Offshore Wind Evidence + Change Programme

Nature Inclusive Cable Enhancement and Protection (NICE) project

Phase 1 Literature Review

FINAL VERSION

THE CROWN ESTATE

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Abbreviations

Abbreviation	Definition
Cefas	Centre for Environment, Fisheries and Aquaculture Science
Defra	Department for Environment, Food and Rural Affairs
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
MMO	Marine Management Organisation
NID	Nature-inclusive design
OWF	Offshore wind farm
OSW	Offshore wind
ROV	Remotely Operated Vehicle

Document Control

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1. Executive Summary

To meet national energy security needs, to reduce national greenhouse gas emissions, and to decarbonise the United Kingdom (UK) economy to meet a Net Zero target by 2050, the UK government has (amongst other plans and policies for power), committed to developing up to 50 gigawatts (GW) of offshore wind by 2030. The required expansion of the UK offshore wind (OSW) energy sector from today's 13 GW (approx.) to the 2030 target, will require associated subsea and onshore cabling. This means a potential for a significant scale-up of the amount and the overall spatial footprint of external cable protection (typically hard substrata), to be placed on the seabed within UK waters, where required and permitted. The likely up-scaling of the spatial footprint of subsea cabling and cable protection for OSW, requires scientific assessment of the potential impacts (whether positive or negative) to benthic biodiversity and marine ecosystem structure and functioning (including linkages with marine ecosystem goods and services). The potential impacts associated with cable protection will occur during both the operational phase of an Offshore Wind Farm (OWF), and during decommissioning of the infrastructure.

With the expansion of OSW (in the UK and globally), there is a growing awareness and interest to investigate the potential environmental benefits of using nature-inclusive design (NID) or nature-based design principles for OSW infrastructure. NID can be defined as "options that can be integrated in or added to the design of an offshore wind infrastructure to create suitable habitat for native species (or communities) whose natural habitat has been degraded or reduced" (Hermans *et al*., 2020). The interest in NID for OSW infrastructure is, in general, linked with the aims of seeking to enhance ecological functioning, marine biodiversity and marine ecosystems, with the eventual policy goal of achieving a net positive impact.

This report forms part of the Phase 1 of the delivery for the Nature Inclusive Cable Enhancement and Protection (NICE) project. The NICE project is a project led by Cefas and in partnership with Accelerating Reef Creation (ARC) Marine, that is funded under the Crown Estate's Offshore Wind Evidence and Change (OWEC) Programme. In summary, the NICE protection project aims to provide evidence on the potential ecological impacts (focused on benthic epifauna), of NID technologies for cable protection, compared to existing 'standard' cable protection technologies. This is to be achieved through phases of work consisting of:

- Phase 1: Literature review (this report).
- Phase 2: Deployment of a standard and a NID type of subsea cable protection at a UK study site.
- Phase 2: ROV survey to determine presence of epifauna and development stage.

- Phase 3: Data analysis and reporting.

In fulfilment of Phase 1 of the NICE project delivery, this report contains a composite of information that will support further phases of work during the NICE project. The Phase 1 review findings and summary will help to shape the study design and analyses in Phases 2 to 3, and input to the Phase 3 report.

This Phase 1 report contains a summary of methods for seabed preparation (sand wave/ mega-ripple pre-sweeping, boulder clearance and pre-lay grapnel run) and subsea cable burial methods (ploughing, jetting, vertical injectors and mass flow excavators). This is coupled with information about the different types of standard external cable protection measures used in the offshore wind sector (as well as those used in other marine sectors) – including rock dump, concrete mattresses, sand/grout bags, tubular protection. There is also information on indicative quantities and other types of protection measures used in the UK presently.

A high-level review of direct benthic ecological impacts associated with the installation, operation and decommissioning of subsea cables and external cable protection was undertaken, based on peer-reviewed studies and reviews that include post-consent monitoring data in the UK. Where relevant information about external cable protection / subsea protection systems exists from other sectors e.g., oil and gas sector, wave and tidal sectors, this has also been incorporated. Twelve relevant studies of benthic community presence and development on external cable protection types, and/or subsea protection systems for pipelines (in the case of the oil and gas industry) were identified during this review. These reflect the different sectors of offshore wind (fixed and floating wind), tidal energy devices, wave energy devices, oil and gas, plus a study that compared benthic communities on oil and gas infrastructure with those observed on fixed offshore wind farms. The studies include research conducted in the UK, France, The Netherlands, Belgium and Australia.

From the studies reviewed, the key ecological metrics (i.e., species density, biomass, relative species abundance, and/or species richness and community composition), have typically been used to evaluate changes (over time and/or space) of epibenthic communities, from the presence of subsea cable protection, scour protection, turbine foundations, pipelines, oil and gas platforms. Depending on the datasets, the studies were able to characterise the benthic community assemblages on the various structures and indicated ecological patterns from initial settlement through to succession of communities over time and space. A variety of data collection methods have been utilised in the respective studies: towed video camera system, ROV, scuba diver surveys and scrape sampling, with varying monitoring sampling designs.

This report also identifies relevant information from decommissioning guidelines in the UK on options for decommissioning subsea cables and cable protection, including highlighting whether future use of NID cable protection solutions will affect decommissioning options. A high-level summary of potential decommissioning impacts to benthic communities has also been presented.

The principles of NID in the OSW sector are introduced and examples of NID cable protection measures available are presented, together with an overview of where NID measures are being trialled. An overview is given of ecological and technical considerations, opportunities and risks associated with NID forms of cable protection, based on studies that have drawn on expert knowledge, including some comparative experiences in artificial reef research outside of the OSW sector.

The evidence gathered from the review process has identified pertinent knowledge gaps. These include improving understanding of ecological impacts of different types of cable protection (including NID types) in connection with marine benthic ecological settlement and community succession over time. Also, increasing knowledge of impacts to higher trophic levels arising from benthic artificial reefs forming on the NID and non-NID protection systems, both at individual and regional scales.

From the review conducted, there appears to be a relatively limited number of studies that assessed the ecological effects of standard external cable protection measures on subtidal benthic communities over long timescales (i.e., >5 years), and more specifically, in connection with detecting functional changes, and implications for marine biodiversity and wider marine ecosystems.

There appear to be relatively few documented studies of NID features at OWFs and associated monitoring datasets. This information would help address questions and understanding about whether NID features for subsea external cable protection can potentially enhance marine biodiversity and contribute to a net positive impact. Evidence is being acquired via OSW research programmes, such as the Dutch Governmental Offshore Wind Ecological Programme (Wind op Zee Ecologisch Programma, WOZEP), The Monitoring and Research, Nature Enhancement and Species Protection (MONS) Programme, or via obligations for building a windfarm via site decisions (in the Netherlands).

Information including survey methods, indicators and metrics of benthic community change, and recommendations identified during this review, will help to shape the study design and analyses to be conducted in the Phase 2 / 3 of the NICE project. The information and discussion points about benthic ecological impacts of cabling / cable protection, NID options of cable protection, information on cable/ cable protection decommissioning and evidence gaps identified during the review, will feed into the content of the Phase 3 report for the NICE project.

2. Introduction

2.1 Background

To meet national energy security needs, to reduce national greenhouse gas emissions, and to decarbonise the United Kingdom (UK) economy to meet a Net Zero target by 2050, the UK government has (amongst other plans and policies for energy), committed to developing up to 50 gigawatts (GW) of offshore wind by 2030[1]. The proposed expansion of the offshore wind (OSW) energy sector in the UK will require associated subsea and onshore cabling to transport electricity from the offshore wind farms (OWFs) to the grid connection and grid network on land. For OWFs, this relates to array cables linking wind turbines and to the substation (if at sea), and export cables to transport electricity from collector turbines or the substation to the onshore grid substation.

On the UK seabed there is already an existing network of subsea cabling for operational OWFs, which will significantly increase with OWFs under construction (as of 2022) and yet to be commissioned. The extent of OSW subsea cabling is expected to expand significantly in the coming decade as further OWFs are consented, constructed, and become operational. From 2019 to 2029, there is forecasted to be 4,335 km of export cables and 5,304 km of array cables installed, which is additional to (as of 2018), 1,499 km of export cables and 1,806 km of array cables used by UK offshore windfarms (El Mountassir and Strang-Moran, 2018; RenewableUK, 2019).

Alongside the expansion of OSW cabling, external methods of cable protection such as mattresses and rocks, will likely be deployed (where these are required and are permitted through marine consenting). This means a potential for a significant scale-up of the amount and the overall spatial footprint of external cable protection, to be placed on the seabed within UK waters. A likely up-scaling of the spatial footprint of subsea cabling and cable protection for OSW will require careful assessment of potential impacts to benthic biodiversity and marine ecosystem structure and functioning (including linkages with marine ecosystem goods and services), at the stage of installation, the operational presence (i.e., 20-30 years+) and at the stage of decommissioning. Consideration should be first at a site basis, to determine what changes occur and then look at whether these changes will translate to potential cumulative effects. (e.g., Gușatu *et al.*, 2021).

Best practice in the subsea cabling industry (OSW sector included), is to bury cables under the seabed, where possible. However, external cable protection may be utilised where cable burial is not achieved

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[1] HM Government (2021) Net Zero Strategy: Build Back Greener October 2021. Available online at: net-zero-strategy-beis.pdf (publishing.service.gov.uk)

e.g., cable re-burial is unsuccessful, or where cable burial is not possible e.g., cables crossing a pipeline or cables crossing areas of hard rocky substrata. External cable protection guards the cabling from potential disturbance and damage due to natural hazards, such as storms, and / or other marine activities e.g., anchors or seabed contacting fishing gears. A variety of external cable protection solutions are available and utilised. Part of this review provides a synopsis of 'standard' types that are used in the OSW sector together with a synopsis of nature-inclusive designed (NID) infrastructure (including external cable protection) for OSW.

In the UK, there are electricity cables for wind, wave and tidal energy developments, interconnector electricity cables exchanging power between the UK and Europe, and a network of subsea telecommunication cables used to transmit data and communications nationally and internationally (European Subsea Cables Association, 2019). It is, however, considered unusual for external cable protection to be associated with telecommunication cables, except when the cables cross a pipeline or power cables.

The placement of subsea cables on the seabed and burial under the seabed surface results in environmental pressures with the potential to directly affect seabed benthic faunal (infauna and epifauna) communities during the installation, operation and decommissioning phases. This includes, for instance, through disturbance and removal during cable laying operations. A high-level review of direct benthic ecological impacts associated with each of these phases for subsea cables and external cable protection, and the key findings are summarised in this report. Impacts in the context of this report refers to evidence of changes (including ecological functional changes), whether positive or negative to the benthos, that are associated with the cable protection.

With the proposed expansion of OSW (in the UK and globally), there is a growing awareness and interest in investigating the potential environmental benefits of using NID or nature-based design principles for OSW infrastructure. NID substrates can provide a surface for settlement of marine epibenthos and macroalgae. These may develop over time into communities that form artificial reefs, which in turn, potentially support mobile marine fauna requiring food and shelter. Interest in NID options for OSW is linked with the aims of seeking to enhance ecological functioning, marine biodiversity and marine ecosystems, with the eventual policy goal of achieving a net positive impact. For the purposes of this report, we define NID as "options that can be integrated in or added to the design of an offshore wind infrastructure to create suitable habitat for native species (or communities) whose natural habitat has been degraded or reduced" (Hermans *et al.*, 2020). The structures are inspired by natural features / elements and purposefully designed to help optimise habitat value for native species / communities, which may be of ecological and commercial value in a given area.

NID principles may be included in the design of external cable protection (i.e., the focus on this report) as well as in options for designing the turbine foundation, scour protection layer or offshore substation (Hermans *et al*. 2020). Interest in NID solutions in the OSW sector has been emerging in countries, particularly The Netherlands and the United States of America, thus providing an opportunity to draw from relevant information from these other countries to determine the potential use of NID in the UK OSW sector.

In summary, the report covers the following elements:

- A summary of seabed preparation methods required prior to cable installation.
- A summary of cable installation methods and summary of types of external cable protection that are used as standard in the OSW sector (and other marine sectors).
- A summary of decommissioning methods for subsea cables and external cable protection.
- A high-level review of direct benthic ecological impacts associated with the installation, operation and decommissioning of subsea cables and external cable protection, based on relevant published evidence. Where relevant information about external cable protection / subsea protection systems exists from other sectors e.g., oil and gas sector, wave and tidal sectors, this has been incorporated into the review.
- A synopsis of NID principles for OSW infrastructure, including examples of NID cable protection methods, status of knowledge for NID measures and associated knowledge gaps.
- Key findings, evidence gaps and conclusions.

