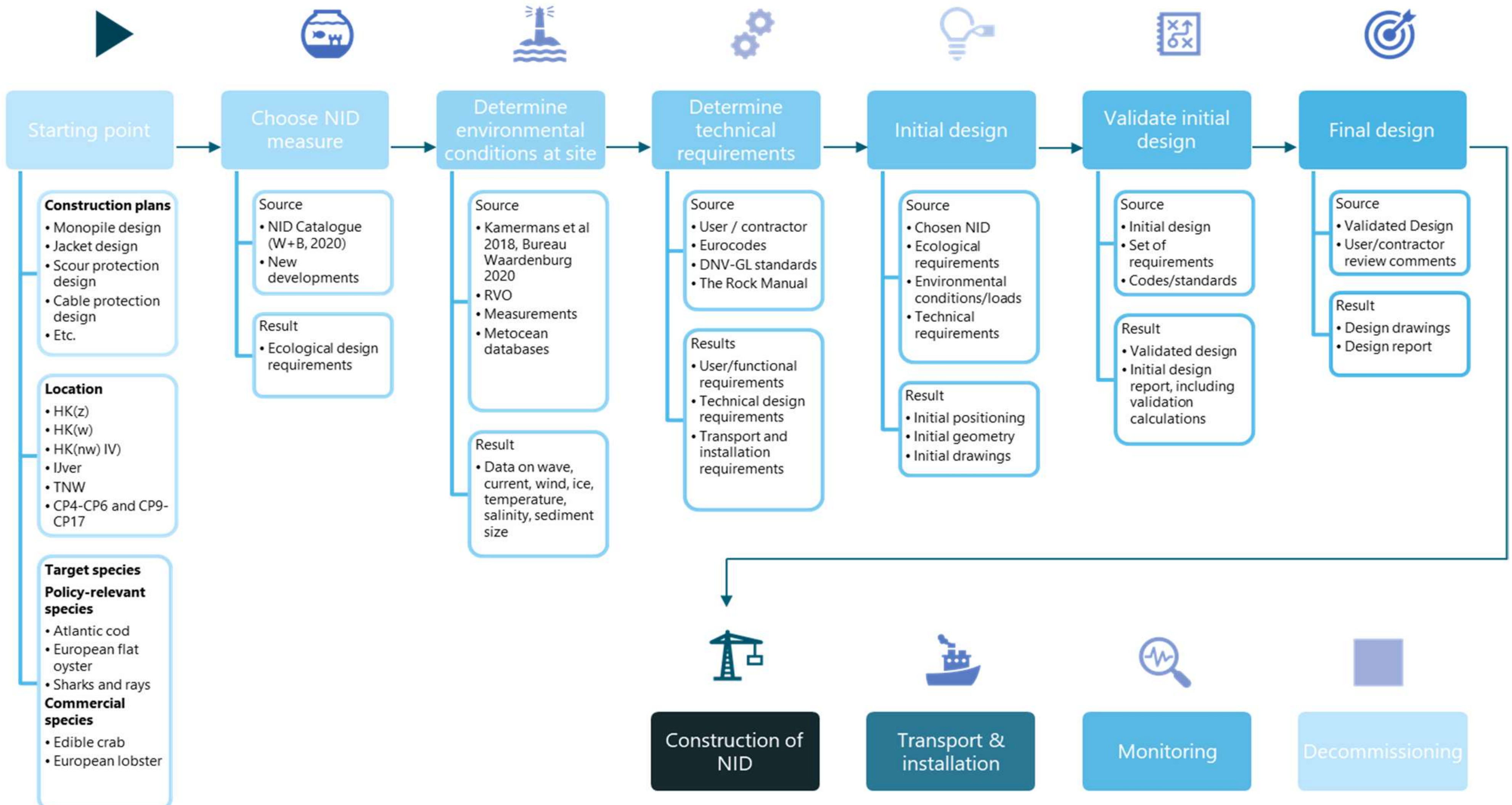
Patented design by ARC marine (arcmarine.co.uk)



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.



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 Mercader, Mercière, et al. 2017 Selfati et al. 2018 Mercader, Fontcuberta, et al. 2017 Lossent et al. 2018	https://doi.org/10.3354/meps11641 https://doi.org/10.1016/j.ecoleng.2017.03.022 https://doi.org/10.1016/j.biocon.2018.01.013 https://doi-org/10.1007/s12526-016-0498-x 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 Rozemeijer & Van de Wolfshaar, 2019 Van Duren et al. 2017 Lengkeek et al. 2017 Degraer, Brabant, Rumes, & Vigin, 2018	https://library.wur.nl/WebQuery/wurpubs/522329 https://doi.org/10.18174/466861 http://publications.deltares.nl/1221293_000_Eng.pdf https://edepot.wur.nl/411374 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 Folpp et al. 2013 Vlaams Insituut voor de Zee, 2014 Dos Santos, Brotto, & Zalmon, 2010 Sisson & Shen, 2012	https://library.wur.nl/WebQuery/wurpubs/fulltext/333153 https://doi.org/10.1371/journal.pone.0063505 http://www.vliz.be/en/2014-04-23-artificial-reefs https://doi.org/10.1016/j.jembe.2010.01.018 https://doi.org/10.21220/V5TB4S
	Reef cube®	Liu et al. 2012 Lindberg et al. 2006 COAST laboratory, 2018 Moustaka et al. 2018 Rifqi Fauzi et al. 2017	https://doi.org/10.1080/19942060.2012.11015440 https://doi.org/10.1890/1051-0761(2006)016[0731:DHSAPB]2.0.CO; https://www.plymouth.ac.uk/research/esif-funded-projects/arc-marine-a-case-studyhttps://doi.org/10.1007/s00338-018-1690-1 https://doi.org/10.12962/j23546026.y2017i6.3284
	3D printed units	see Reefball®	
	Eco armour block®	Dennis et al. 2018 Sella & Perkol-Finkel, 2015 Perkol-Finkel, et al. 2019 Abdo, Perkol-Finkel & Gonzalez, 2015	https://doi.org/10.1016/j.ecoleng.2017.05.031 https://doi.org/10.1016/j.ecoleng.2015.09.016 https://search.informit.com.au/documentSummary;dn=800571314459488;res=IELENG 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