This report forms part of the Phase 1 of the delivery for the Nature Inclusive Cable Enhancement and Protection (NICE) project. The NICE project is a project led by Cefas and in partnership with Accelerating Reef Creation (ARC) Marine, that is funded under the Crown Estate's Offshore Wind Evidence and Change (OWEC) Programme. In summary, the NICE protection project aims to provide evidence on the potential ecological impacts (focused on benthic epifauna), of NID technologies for cable protection, compared to existing 'standard' cable protection technologies. This is to be achieved through phases of work consisting of:

- Phase 1: Literature review (this report).
- Phase 2: Deployment of standard and NID cable protection at the UK study site.

- Phase 2: ROV survey to acquire imagery to determine presence of epifauna and development stage on the deployed cable protection measures.
- Phase 3: Data analysis and reporting.

2.2 Scope

The main focus of this review is on OSW subsea cabling; however, it will draw on relevant evidence of subsea cabling and external subsea protection measures from a range of marine sectors / industries (i.e., wave, tidal, telecommunication and interconnector cabling, and oil and gas subsea protection systems). The review considers all phases of OSW developments, from installation to decommissioning, subsea cabling and external cable protection systems, in line with best-available evidence at the time of the report preparation.

The review covers existing types of 'standard' external cable protection currently used in the UK and internationally. Nature Inclusive Design and NID principles are introduced in the context of OSW to provide an overview of the current status of NID knowledge for OSW.

Evidence is drawn from relevant studies in coastal and marine waters of the United Kingdom, from Europe and globally. In terms of geographic locations, OWFs are planned for, or are already sited, in shelf sea areas and on the Continental Shelf in the UK, Europe and internationally. Therefore, to keep the consistency in this review to coastal areas and continental shelf seas, we have excluded studies about benthic ecological communities on, or associated with, deep water subsea cabling and oil and gas pipelines (i.e., >2,000m), and in high sea areas i.e., outside of 200 NM of the Exclusive Economic Zone (EEZ) limit.

The review scope is restricted to looking at direct impact pathways and resultant effects to the physical subtidal benthic environment and marine infauna and epifauna (benthic invertebrates) from the installation, operation and decommissioning of OSW cabling and external cable protection. The review briefly considers the potential for impacts from electromagnetic fields (EMF) and thermal radiation directly created by the transmission of power through a cable and effects on benthic epifauna; however, these topics are not well understood and are not the focus of the review of cable protection.

3. Aims and Objectives

3.1 Aims

The aims of this Phase 1 review are to concisely draw together published evidence about methods for cable installation, operations of cable and external cable protection and decommissioning, together with a synthesis of key evidence about benthic ecological impacts associated with subsea cable and external cable protection during all phases of OSW energy. Additionally, the review will provide a synopsis of NID principles and examples of NID cable protection measures applicable to the OSW sector (in the UK).

3.2 Objectives

The review objectives are to:

- Summarise methods of pre-cable installation work, subsea cable installation methods and types of external cable protection in use, primarily within the OSW cable sector using published evidence sources.

- Provide a concise synopsis of evidence for direct effects on benthic infauna and epifauna from the cable and external cable protection installation, operation, and decommissioning, to determine whether these represent positive or negative impacts.

- Provide a synopsis of types of NID measures in use / being considered in the OSW sector.

- Bring together evidence from the synopsis with broader concepts and questions for potentially using external methods of NID cable protection as an option for marine nature enhancement. This includes highlighting applicable knowledge gaps from the available literature.

- Utilise Phase 1 review findings and summary to shape the study design and analyses in Phase 2-3 and as background to and recommendations for framing the Phase 3 comparative assessment report.

4. Method

4.1 Search Strategy

4.1.1 Identification of Relevant Evidence Sources

Relevant evidence sources were obtained through searches of journal databases (Web of Science, Science Direct, Directory of Open Access Journals), searching Google Scholar, and searching websites of relevance to the review topic, including The Crown Estate Marine Data Exchange[2], European Subsea Cables

[2] https://www.marinedataexchange.co.uk/

Association[3], Tethys offshore wind and marine renewable knowledge base[4], the Carbon Trust's UK Offshore Renewables Joint Industry Programme[5] and the International Cable Protection Committee[6]. Sources advised by the Project Advisory Group (PAG) members and members of the project delivery team were also reviewed.

4.1.2 Search Terms / Parameters for the Search String

Search strings were modified to the respective key search database:

- Web of Science - *benth* AND (cabl* OR renewabl*) AND *diversity.
- Science Direct - **(benthic OR benthos OR epibenthos) AND (cable OR cabling OR renewable) AND (diversity**).
- Google Scholar and Directory of Open Access Journals:
  - '**benthic and renewable and cable and diversity**'
  - **'cable protection and interaction and benthic'**
  - '**nature inclusive design and offshore wind'**

- Searches of relevant organisational websites (The Crown Estate Marine Data Exchange, European Subsea Cables Association, Tethys offshore wind and marine renewable knowledge base) using terms 'benthic', 'renewable' , 'cable' and 'diversity'.

4.1.3 Search Inclusion Criteria

Only articles, reports or websites written in English and available electronically were included. If a conference article or thesis had a more recent journal version, then the journal article was included. Research and studies from the UK, from across Europe and globally were included, where relevant. Studies were also required to be within coastal shelf seas and on the Continental Shelf (and not in areas of High Seas and in deeper waters of >2,000 metres (m)). To capture the expansion of the OSW sector and developing knowledge, studies from the last 11 years (2012-2023) were used. The primary focus of the review was offshore renewables (fixed and floating wind), but we have sought to include literature from wave and tidal energy, telecommunication and interconnector cabling sectors, and subsea protection

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[3] https://www.escaeu.org/

[4] https://tethys.pnnl.gov/knowledge-base

[5] http://www.orjip.org.uk/

[6] About the ICPC (iscpc.org)

systems utilised in the oil and gas sector. This is due to the breadth and depth of studies for these sectors that are likely of relevance to this review.

Subtidal infauna (taxa living with the seabed) and invertebrate epifauna (taxa living on or attached to the seafloor / structures) were the primary focus of this review. However, where studies also included data on benthic fish taxa and macroalgae, this information has been mentioned for completeness in this review. The review scope excluded intertidal marine species and habitats, pelagic fish, elasmobranchs, marine mammals and seabirds.

4.2 Searches

The search strategy involved an initial step of searching key scientific databases, Google Scholar and organisational websites, using the applicable search string / terms (see 4.1.1.). Located articles / reports were screened for relevance by title and abstract (using inclusion criteria in section 4.1.2.). This was combined with a snow-balling approach where the citation list of the reviewed article / report (the starting set of articles) evaluated to identify additional relevant articles / reports to be obtained and reviewed. A full review of the relevant articles / reports was then conducted, with key information about the studies (e.g., location, type of cable protection, survey methods, ecological response metrics etc) and key results and conclusions, were extracted and included in this report.

5. Synthesis of Review Topics

Using the identified literature, a synthesis of activities undertaken during the cable pre-installation phase has been produced. The synthesis provides the context for the operational and decommissioning phase activities, which are discussed later.

5.1 Cable Pre-Installation Activities

In the case of subsea cabling, a pre-installation phase can involve several seabed impacting activities: sand wave/ mega-ripple pre-sweeping, boulder clearance and pre-lay grapnel run. Sand wave/mega-ripple pre-sweeping is undertaken to create a flat seabed area for cable installation tools to operate on and involves removing the mobile layer of sand pre-installation to support achieving the required cable burial depth. Pre-sweeping is undertaken with Trailing Suction Hopper Dredging or Mass Flow Excavation (RPS Ltd, 2019). Boulder clearance enables cable installation tools to operate effectively in the cable installation area. It involves the clearance of boulders with a displacement plough and a subsea grab, to areas away from the cable trench (RPS Ltd, 2019). Pre-lay grapnel run is undertaken to clear debris on the seabed or buried in the very top layer of the sediment, prior to cable installation works (RPS Ltd, 2019).

Following completion of cable route clearance work, the cable can then be installed following the cable installation techniques described below.

5.2 Cable Installation Phase

Cable installation involves cable deployment and burial below the seabed, in line with project/consenting requirements. The key methods for installation are (from: RPS Ltd, 2019):

- Post Lay Burial - where the cable laying and burial are two separate operations or,
- Simultaneous Lay and Bury - where the cable is deployed and buried simultaneously behind a vessel.

The selection of cable burial equipment is directly related to the seabed conditions, including sediment type and sediment properties in the chosen cable route. The type of burial tool is also influenced by a range of factors including the required burial depth below the seabed, marine licence conditions, presence of cable crossings and cabling vessel needs (RPS Ltd, 2019).

Subsea cables are usually buried within the seafloor by different techniques, outlined as follows:

a) Trenching

Trenching involves using either a jet trencher or mechanical trencher. A jet trencher uses high pressured seawater to fluidise seabed sediment to create a trench and then the cable is lowered into the trench. A mechanical trencher physically cuts a trench and the cable is laid into the trench and buried (RPS Ltd, 2019).

b) Ploughing

Ploughs are towed from a vessel or barge and some ploughs are designed to allow for simultaneous lay and burial. Non-displacement ploughs trench and bury the cable in a single pass, leaving less disturbance on the seabed and are typically used for simultaneous lay and burial. They are often fitted with additional features to improve performance in certain soils, for example water jets for burying in sand. Displacement ploughs are typically heavy-duty ploughs used to pre-cut a trench. The cable is then laid into the trench and a secondary backfill pass is carried out to bury the cable (RPS Ltd, 2019).

Subsea cabling installed at shallower depths (i.e., <200 m but also possible up to 2,000m water depth) are commonly buried using mechanical ploughing or jetting, with burial achieved to a sufficient depth to protect the cabling against potential hazards (Carter and Burnett, 2015).

c) Jetting

Jet sleds are a hybrid of a jet trencher and a cable plough and are towed or pulled along the seabed (RPS Ltd, 2019).

d) Vertical Injectors

Vertical injectors can be mounted on sleds / tracks or suspended over the side of a vessel. They are used mainly for very deep burial of cables (RPS Ltd, 2019).

e) Mass Flow Excavators

Mass flow excavators can be used as a post lay burial tool, where these can be used to either fluidise the seabed beneath the cable and allow it to sink into the trench or used to jet the seabed sediment across and into the cable trench (RPS Ltd, 2019).

5.3 Cable Protection Installation

Subsea cables have either a single or double armouring layer that provides a fundamental level of protection to the cables from mechanical stress (ESCA, 2019). However, external protection may be achieved simply by burying the cable under the seabed surface, or by using additional external cable protection on top of the cabling. Sufficient burial is needed to protect cabling from damage due to natural forces e.g., changes in seabed mobility, or human activities e.g., anchor strikes or fishing gear entanglement. Achieving sufficient burial depth is also typically a licence / consent requirement (ESCA, 2019).

The preferred option and industry best-practice (particularly in 'shallow' waters of <2,000 m), is to bury subsea cables. It should be noted that 'deep water' subsea telecommunications cabling installed at depths > 2,000 m are laid on the seabed surface and are not buried.

However, cable burial may not be feasible in some situations, such as where subsea cabling cross over existing infrastructure (e.g., installed pipelines), or due to the presence of hard rocky substrata, or where cable repairs have taken place and the cable cannot be re-buried. Consequently, external cable protection measures may be required and installed. It is during the cable post-installation phase, that external cable protection is placed on areas of asset (pipeline and cabling) crossings, or areas of cable where burial was not sufficiently achieved.

Protection of cabling is important for avoiding costly cable repairs, avoiding the risks of exposed cables to other seas users, and avoiding potential for additional environmental impacts from repeated seabed disturbances e.g., in event of cable repair work.

5.4 External Cable Protection Types

Standard types of external cable protection that are used in the marine renewable industry (OSW, wave, tidal energy) include (but are not limited to) the following: concrete mattresses, rock placement/rock bags, sand / gravel / grout bags and tubular protection systems. A summary of each type is given below.

a) Concrete mattress

Concrete mattresses consist of segmented blocks of concrete or bitumen connected by polypropylene ropes (Figure 1.A). The structure can be laid over a subsea cable to stabilise and protect the cable(s). Additionally, any gaps between sections can be filled with pre-filled grout bags or gabion bags to support reduction in winnowing and possible sagging of the cable due to scour (RPS Ltd, 2019).

b) Rock placement

Rock placement involves the installation of crushed stone of varying sizes to form a protective barrier over the cable. This method is generally used as scour protection at infrastructure crossings, or where minimum burial depth has not been achieved (RPS Ltd, 2019).

c) Grout/sand/gravel bags

Rock filled bags (sand, gravel, grout) are placed over the cable as a protective barrier and fill in between other forms of cable protection, such as a concrete mattress (Figure 1. B-C).

d) Tubular protection methods

Tubular protection includes protective sleeves that consist of sections made from polyurethane or ductile iron (Figure 1. D). The tube is generally a cylindrical half-shell that fits around the cable. The tubular protection products are often used in combination with mattresses or rock placement to support stability of the cable and protect fishing gear from entanglement (RPS Ltd, 2019).

The use of protection measures is site-specific and depends on the risk to the cables (e.g., fishing activity) in the locations of the developments (RPS Ltd, 2019).

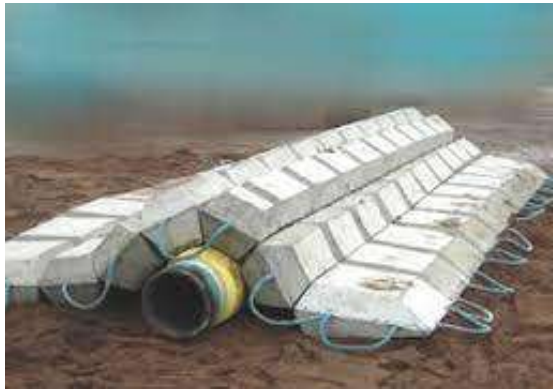	
(A) Concrete Mattresses example (image © Subsea Protection Systems 2022. (Source: Anti-scour frond mattresses | Frond Mats - Subsea Protection Systems - Subsea Protection Systems).	**(B) Rock placement** (rock filter bags image © Subsea Protection Systems 2022. (Source: Rock Filter Units - Subsea Protection Systems).
	
(C) Grout/sand/gravel bags example (image © Synthetex 2022. (Source: Scour Protection or Correction for SubSea Pipelines - Synthetex).	**(D) Tubular protection – fibreflex system example** (image © Fixed offshore wind turbine cable protection systems (Source: balmoraloffshore.com).

Figure 1: Examples of non-burial methods of cable protection, clockwise from the top: (A) concrete mattress, (B) Rock bags/rock placement, (C) Grout/sand/gravel bags and (D) tubular protection.

Standard types of external hard cable protection are installed, subject to applicable consenting requirements, to help protect cable assets which can be associated with OSW and other sectors e.g., interconnector cabling. The Defra Marine Biodiversity Impact Evidence Group (MBIEG) commissioned a project that looked at the existing distribution and types of hard protection in England and Wales (MBIEG, 2020). The MBIEG project collated existing spatial data to help better understand the presence, distribution, and types of existing hard protection (including cable protection), in use in the marine environment.

Figure 2 shows the distribution of hard protection for assets in offshore waters, as identified by the MBEIG project report (MBIEG, 2020). The available spatial data for OWFs (red) and export cable protection (orange) are identifiable for a range of developments in English offshore waters.

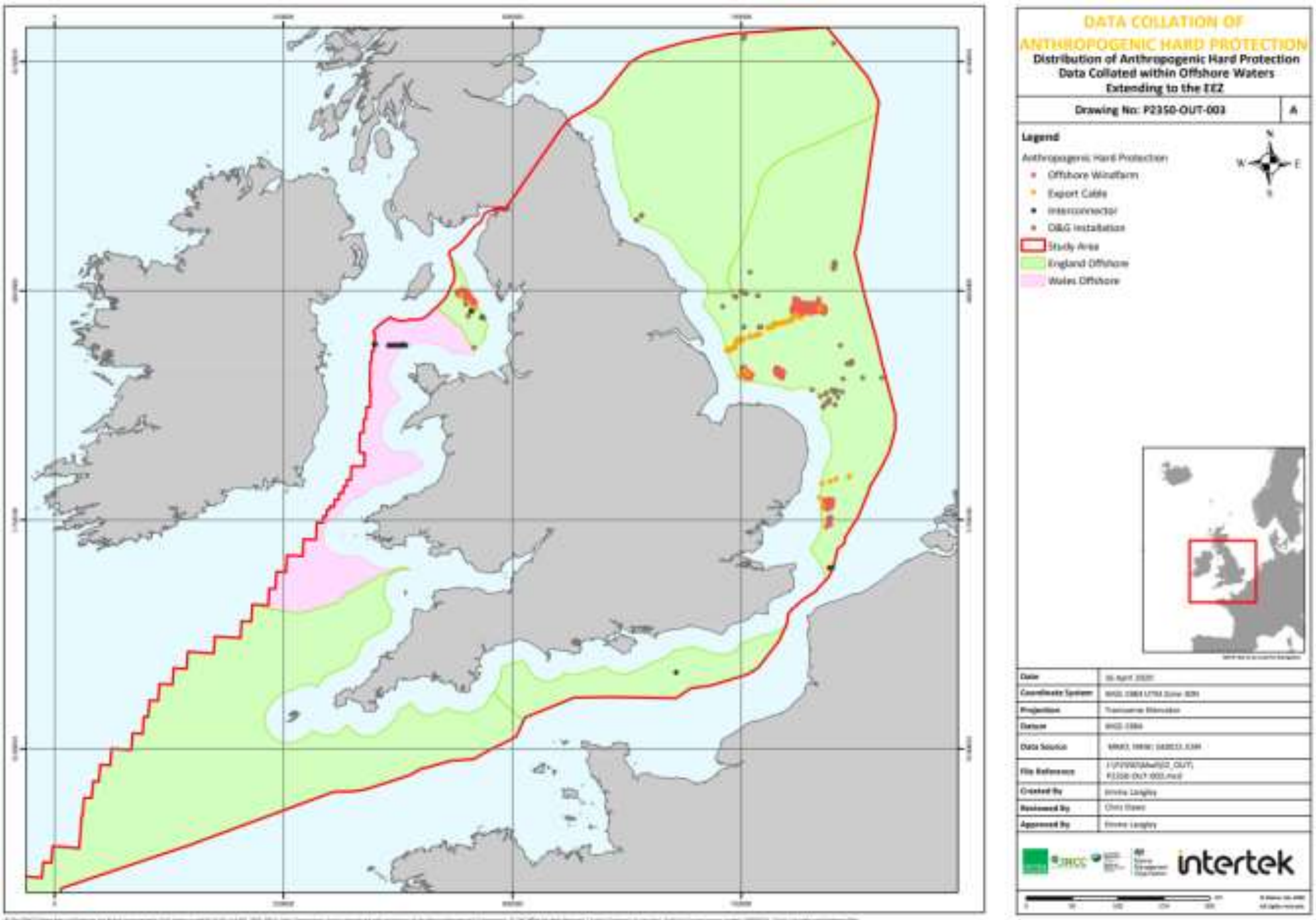

Figure 2: The distribution of cable protection (data as of 2020), within offshore waters and out to the EEZ boundary. From: MBIEG (2020).

Figure 3 shows the mapped distribution of different types of hard protection installed in the offshore wind industry, as identified in the MBIEG project report (MBIEG, 2020). From Figure 3, it appears that mattresses (in dark green) are present along numerous OWF export cable routes, although noting that other forms of protection e.g., rock armour are also utilised in the offshore wind industry.

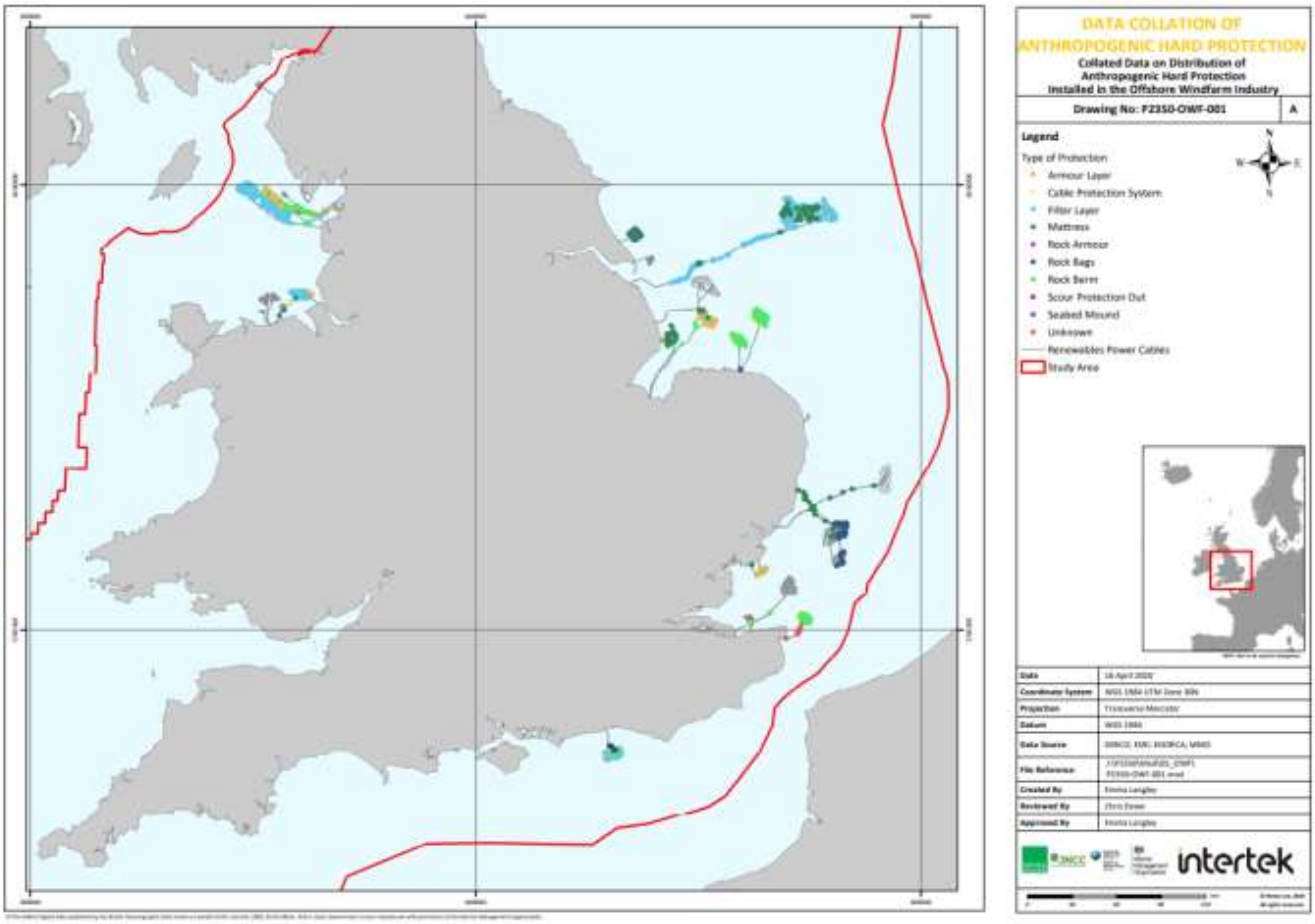

Figure 3: Collated spatial data on types of hard protection installed in the offshore wind industry in the EEZ boundary, as of 2020. From: MBIEG (2020).

Similarly, RPS (2019) reported that rock and mattress protection are the predominant types of cable protection measures used for protecting offshore wind export cables and interconnector cabling in the UK. This was based on data assimilated through a data mining and questionnaire exercise.

5.5 Operational Phase Activities

Marine renewable and telecommunication cables have a typical design life of 20-25 years (EMEC, 2015; Carter and Burnett, 2015) and unless there is a need for repairs or cable replacement (partially or fully), the cables remain buried and external cable protection remains in place for the operational life span of developments.

If cable sections need to be recovered for repairs or replacement, this may require work to subsequently re-bury the cabling, typically using methods similar to the initial installation process. Alternatively, new or additional external cable protection may be used if cable re-burial cannot be achieved after repairs/replacement work. External cable protection measures tend to remain in place for the operational life span of developments, hence may be in place for decades. If the cabling is left *in-situ* at the time of decommissioning, then additional cable protection may also be required and may necessitate an Environmental Impact Assessment (EIA) and related marine licensing for use.

5.6 Benthic Ecological Impacts Synopsis

5.6.1 Cable Installation Phase

Several literature reviews were found that reported on a range of (direct and indirect) impacts to subtidal benthic ecological communities, from subsea cable installation and external cable protection, which are discussed in the following report sections. Typically, this related to the introduced hard substrate placed in soft sedimentary habitats (or hard substrata areas of seabed), and hence constituting a change in habitat type and an assumed long-term loss of natural habitat.

Given the rapid OSW sector development in the last 10+ years, this review focussed on evidence (including technical reviews and syntheses) from 2012 to 2023. However, it is acknowledged that earlier reviews on the environmental effects of cabling on a wide range of receptors in the UK have been conducted, such as the UK Department for Business Enterprise and Regulatory Reform, (BERR) (2008) review of cabling techniques and environmental effects applicable to the offshore wind farm industry.

The Marine Management Organisation (2014) together with Defra and Cefas, commissioned a review of OWF post-consent monitoring data to help inform recommendations for improving future licence-related monitoring strategies. In the UK, there have been OWFs with marine licence conditions requiring post-consent benthic habitat and community monitoring to verify the predictions made in the EIA by developers/applicants (i.e., EIAs provided with the marine licence applications). The MMO (2014) review found that the resultant OWF monitoring data identified a lack of ecological impacts due to the OSW cable laying. This was typically where seabed samples mainly targeted seabed infauna and had been collected using seabed grabs in OWF cable corridors (and the OWF array). Cabling works typically caused an initial disturbance to the seabed, and associated infaunal communities, that was followed by a period of recovery. No changes in epibenthic communities (and smaller fish) were detected. However, The MMO (2014) review noted important limitations in the monitoring design and data analyses, which made it difficult to clearly differentiate between natural variability and impacts arising from construction of the OWFs and introduced uncertainty in the final assessment of non-significant impacts to benthos

Renewables Grid Initiative, RGI (2015) provided a general overview, from available literature, of potential ecological impacts over the subsea cable lifetime. For intertidal and offshore benthic habitats, the impacts covered in the review were seabed disturbance, increase in suspended sediment concentration and deposition, potential contaminant release from sediment, electromagnetic fields (EMF) and thermal radiation. The RGI (2015) report determined that in line with other reviews e.g., BERR (2008), seabed disturbance resulting from subsea cable activities is generally considered temporary and of a relatively limited spatial extent.

Taormina *et al*. (2018) reviewed existing knowledge on potential ecological impacts from subsea cabling and identified knowledge gaps and recommendations for monitoring and mitigation. For the installation, decommissioning and operational maintenance stages, Taormina *et al*. (2018) identified the following impacts of relevance to benthic invertebrates:

- Physical seabed changes and seabed disturbance.
- Sediment re-suspension.
- Release of sediment buried contaminants.
- Underwater noise.

In regards to the presence and operation of the cables, Taormina *et al*. (2018) listed the following impacts of relevance to benthic invertebrates:

- Benthic epifauna fauna colonisation and presence on/around artificial hard substrate of the cable and protection system, and a resultant 'reef effect'.
- Potential presence of invasive non-native species on introduced hard substrate of the cables and protection measures.
- A potential reserve effect if the cables/cable protection measures prevent or minimise seabed impacting activities e.g., fishing and anchoring.
- EMF and heat emissions from the cabling.

Taormina *et al*. (2018) produced a synthesis of the importance of potential impacts caused by subsea cabling during the cable lifetime, based on a literature review. For instance, the authors determined that turbidity increases from cable installation constitute localised and short-term effects, and that sediment-buried contaminants suspension during cable installation disturbance, is considered to be spatially localised and unlikely to have significant impacts on benthic communities. In regard to reef effects, it is highlighted that the extent of the reef effect depends on the size and nature of the cable protection structure, but also the characteristics of the surrounding area and native populations. Taormina *et al*. (2018) note that reef effects from the presence of the cables and cable protection measures may be viewed as positive, in terms of potentially increasing density and biomass of epifauna and mobile fauna that are native species. Yet, this is balanced with the potential for negative environmental effects if the cable protection measures facilitate the settlement and spread of non-native invasive species. Taormina *et al*. (2018) considered there to be a localised impact from EMF where a cable is buried, but indicated a potential high uncertainty for benthic invertebrates being impacted from EMF in view of evidence gaps (at the time of writing). Furthermore, Taormina *et al*. (2018) highlighted that knowledge gaps remain, including better knowledge of amplitude and duration of impacts associated with subsea cables, particularly EMF impacts and assessment of cumulative impacts.

RPS Ltd (2019) reviewed the effectiveness of cable installation techniques and reviewed available evidence for environmental impacts, and recoverability of subtidal seabed habitats from OSW and interconnector cabling. Cable installation techniques, including route selection, installation tools and methods and types of standard cable protection were reviewed. Some of this detail (i.e., installation methods and technical detail of cable protection measures), has been captured in this report in Sections 5.2 and 5.4.

RPS Ltd (2019) gathered information on external cable protection measures in place around OSW case study regions in England (North East, East Anglia, The East, South East and North West).
This was achieved via a data mining process of publicly available data and using project-specific information from a questionnaire to companies/developers of defined interconnector cables and offshore wind/offshore transmission owners. They determined that 26.45 km of cable was protected by rock placement, that 3.74 km of cable was protected by concrete mattresses, and that 0.05 km of cable was protected by concrete bags.

RPS Ltd (2019) completed a review of publicly available monitoring reports, mainly from OSW cables. Several of the OWF post-consent monitoring studies were the same as those included in the MMO (2014) report as these were prior to and up to 2013/14. However, the RPS (2019) report also included relevant and available benthic monitoring studies between 2015 and 2017. The RPS Ltd (2019) review of the UK OWF monitoring data was intended to help improve the evidence base about impacts and recoverability of seabed habitats and benthic habitats/communities, specifically relating to the extent of direct impacts on the seabed (e.g., from cabling or external able protection, including scour). In the case of the OWF post-consent monitoring studies reviewed by RPS Ltd (2019), little or no benthic ecology data were available from within the direct disturbance areas of cable installation i.e., cables trenches. The exception was seabed imagery data for the Humber Gateway OWF. In considering physical impacts to the seabed from cable installation and indirect effects to benthic fauna receptors e.g., from sediment deposition due to cable trenching, the OWF monitoring data reviewed by RPS (2019) were mainly geophysical datasets. The geophysical datasets were usually related to marine licence requirements, e.g., post-construction monitoring of scour effects around the turbines and cable protection, or cable integrity monitoring, rather than being collected for the specific purpose of assessing seabed recovery or changes in seabed sediments.

Of the post-construction monitoring studies where benthic sampling along the export cable route had been conducted, the monitoring datasets reviewed by RPS Ltd (2019) identified no significant effects on benthic communities in a range of sediment types. Any changes recorded in benthic communities that were monitored were concluded to be within the natural variability in the regions surveyed in the UK. The lack of significant effects was noted to be limited to indirect impacts, as direct benthic impacts were not monitored in the studies (RPS Ltd, 2019). The review by RPS Ltd (2019) also referenced mitigation measures used by the sectors, such as cable routing to avoid sensitive benthic habitats, and highlighted knowledge gaps at the time e.g., improved quantification of suspended sediment from different types of cable installation techniques.

Natural England (NE) and The Joint Nature Conservation Committee (JNCC) produced guidance in 2022 on nature conservation considerations and environmental best practice for subsea cables, for English inshore and UK offshore waters. Links between activities and pressures to marine features within Marine Protected Areas (MPAs), including benthic communities, were identified to help inform conservation advice. It is noted that the pressures identified are also considered relevant for features and exposure to marine activities and associated risks to features outside of MPAs.

A pressure is defined as the mechanism through which an activity has an effect on any part of the ecosystem (JNCC, 2019). The nature of the pressure is determined by activity type, intensity and distribution, and cable related activities can consist of multiple pressures (Natural England and Joint Nature Conservation Committee, 2022). Additionally, due to variations e.g., environmental conditions and types of cables, potential pressures and the scale of those pressures exerted on the marine environment may be significantly different for each cable application dependent on the type of activity taking place (Natural England and Joint Nature Conservation Committee, 2022). The most commonly occurring pressures identified were for cable laying preparation works, cable burial and the installation of external cable protection, drawing on previous MPA based work.

The NE and JNCC (2022) guidance identified pre-sweeping, sand wave clearance, pre-lay grapnel run and boulder clearance as the most commonly occurring pressures, for cable laying preparation works. The effects included:

- Habitat structure changes- removal of substratum (extraction).
- Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion.
- Abrasion/ disturbance of the substrate on the surface of the seabed.
- Changes in suspended solids (water clarity).
- Smothering and siltation rate changes.

It is noted that the list is not exhaustive and there may be other relevant pressures not listed that could need considering (for example in a consent application).

For cable burial, the most commonly occurring pressures were identified as:

- Habitat structure changes- removal of substratum (extraction).
- Penetration and/or disturbance of the substrate below the surface of the seabed, including abrasion.
- Changes in suspended solids (water clarity).
- Smothering and siltation rate changes.
- Abrasion/ disturbance of the substrate on the surface of the seabed.
- Water flow (tidal current) changes, including sediment transport considerations.

Commonly occurring pressures associated with the installation of external cable protection e.g., rock, mattresses, grout bags were identified as**:**

- Physical change (to another seabed type),
- Physical change (to another sediment type),
- Changes in suspended solids (water clarity),
- Abrasion/ disturbance of the substrate on the surface of the seabed,
- Water flow (tidal current) changes, including sediment transport considerations.

For the cable installation phase, the NE and JNCC (2022) best practice guidance covered environmental considerations when selecting a cable route, by using the avoid, reduce, mitigate hierarchy to reduce environmental impacts.

The NE and JNCC (2022) guidance summarised the sensitivity of a range of species and habitats (intertidal and subtidal) to the different pressures arising from cabling activities (installation and operation). For example, biogenic reefs e.g., mussel reef, are considered to be tolerant to a limited amount of smothering, but are considered highly sensitive to damage by abrasion, loss and penetration. While our review does not intend to focus on or to detail benthic species and habitat recoverability from OWF related pressures per se, it is nonetheless important that receptor sensitivity is acknowledged, as it is a key component of regulatory required impact assessments e.g., EIAs and Habitat Regulation Assessments.

The NE and JNCC (2022) guidance highlighted methods of reducing cable related environmental impacts, including minimising the amounts of external cable protection utilised and avoiding use of cable protection in MPAs or in particular habitats. The report highlighted methods for mitigating environmental impacts and in the case of external cable protection, this includes selecting cable protection materials to best match the installed environment. The removal of the cable protection at decommissioning was also a recommendation in the report, unless the environmental impact of removal is greater on assessment at the time.

5.6.2 Operational Phase – Cables and External Protection Systems

The Marine Management Organisation (2014) report contained synthesised monitoring data of turbine foundation epifauna colonisation from operational UK OWF, and provided recommendations related to the monitoring outcomes. Although focused on turbine foundations, the synthesised information is considered useful context to highlight in the current report, as it is nonetheless available information on OWF hard substrate epifauna colonisation and community presence.

At the time of the 2014 report, seven of the Round 1 and Round 2 OWFs in the UK had marine licence conditions requiring post-construction monitoring of benthic community colonisation of the turbine monopiles. The monitoring was conducted with either diver operated video or drop-down video, and involved sampling e.g., scrape sample for biomass determination. The results were generally presented as a characterisation of epifauna community occurrence and composition on the hard substrata that had been placed in soft sedimentary environments. Results were presented as trends over time and dissimilarity/similarity analysis. It was also possible from the monitoring studies to calculate total biomass provided by the epibenthic species, as well as making observations on mobile epibenthic species attracted to the turbines (MMO, 2014). Monitoring also included identifying the occurrence of any non-native species in the epifouling communities studied.

It was recognised that, overall, there were a limited number of studies that monitored the epifaunal communities on OWF turbine foundations, with available studies being of limited duration (i.e., one year). There was also a lack of studies, at UK sites, considering the long-term consequences of the turbine colonisation on the wider marine community e.g., food web interactions (MMO, 2014). Non-UK data from OWF monitoring programmes in Denmark (Horns Rev OWF) and The Netherlands (Eegmond aan Zee OWF), were highlighted as examples where studies had investigated wider trophic interactions from benthic communities on OWF hard substrata.

The MMO (2014) report highlighted that data analyses capable of detecting statistical significance of changes would be beneficial in relation to monitoring epifauna colonisation on the OWF associated hard substrata. Regarding future monitoring, the report recommended that turbine (and scour protection measures) colonisation studies should continue and be better linked to predicted impacts (from the EIAs), and to look at wider trophic impacts from the epifouling communities.

RPS Ltd (2019) highlighted a paucity of monitoring data on the effects of cable protection on benthic communities, e.g., colonisation of artificial OSW substrata, from the UK continental shelf. The report recommended that further studies to investigate benthic colonisation of cable protection should be undertaken, to improve understanding and address this knowledge gap. It was also noted that cable protection colonisation studies could help with understanding whether different cable protection measures have a different level of effect, e.g., allowing ecological function to continue to different degrees, and whether there is potential for ecological improvements in protection measures (RPS, 2019). Notably, the report also highlighted that colonisation studies should be undertaken, in which comparisons are made between different types of cable protection and/or in different environments (e.g., sediment types), to help identify the influence of protection design and environmental conditions on benthic colonisation (RPS, 2019). Particularly of relevance to this review is that the RPS Ltd (2019) report suggested that cable protection colonisation studies could be delivered, either through project-specific monitoring conditions, or through a wider initiative of collecting data over existing cable protection deployed on operational cables.

Cefas (2021) in an evidence project for Defra, investigated how to determine the potential implications of subsea cable protection on seabed benthic assemblages. A literature review covered knowledge on benthic faunal assemblage response to cable installation, with a specific focus on protection materials, and also discussed data collection methods to assess these changes. The key findings from the Cefas (2021) study were that literature on infaunal and epifaunal assemblage change associated with subsea cable protection is very limited. It was identified that hard cable protection is readily colonised by taxa normally associated with natural hard seabed, but with a lower diversity. The study concluded there is very little knowledge available on determining the potential ecological consequences resulting from changes in benthic communities associated with cable protection. Therefore, recommendations were to acquire new knowledge and imagery-based survey data, which could potentially help fill the knowledge gaps (Cefas, 2021).

The Cefas (2021) literature review highlighted the paucity of work undertaken on using imagery data to determine effects of cable protection on epifaunal communities. The review indicated a requirement for a method capable of extracting quantitative data from available ROV imagery, such as ROV imagery collected for OWF asset monitoring. As part of the project, Cefas (2021) discussed how seabed imagery data can be used to estimate changes in characteristics of colonising taxa, to aid in identifying whether/how cable protection might have implications for local ecological functioning. The report also provided guidance for key aspects of data collection and analysis required to determine meaningful seabed community changes resulting from cable protection (Cefas, 2021).

During the Cefas (2021) project, ROV footage was acquired from an anomaly survey at a UK OWF and converted to 3D models using a Structure from Motion (SfM) approach. Benthic epifauna were annotated in the orthomosiacs (3D models) produced from the SfM approach, and it was also possible to quantify size and biomass of the distinctive soft coral (*Alcyonium digitatum*) from the orthomosiac 3-D imagery. Using empirical data extracted from the 3D orthomoasics, it was considered possible to be able to capture the ecological traits composition of these assemblages, to allow assessment of ecological functional change.

The North Sea 3D project, part of the INSITE Programme, is currently using seabed ROV imagery data at OWFs to extract quantitative benthic ecological data. One of the objectives of the North Sea 3D project is to quantify biomass and secondary production associated with artificial structures (OWF turbines and oil and gas platforms) in the North Sea, using 3D imaging techniques to analyse ROV footage from industry[7].

Supplementary to the published reviews already mentioned, we have synthesised information from our literature search. This was conducted using the search strategy and criteria outlined in Section 4.1. The review process identified peer-reviewed studies that have investigated benthic community presence and development on external cable protection types, and/or subsea protection systems for pipelines (in the case of the oil and gas industry). Twelve relevant studies were identified, and these have been reviewed and key findings extracted for this report. The studies reflected the different types of marine sectors: offshore wind (fixed and floating wind), tidal energy device, wave energy device, oil and gas, plus a study that compared benthic communities on oil and gas infrastructure with those on fixed offshore wind farms (

[7] Application of novel 3D imaging techniques to quantify biomass associated with North Sea artificial structures (NS3D) - INSITE North Sea

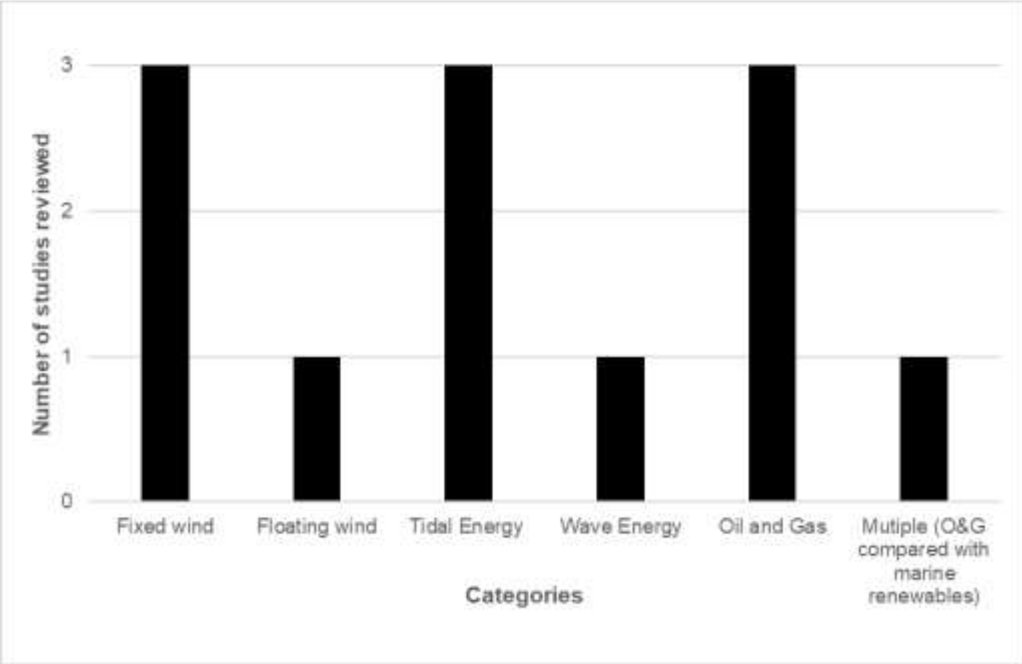

Figure 4). A summary of the number of studies reviewed, by sector and by study country are shown in Table 1.

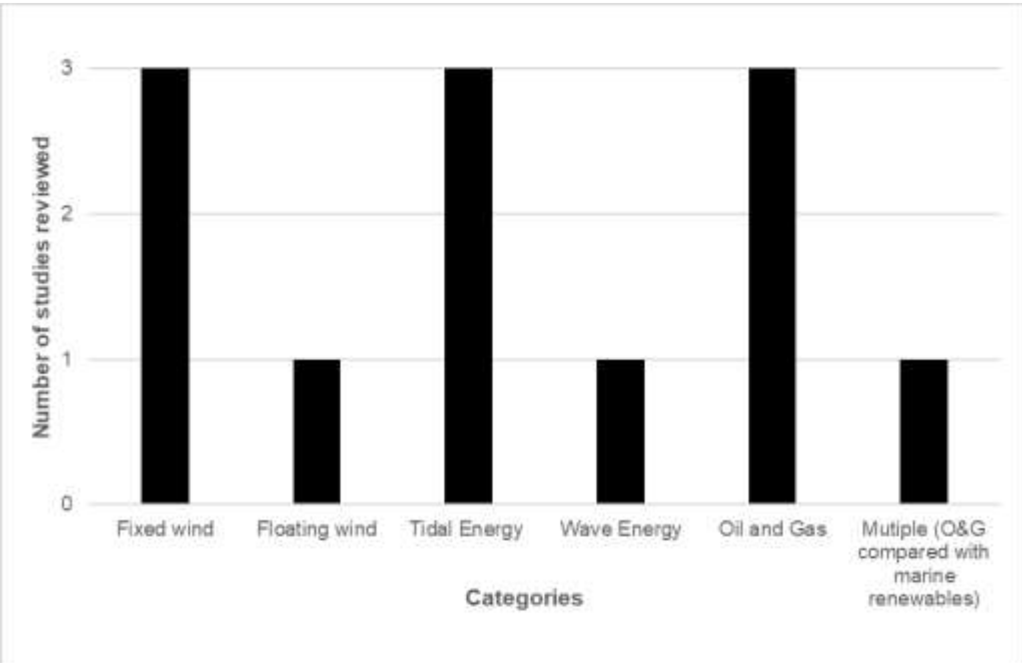

Figure 4: Number of studies reviewed, displayed by sector category - fixed and floating offshore wind, tidal and wave energy, oil and gas and multiple categories included in 1 study.

Table 1: The sector categories and countries of studies reviewed about operational impacts of subsea cable protection/ protection systems.

Of the 12 studies reviewed, it was clear that multiple ecological 'populations' were often included and reported. All of the studies reported sessile and/or mobile epifauna (invertebrate), either at a phylum, genus or species level. Several of the studies also reported data on fish and macroalgae, if these were present and captured in the survey data. The results of the studies varied in terms of presenting an inventory of phyla and specific species, and/or by functional feeding groups e.g., herbivore, omnivore or predators. Colonial growth forms were expressed as hard or soft growth or taxa , if identification enable this, as well as the corresponding percentage cover and mean colony thickness.

Very few of the studies used an ecological-traits based approach (groupings of taxa with similar traits) or indicators to specifically study functional changes in benthic communities due to the presence of the artificial external cable protection/subsea protection structures. Indeed, Taormina *et al.* (2022) highlighted the potential merits of using indicators to help assess epibenthic community ecological changes (from biological traits or functional diversity analyses) in relation to artificial structures, as well as using a multi-metric index to help assess ecological quality of epibenthic communities on artificial structures.

Sector categories	**Number of studies – operational stage only**	**Countries**	**References**
Fixed offshore wind	3	2 studies in the Netherlands and 1 study in Belgium.	Coolen et al. (2020); ter Hofstede *et al*. (2022); Coolen *et al*. (2020)
Floating offshore wind	1	Scotland, UK.	Karlsson *et al*. (2022)
Tidal energy	3	1 study in Scotland, UK and 2 studies in France.	Broadhurst and Orme (2014); Taormina *et al*. (2020a and b)
Wave energy	1	1 study in England, UK	Sheehan *et al*. (2020)
Oil and gas infrastructure	4	2 studies in UK and 2 studies in Australia. (1 study in The Netherlands also covering fixed OWF)	Lacey and Hayes (2020); Redford *et al*. (2021); McLean et al. (2021); Sih *et al*. (2022) Coolen *et al*. (2020)

Regarding the type of cable protection measures investigated, two studies (Taormina *et al*., 2020 and Karlsson *et al*. 2022) investigated epibenthic species / community presence specifically on subsea concrete mattresses. Sheehan *et al*. (2020) and ter Hofstede *et al*. (2022) investigated epibenthic species/community presence on rock dump/rock armouring. The study by Lacey and Hayes (2020) included concrete mattress, Link-lok mattress, rock dump and 3-layer polypropylene (3LPP) yellow plastic sheath.

In terms of comparisons between cable protection and surrounding seabed, most of the studies focused on epibenthic invertebrate species and communities on subsea protection systems compared to bare (unprotected) seabed. Two studies (Taormina *et al*., 2020 and Lacey and Hayes, 2020) compared epibenthic species (abundance/community composition) between different types of subsea protection system. Taormina *et al*. (2020) compared concrete mattresses (6 metres (m) long, 3 m wide, 40 centimetres (cm) high) and steel half cast shells (50 cm long and 15 cm diameter), that were installed in 2013. Lacey and Hayes (2020) compared benthic fauna communities between covering types, classified as exposed seabed with no protective measure, pipeline buried under sediment, pipeline with either concrete mattress, Link-lok mattress, rock dump or yellow plastic sheath protective measures.

None of the studies reviewed had a survey design consisting of before-after-control-impact or a before-after gradient approach. Instead, the studies tended to be a control-impact study design (e.g., Broadhurst and Orme, 2014; Coolen *et al*., 2020; Sheehan *et al*., 2020; ter Hofstede *et al*., 2022).

Of the studies reviewed, few specified if the subsea cable(s) were live or not live at the time of the data collection at the study sites. This was noted because of the potential for the live cables to then emit EMF and heat emissions which may influence the presence and distribution of benthic and fish taxa.

Ecological response metrics that were discussed in the reviewed literature tended to be relative species abundance and/or species richness (and sometimes biomass), expressed as univariate indices. Benthic community composition results were presented from various multivariate tests, depending on the available study data e.g., Analysis of similarities (ANOSIM), Similarity Percentage (SIMPER) analysis and permutational multivariate analysis of variance (PERMANOVA).

A variety of data collection methods were utilised in the studies reviewed and these were either:

- Video and stills collected with a towed video camera system.
- Video and stills collected with a towed video camera system plus catch data for crustaceans caught in deployed fishing pots.

- Video and stills collected with an ROV – often using industry inspection footage from cable/pipeline inspection surveys or bespoke scientific ROV surveys.

- Video and stills collected by scuba divers.

- Baited remote underwater stereo-video systems (stereo-BRUVs) to collect imagery of fish fauna to characterise fish communities on the various structures surveyed. Images from the BRUVs were analysed for identification of fish species and estimated species richness, relative abundance and fish lengths.

- Scrape samples of benthos from hard substratum, usually with samples collected by a diver.

A summary of the reviewed studies and key findings has been provided in the following section, grouped under different marine sectors for ease of reference.

<u>Fixed offshore wind</u>

To date, published benthic ecological studies for OWFs have generally focussed on the settlement, colonisation and development of epifaunal benthic communities on offshore wind fixed turbine foundations and scour protection. They include, for example, Wilhelmsson and Malm (2008) and Kerckhof *et al.* (2012) who studied the C-Power OWF at Thorntonbank and the Belwind farm, Belgium respectively, as well as Bouma and Lengkeek (2013) who studied the Egmond aan Zee OWF. Research has been conducted (e.g., Colson *et al.* (2017) and Lefaible *et al.* (2023)), on the epifouling communities on turbine foundations and influences, such as enrichment effects on soft sediment macrobenthic communities, in the vicinity of the foundations. There have also been studies of the artificial reef effect due to the colonisation and development of epifauna on OSW structures over time, which in turn can provide habitat, shelter and food sources for higher trophic levels (Krone *et al.*, 2017; Raoux *et al.*, 2017; Degraer *et al.*, 2020; Glarou *et al.*, 2020).

The following study by ter Hofstede *et al.* (2022) has been highlighted as it involved ROV surveys of hard substrate epibenthic communities (in relation to scour proteciton), and is thus considered informative for this review. Also, it is considered relevant in view of the ROV monitoring survey proposed in Phase 2 of the NICE project, and associated ROV imagery analyses and reporting to be completed in Phase 3 of the NICE project.

ter Hofstede *et al.* (2022) used ROV research monitoring data to investigate structure and composition of epibenthic communities on rocky scour protection in OWFs in the Southern North Sea. These were the Gemini, Luchterduinen, and Princess Amalia OWFs in The Netherlands, and the Belwind OWF in Belgium.

The scour protection age (time since installation) was approximately 5 years. ROV surveys of the scour protection and adjacent seabed area (sandy seabed) were conducted in 2021 with ROV images analysed for species presence and densities or percentage cover (for encrusting/turf taxa), followed by multivariate analysis of epibenthic community comparison between the soft (seabed) and hard scour protection substrata within and between OWFs. Differences were observed in the epibenthic species between the armour layer and sandy seabed, as well as its overlapping properties in the transition zone between the rock and sandy seabed (ter Hofstede *et al*., 2022). A higher Shannon Diversity Index (H') was identified at the armour layer in three OWFs (Belwind, Gemini, and Princess Amalia); however, a lower species diversity was observed on the armour layer at the Luchterduinen OWF (ter Hofstede *et al*., 2022). Community structure did not differ significantly between the OWFs, due to the similar age and structural composition of the scour protection and similar offshore environmental conditions at the study sites. The authors concluded that the epibenthic community sampled from the scour protection in the OWFs compared with surrounding seabed areas differed, noting species abundance was higher on the scour protection than on the surrounding seabed. The presence of several reef associated species, such as lobster and wrasse, were noted at the scour protection surveyed (ter Hofstede *et al*., 2022).

Floating offshore wind

Karlsson *et al.* (2022) used footage from an ROV inspection survey to study artificial hard-substrate colonisation in the floating offshore wind, Hywind Pilot Park, in Scotland, United Kingdom (UK). The floating OWF was constructed in 2017 and the ROV survey in 2020 was 3 years after the cables and mattresses were deployed. The seabed area in the study site consisted of mainly sand and gravel substrates with mixed sediments also present. From ROV footage collected in June 2020, the authors identified the presence of epibenthic taxa on the cabling and concrete mattresses. One of the (partially buried) concrete mattress had a fauna coverage in which the Ross worm (*Sabellaria spinulosa*) and hydroid (*Ectopleura larynx*) as well as other epifouling fauna e.g., hydroids (*Tubularia indivisa* and *Urticina* spp.) were present. The authors noted that barnacles (Balanoidea) were present abundantly along all four cables. Mobile epifauna including Asteroidea, Galatheoidea, brown crab (*Cancer pagurus*) and the Norway king crab (*Lithodes maja*) were also identified from the ROV imagery.

Wave energy

Sheehan *et al.* (2020) investigated the development of epibenthic assemblages on rock dump (and mattresses) associated with the cable present in the Wave Hub energy test site, North Cornwall in England. Repeated towed video surveys were conducted in June 2012, 2014, and 2015, with control transects perpendicular to the cable and rock protection, and impact transects over the cable protection types. Based on the results collected, it was determined that 5 years after deployment, the assemblage composition on the cable was still significantly different from the assemblage composition in the controls (Sheehan *et al*., 2020). Ecological succession was evident on the cable rock armouring from the first survey, 2 years after deployment (see example imagery in Figure 5). The results suggested that areas of cable rock armouring are becoming similar in epifauna composition to the adjacent natural rocky/coarse habitat. Longer-term monitoring was advised by Sheehan *et al*. (2020), given the length of time required for succession and development of some of the taxa associated with rocky reef habitat. Overall, this study provides an insight into the epibenthic assemblages that have developed over 5+ years, on concrete mattresses and rocks used for subsea cable protection, in an area of natural subtidal rocky reef and coarse substrate.

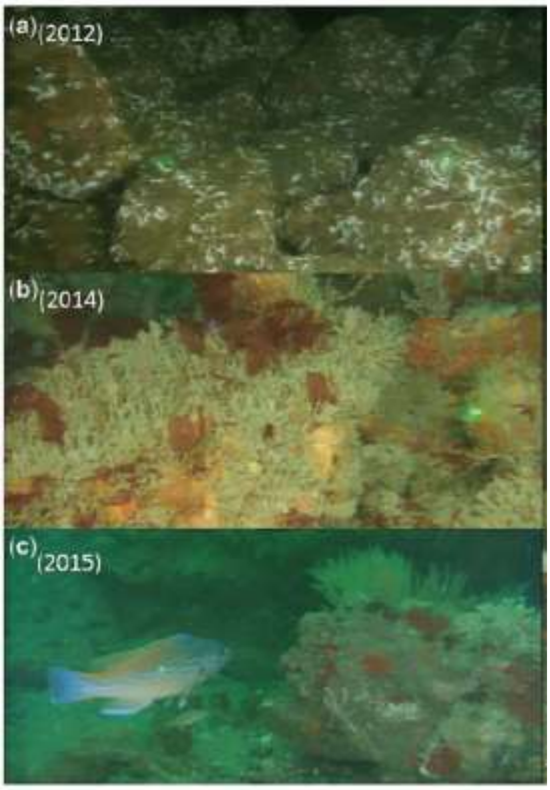

Figure 5: Video images of cable rock armouring and associated benthic taxa in 2012 (image A), 2014 (image B) and 2015 (image C). Images from Sheehan et al. (2020).

Tidal energy

Broadhurst and Orme (2014) completed a study at a tidal energy site in the Orkney Isles, Scotland, UK. The study compared the benthic community composition in proximity (200m, 400m, 600 m) to the operational tidal energy device with a nearby control site. The study site was in an area of high tidal current, with seabed substate consisting of gravel and pebbles, bedrock and large stands of kelp (*Laminaria hyperborea*), and other macroalgae species. The study focused on crustaceans, echinoderms and molluscs, comparing catches from fishing pots and imagery from towed video (including identification of physical seabed substrate and ecological cover). Species richness, Shannon-Wiener Diversity Index and Pielou's Evenness were calculated, and a comparison made of species, taxa and feeding regime between control and test sites over 3 seasons (2009-2010). The results of Shannon-Wiener Diversity (H′) analysis indicated significant differences between the control and device survey sites over the seasonal sampling periods. Pielou's evenness (J') was not significantly different within or between sites (device or control sites) or between seasonal sampling periods (Broadhurst and Orme, 2014). The composition of the benthic species recorded within the device and control sites were largely represented by the crustaceans, velvet crab (*Necora puber*) and brown crab (*Cancer pagurus*). Whereas European lobster (*Homarus gammarus*) were frequently observed at the device site only. Broadhurst and Orme (2014) concluded that increased species biodiversity and compositional differences within the device site were observed, compared to a control site. The tidal energy device was also concluded to be acting as a localised artificial reef structure. The authors highlighted that further investigations (with additional methods or wider scale studies) were recommended to expand on the small-scale study (Broadhurst and Orme, 2014).

At the Paimpol–Bréhat tidal test site in Brittany, France, Taormina *et al.* (2020a) studied epibenthic succession on concrete mattresses and steel half cast shells installed in 2013 to protect cabling at the site (Figure 6) and comparison with a control site. Repeat surveys were undertaken in summer 2014, winter 2015, summer 2015, summer 2016, summer 2017 and winter 2018), where divers collected still imagery of the cable protection systems and neighbouring natural seabed. The study site had strong tidal currents and seabed consisting of pebbles, rock, and some coarse substrate. Data from the surveys showed that the composition and ecological succession of epibenthic communities differed between the different habitats. Taormina *et al*. (2020a) reported that epibenthic communities on artificial substrates were significantly different between mattress and half-shell habitats, except during the 2014 and 2015 summer campaigns (based on pairwise PERMANOVA tests conducted based on Bray–Curtis similarities in epibenthic taxa percentage cover). Across all sites and habitat types, community composition changed significantly over time (based on pairwise PERMANOVA tests conducted based on Bray–Curtis similarities in epibenthic taxa percentage cover). Taormina *et al*. (2020a) concluded there were clear differences in community structure between artificial and natural habitats; differences in community structure between the three sites; and larger temporal changes in communities colonising artificial habitats relative to those found on natural hard substrates. Overall, this study provides an informative insight of benthic community succession on artificial substrata over 4+ years.

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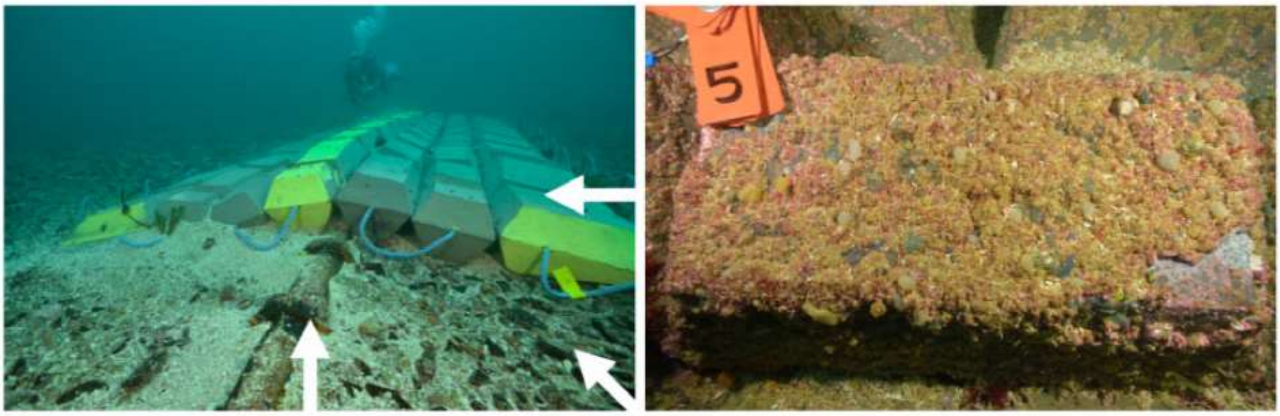


Figure 6:. Image of cast iron half-shells and a concrete mattress (following installation), together with natural seabed habitat on left; and a close-up of a concrete mattress unit several years after installation, with evidence of colonised benthic fauna. Images from Taormina et al. (2020a).

At the same tidal energy test site in France, (Taormina *et al.*, 2020b) investigated the habitat potential of concrete mattresses specifically for five target species: European lobster (*H. gammarus*), brown crab (*C. pagurus*), conger eel (*C. conger*), Ballan wrasse (*L. bergylta)*, poor cod and pouting (*Trisopteru*s spp). Diver surveys were undertaken between June 2015 to September 2019, surveying 45 different concrete mattresses that had been in place for 3+ years. Divers recorded the counts of the five target species and collected video of the mattresses, for identification of substratum type and number of cavities (classified as either holes or caves) on the mattresses. The authors derived abundance data for each key species and community composition analysis. They found that poor cod and pouting were the most abundant taxa recorded. Excluding poor cod and pouting, no significant temporal change in total abundance was identified. Species richness per mattress did not significantly change over time. Redundancy analysis showed that the environmental variables that best correlated to the variability in taxa composition were, in order of importance: number of caves, percentage of boulders, exposure to current, number of holes and percentage of pebbles. Based on data collected, Taormina *et al*. (2020b) estimated a species-specific density of around 0.1 individuals per m^2 for each mattress. By extrapolating these density estimates to all the 120 mattresses, Taormina *et al*. (2020b) determined that the associated populations inhabiting these structures could be up to around 125 lobsters (*H. Gammarus*), 162 conger eel (*C. conger*), 162 brown crab (*C. pagurus*), 119 Ballan wrasse (*L. bergylta*), and 357 Poor cod and pouting (*Trisopteru*s spp.).

Figure 7 from Taormina *et al*. (2020b) displays a helpful visualisation of epibenthic colonisation on natural habitat (left image), half-shells (middle image) and mattresses (right) of the Paimpol–Bréhat tidal test site, noting the differing influences of the elevation, stability and materials of each of these protection measures on epibenthic colonisation and development.

Figure 7: Conceptual diagram of the epibenthic colonisation of the three different habitats of the Paimpol–Bréhat tidal test site. Natural habitats (left), Half-shells (middle) and mattresses (right). From Taormina et al. (2020b).

Oil and gas sector

Lacey and Hayes (2020) used ROV pipeline survey footage from surveys in the UK Continental Shelf, to investigate differences in composition of epifauna between protection types, for a range of operational pipelines in the North Sea. Sediments in the North Sea study areas were a mix of sand and mud, with areas of coarse sand, gravel and rock. The analysed ROV footage (2012-2013) covered various pipelines across the Central and Northern North Sea, at varying water depths. The available footage was concentrated in the 500 m safety zones surrounding the platforms. ROV footage from a 600 m distance from the platform and sections at located distances along the pipelines (mid-line sections) were also analysed. Lacey and Hayes (2020) identified six types of protective structure used in the analyses; (i) exposed pipeline with no additional protection; (ii) buried, completely covered by sediment; (iii) concrete mattress; (iv) Link-lok mattress; (v) rock dump and (vi) 3-layer polypropylene sheath. From the ROV footage, Lacey and Hayes (2020) derived estimates of temporal and spatial changes in epifaunal species richness and community composition. Significant differences in species richness were only found between the exposed, surface laid pipeline and the 3-layer polypropylene sheath. The concrete mattress and Link-lok mattresses had the highest numbers of observable taxa, which could be related to the habitat complexity provided by the protective measures (Lacey and Hayes, 2020). In terms of the community composition, there were greater proportions of the cup coral (*Caryophyllia smithii*) on the concrete mattresses, which potentially reflected a preference for concrete surface over the plastic component of the Link-lok structures (Lacey and Hayes, 2020). The study did not have data on timings the mattresses and rock dump were installed. Hence, the potential variation in the dates these were installed (over the lifetime of the pipelines) and the similar age of the pipeline structures (>10 years), may have contributed to the low proportions of explained variance across the data set (Lacey and Hayes, 2020). The authors concluded that the benthic community composition varied between covering type and the variance in data was affected by the date the pipeline and protective layer were installed and the water depth.

Redford *et al.* (2021) utilised industry ROV pipeline inspection footage, from parts of the North Sea around the UK coast, to quantify epibenthic and fish associations with oil and gas pipelines and pipeline protection (concrete mattresses or rock). North Sea pipeline inspection footage, undertaken between 2013 and 2018, was obtained from 55 pipelines. Data on the exact age of all pipelines and protective structures was unavailable. ROV images and transects were randomly selected according to the North Sea region, based on depth bands (0–30m, 30– 60m, 70–110m and 110–150 m), and based on the pipeline protection types (concrete mattress, rock dump, bare pipeline). Redford *et al.* (2021) compared the abundances of taxa groups between treatments (bare pipeline, rock, mattress). The authors found that rock mattresses associated with pipelines had the highest number of filter / suspension feeders, compared to rock (dump) and bare pipelines surrounded by soft sediment. Abundance was 1.16 times higher on rock mattresses than on the bare pipelines and 1.38 times higher abundance on bare pipelines than rock dumps. This was hypothesised to be due to the lower numbers of predators associated with the less complex structure (Redford *et al*. 2021).

McLean *et al.* (2021) utilised ROV footage of pipelines in northern Australia to quantity the epifauna and fish community and make a comparison of marine communities along the subsea pipeline with surrounding seabed areas. Analysis of ROV imagery showed motile (e.g., crinoids) and sessile (e.g., filter feeder communities) species attached to the pipeline, which were at higher densities than on natural substrates. Turf communities attached to the pipeline comprised of >75% cover of coralline algae, ascidians, bryozoans, sponges and soft coral, that were considered different to the communities observed from hard substrata nearby. McLean *et al*. (2021) concluded that the pipeline provided a long corridor of hard substratum across a sand and mud-dominated region, which supported high coverage of predominantly faunal turf and low-complexity epibenthic communities, and a distinct fish assemblage characterised by commercially important fish species.

Sih *et al*. (2022) investigated epibenthos, and fish presence and abundance, around offshore oil and gas structures (two unprotected pipelines and two oil and gas platforms) in south-eastern Australia. They used industry inspection ROV footage and selected footage from the platforms from 2014-2015 and footage from March-April 2014 for the pipelines. Analysis of the ROV imagery identified that the platforms had diverse and well-established communities of fish, invertebrates and benthic biota, with the greatest abundance of marine life at the base of these structures. Sih *et al*. (2022) reported that the pipelines were providing a complex habitat where abundant invertebrates and fish were present, but the composition of species differed among platforms and pipelines, with different subsets of commercial fish species observed near the platforms and pipelines surveyed.

Multiple sectors (fixed offshore wind, and oil and gas)

Coolen *et al.* (2020) studied biodiversity on oil and gas platforms, at an OWF (including Princess Amalia OWF) and on natural rocky reef at sites offshore of The Netherlands. The study compared keystone taxa (sea urchin, sea anemone, mussel, and a hydroid species) species richness and composition, between the OWF, oil and gas platforms and rocky reef. Variables of water depth, age / location of structures, substrate type (rock versus steel) and if the OWF had been cleaned within five years of the sample collection timing were factored into the modelling and analyses. The oil and gas platforms were older than the OWF foundations (Princess Amalia OWF). Univariate analyses did, however, not show a significant effect of structure age on species richness. The predicted species richness in the models for the OWF fell within the range predicted for the individual oil and gas platform locations. Substrate type had only a small and insignificant effect on species richness, but a significant effect on species composition. There were observed differences in the presence of key species on artificial and natural reef habitat (Coolen *et al*., 2020). For instance, species that are very common on the artificial (steel) habitat and were also present on the rock dump around platforms were amphipods (*Jassa herdmani* and *Stenothoe monoculoides)* and the common mussel (*Mytilus edulis*).

Table 2 provides a summary of the studies reviewed and discussed in Section 5.6.2 of this report.

Table 2: Summary of available studies reviewed for each marine sector.

Marine sector	**Study**	**Summary**
Fixed offshore wind (and Oil and gas)	ter Hofstede *et al*. (2022)	The study researched structure and composition of epibenthic communities on rocky scour protection in place for 5 years, at in OWFs and steel oil and gas platforms in the Southern North Sea.
Floating offshore wind	Karlsson *et al*. (2022)	The study provides an insight into the presence of epibenthos approximately 3 years after the cables and mattresses were deployed in Scotland, UK.
Wave energy	Sheehan et al. (2020)	The study provided evidence of the development of epibenthic assemblages on rocks and concrete mattresses protection, 5 years after deployment at the site in England, UK.

Marine sector	Study	Summary
Tidal energy	Broadhurst and Orme (2014)	The study investigated benthic species biodiversity, community composition, trophic functionality and habitat type around a tidal energy test device and control sites, approximately 3 years after deployment.
	Taormina et al. (2020a)	Changes in the composition of epibenthic assemblages colonising concrete mattresses and cast iron half shells, as well as the surrounding natural habitat, up to 4 years after deployment were investigated.
	Taormina et al. (2020b)	The study investigated habitat capacity of concrete mattresses (deployed > 4 years), and interactions and preferences of the artificial structures related to crustacean species *Homarus gammarus* (European lobster) and *Cancer pagurus* (edible crab), and the demersal fish species: *Conger conger* (European conger), *Labrus bergylta* (Ballan wrasse), and two species of the genus *Trisopterus: T. luscus.*
Oil and gas	Lacey and Hayes (2020)	The study demonstrated insight into epifauna community compositions and species association, on and adjacent to protection structures of operational pipelines (and pipelines) in the North Sea.
	Redford *et al.* (2021)	The study researched the associations of fish and benthic taxa with pipelines and associated protective materials located in the North Sea, linked with artificial reef effects of the structures.
	McLean *et al.* (2021)	This study provided insights into the epifauna and fish communities associated with a subsea pipeline (and adjacent seabed) in northern Australia.

Marine sector	Study	Summary
	Sih *et al*. (2022)	This study evaluated benthic sessile and mobile invertebrate and fish communities associated with O&G structures, comparing ROV imagery analysis with reported fishery data.

5.6.3 Decommissioning Phase – Cables and External Cable Protection Systems

Decommissioning guidelines exist in England and Wales (Department for Business Energy & Industrial Strategy, 2019) and in Scotland (Scottish Government, 2022), for the decommissioning of marine renewable installations, including subsea cables and cable / scour protection systems. The guidelines include information on decommissioning requirements and required content and process connected with decommissioning programmes, as well as information on environmental and safety considerations. The guidelines also refer to international obligations for decommissioning disused installations, under the United Nations Convention on the Law of the Sea (UNCLOS) 1982 and work through the Oslo-Paris (OSPAR) Convention with OSPAR Guidance (2008) on Environmental Consideration for Offshore Wind Farm development (including consideration of decommissioning).

The various guidelines in the UK (Department for Business Energy & Industrial Strategy, 2019; Scottish Government, 2022) indicate an expectation that all offshore renewable energy installations will be fully removed at the end of their operational life, to maximise re-use of seabed areas, for the safety of marine users, and to minimise residual liabilities. However, exceptions can be considered on a case-by-case basis prior to decommissioning, taking on-board environmental conditions, the balance of risk, cost and technological capabilities at that time, with evidence provided in decommissioning programmes to enable a full evaluation of options by the relevant decommissioning authority.

Published information exists regarding methods, options and feasibilities of decommissioning OSW cables, external cable protection and scour protection systems. For instance, Arup (2018) on behalf of Marine Scotland, reviewed approaches to decommissioning offshore wind installations, and noted that to decommission cables can either mean leaving cables *in-situ*, or completely removing the subsea cables. When leaving cables *in situ*, there is the requirement for a clear seabed, therefore, the cable ends need to be located and buried at an acceptable depth below the seabed. Where the cable is already buried along its length, limited activity is generally required, while exposed sections of cable will most likely be cut and removed, or subjected to placement of rock to ensure the cables can be trawled over safely (Arup, 2018). Where cables are cut and removed, the cable end must be located and lifted to the cable removal vessel.

The lifting operation can be performed using a grapnel deployed by the vessel or using an ROV to fit a lifting attachment to the cable. Once the end of the cable has been recovered the rest of the cable is 'peeled out' using winches on the recovery vessel and is retrieved onto the vessel (Arup, 2018).

Cable decommissioning plans require consideration of the safety, environmental, technical, commercial and societal impacts of decommissioning options. Available decommissioning plans for OWFs in the UK, e.g., Beatrice OWF, indicate cable burial below the seabed will not pose a risk to marine users; that there is no associated environmental impact of buried cables and no residual pollution risk, and that it is considered more economical than complete cable removal (Arup, 2018).

Peritus International Ltd (2022) on behalf of Natural England, completed a study on scour and cable protection decommissioning. The study considered the feasibility and options for removal of scour prevention and cable protection systems during the decommissioning phase, and briefly highlighted implications for benthic habitats. Information about current industry best practice was obtained from reviewing published oil and gas decommissioning applications / plans, as the OSW sector was considered to have fewer decommissioning data available. Information on decommissioning best practice, together with recommendations and possible future improvements, were obtained through engagement with suppliers and contractors of scour / cable protection systems. Information from oil and gas and marine renewables sectors was considered, where information was available. The report discussed decommissioning options and limitations associated with either full removal or leaving in place the following protection systems: rock dump, rock bags, concrete mattresses, poly mat mattress, fronded mattresses and bitumen mattresses (the latter being in place from legacy use in oil and gas sector, but not tending to be used at OWFs).

The Peritus International Ltd (2022) report assessed available removal methods for the various protection systems (using methods such as divers, dredges, lifting baskets, subsea grapples), degradation resistance of the protection materials, highlighted the track record of removals, the current ease of removal, and the availability of future technologies to assist with removal. Each of these factors was given a score from 1 (very poor) to 5 (very good) to provide an overall ranking for each type of protection system. The assigned ranks, from highest to lowest were: (1) rock bags, (2) concrete mattresses, (3) grout bags, (4) fronded mattresses, (5) bitumen mattresses, and (6) rock dump. Rock bags were ranked highest in view of the bags being straightforward and efficient to remove, since there are available removal options and there is also a track record of rock bag removals. Rock dump was ranked lowest as the loose rocks are considered difficult to fully remove, and there are no known cases of rock protection deposits being removed. However, the rock material was noted for resistance to degradation over time when in place. The report recommended that for future projects requiring scour protection [and cable protection], developers may wish to consider solutions, such as NID solutions, that can be left *in-situ* at the end of the project lifespan. This was based on the consideration that NID solutions may have minimal to no negative environmental impacts and it is likely to be more cost effective and potentially sustainable to leave the NID measures in place.

There is a requirement in the UK for an EIA of decommissioning activities, prior to removal, to inform options for decommissioning OSW infrastructure based on best environmental practices. Knowledge of potential impacts arising from decommissioning depend on whether the cables and cable/scour protection systems are fully or partially removed. Hall *et al.* (2022) summarised potential benthic ecology impacts arising from decommissioning of cables and cable protection. Potential impacts from decommissioning include changes in sediment movements, mobilisation of contaminants, increased turbidity and introducing new material to fill voids, as well as potential for fluidisation of seabed, and habitat smothering and loss of habitat – notably artificial reef habitat - when the cable protection measures are removed. It is, however, acknowledged that impacts may vary depending on the type of seabed, surrounding habitats present, and removal methods available.

Hall *et al*. (2022) highlighted the potential for a range of impact pathways between effects to benthos and the processes which thus support ecosystem services. The authors also noted that the significance of habitat loss (i.e., protection structure and epifouling fauna on the structures), would likely depend on the direct/indirect use and thus importance of the habitat, by marine fauna, and if invasive species were established. Additionally, in the scenario of full removal, there is the debate as to whether the benthic habitats and communities will recover to a pre-impacted state. There is also ongoing debate about the merits of using OSW infrastructure as long-term, artificial reefs and the potential environmental benefits of leaving the OSW infrastructure in place.

5.7 Nature-Inclusive Design and OSW

Marine NID refers to structures that have been designed to mimic natural structures, using natural elements and features. The purpose being to create habitat suitable for native species/communities where the natural habitat has been modified, reduced or degraded (Hermans *et al.*, (2020). There are also other terms associated NID, such as building for nature.

With the expansion of OSW, in the UK and internationally, there is interest from various stakeholders to explore marine NID options that can be added to or included in the design of OSW infrastructure. The interest in the use of NID in the OSW sector is generally linked to habitat enhancement potential and potential for habitat recovery within areas of OSW development (Lengkeek *et al.*, (2017); Hermans *et al.*, (2020); Blue Marine Foundation, (2022)).

In the UK there is reference to this developing field of NID knowledge in Natural England's Approach to Offshore Wind (2021). In this Technical Information Note (Natural England, 2021), Natural England refer to the strategic aim for each new offshore wind development to leave nature in a better state. With reference to this aim and NID of hard infrastructure as a potential solution, the technical note states: “There are also opportunities for new thinking on infrastructure design that enhances biodiversity, reduction of pressures on biodiversity, and restoration of habitats and species”.

NID options can be classified into three categories based on the aspect of the offshore infrastructure they apply to (from Hermans *et al.*, (2020)):

i) Add-on options refer to structural additions in a design of an offshore substation (or a monopile). These can include, for example, NID to provide habitat for fish.

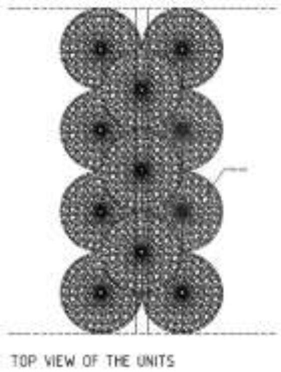
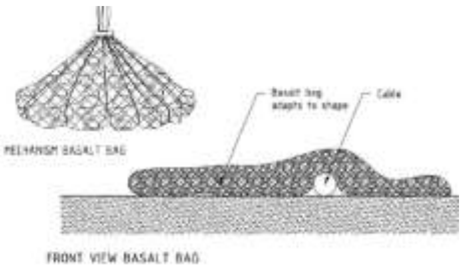
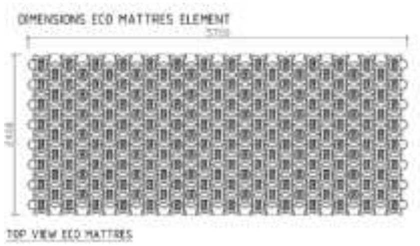
ii) Optimised scour protection layer: optimisation of a standard scour protection design for a monopile or a substation.

iii) Optimised cable protection layer: optimisation of a standard cable protection design for a subsea power cables or cable crossings.

The focus of this report is on **NID principles for cable protection (iii above),** yet relevant information exists from NID scour protection and so this has also been referenced**.** The process of optimising the external cable protection systems refers to adjusting existing cable protection systems. NID design principles can include the addition of larger or small structures to create holes and crevices, to provide adequate shelter / holes for various sized marine species, thereby helping to increase marine habitat complexity. Larger holes or crevices of 1-2 metres diameter or more could increase suitable habitat for larger mobile species, while smaller holes or crevices (few centimetres) may help increase smaller scale habitat complexity for small species or juvenile / early life stages of larger marine species (Lengkeek *et al.*, 2017). Other design principles for NID include using materials that support settlement of species and may mimic properties of natural substrates (Lengkeek *et al.*, 2017).

Hermans *et al.* (2020) produced a catalogue of NID cable protection options available in Europe (including the UK) at the time of writing, and these are summarised in Table 3.

Table 3: Examples of NID cable protection options, and potential associated ecological benefits (Adapted from Hermans et al., 2020).

NID cable protection example	Summary specification	Summary of potential ecological benefits
Filter Unit® 	A mesh net filled with rocks that can be installed for scour and/or cable protection, or at cable crossings. Quarry rock with a well-sorted grading of 40-200 kg and a polyester mesh are used in the units.	Filter units are usually placed for a structural function. The filter unit design can be optimized to fulfil ecological function, such as habitat for juvenile fish and invertebrates. The surface of the filter units offers a surface for colonisation and development of epifouling species.
Basalt bags 	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 and a basalt mesh are used.	Basalt bags create crevices of varying sizes which provide shelter for fish, like juvenile Atlantic cod, and crustaceans such as edible crab and European lobster. Additionally, other species can inhabit the bags, promoting the formation of an artificial reef.
ECO Mats® 	Mattresses which can be used for cable protection. The mattresses are comprised of separate concrete units. The units are linked and give a flexible structure which can be placed on top of subsea cables. ECOncrete®'s admix, added as ~10% of the cement content in	ECO Mats® provide substrates for a wide range of species, including species such as the European flat oyster (*Ostrea edulis*). The mats are placed on top of other structures and create holes of varying sizes for marine taxa to use.

NID cable protection example	Summary specification	Summary of potential ecological benefits
	the mix, strengthens the concrete's compression forces and reduces the CO_2 footprint.	
Reef cube®™  reef cubes® - ARC Marine	Reef cubes are placed in a cage-like structure on top of cables to function as cable protection. Reef cubes are created from low carbon alkali-activated material binder and 98% recycled and plastic-free materials.	Reef cubes have holes that help provide shelter for fish such as juvenile Atlantic cod, and crustaceans such as edible crab and European lobster. Reef cubes also provides substrate for the settlement and growth of sessile epibenthic species.
Marine Matt®™  Marine Matt - ARC Marine	Flexible mattress made of Reef cubes. The mattresses are made from low carbon alkali-activated material binder and 98% recycled and plastic-free materials. There are ridges and crevices to enhance the structural complexity of the mattresses.	The structure and materials allow for the settlement of sessile organisms. Small individuals (juveniles) can also seek shelter in the smaller crevices created in and between the reef cubes.

Consideration of NID options for OSW has gained interest in The Netherlands, in particular. Regulations introduced in 2016 require permit holders of offshore wind farms to "make demonstrable efforts to design and build the wind farm in such a way that it actively enhances the sea ecosystem, helping to foster conservation efforts and goals relating to sustainable use of species and habitats that occur naturally in the Netherlands" (from Hermans *et al*. 2020).

In 2017, a project was commissioned by the Netherlands Ministry of Economic Affairs to look at implementation of 'Building with North Sea Nature' and to enhance native marine biodiversity. The project generated a guide for the eco-friendly design of scour protection structures around monopiles in planned wind farms, with the aim of optimising scour protection to enhance ecological functioning (Lengkeek *et al.*, 2017). The guidelines by Lengkeek *et al.* (2017) cover the type of hard substrate material or products available and how these can potentially enhance ecological functioning (and have added value compared to regular types used). They also include information on how different types of hard substrates and configurations can be (experimentally) designed to enable robust research into the ecological effects of enhancement. They also include information on how the effects of these scour protection structures can be monitored and evaluated, as well as whether site-specific conditions apply to planned OWFs in the Dutch North Sea (Lengkeek *et al.*, 2017).

In The Netherlands, a North Sea 2050 Spatial Agenda[8] has been drawn up and will inform the future development of a North Sea Strategy 2030[9]. One of the themes of the North Sea 2050 Spatial Agenda is 'Building with North Sea nature'. Environmental evidence is being acquired via offshore wind research programmes, such as the Dutch Governmental Offshore Wind Ecological Programme (Wind op Zee Ecologisch Programma, WOZEP), The Monitoring and Research, Nature Enhancement and Species Protection (MONS) Programme, or via obligations for building a windfarm via site decisions (in the Netherlands).

Work in the Netherlands is underway to enhance nature within OWFs in the North Sea, by developing and implementing biodiversity enhancement measures, primarily biogenic reef species e.g., oysters and reef associated species e.g., fish and crustaceans (Bureau Waardenburg, 2020). Biodiversity enhancement is defined as the "process of assisting a general increase in the number of species or species richness" (Bureau Waardenburg, 2020). Among the research being undertaken within the North Sea are pilot projects involving creation of artificial reefs for native oysters at several OWFs, including Luchterduinen, Gemini and Bluewind[10] . Water change holes have also been installed at the Hollandse Kust Zuid wind farm in all

[8] https://www.noordzeeloket.nl/en/policy/noordzee-2050/

[9] https://www.noordzeeloket.nl/en/policy/development-2030/

[10] Home | The Rich North Sea (derijkenoordzee.nl)

140 turbine foundations. Ecological monitoring is underway to ascertain water conditions inside and outside the holes in the foundations and implications for the living conditions of marine communities settling in/outside of the hole structures and adjacent areas over time[11].

Biodiversity enhancement measures include artificial substrates deployed to create artificial reefs on soft sediment or scour protection or cable protection measures. Bureau Waardenburg (2020) investigated options for biodiversity enhancement in existing OWFs in the Dutch Continental Shelf waters. The report provided information on strategies and measures to enhance biodiversity, including considering types of materials used for artificial reefs. These include natural stones, large artificial structures with holes, smaller scale structures with fine habitat complexity, or use of materials that provide/mimic natural substances e.g., shell material.

Bureau Waardenburg (2020) considered the potential for biodiversity enhancement in existing and planned OWFs in The Netherlands. This included factoring in the range of (biotic/abiotic) conditions at sites that are required for the biodiversity target species being researched i.e., reef building species e.g., mussels, oysters, polychaete worms; reef associated species e.g., soft corals, anemones, sponges, fish, crustaceans; and reef benefiting species e.g., pelagic and demersal fish and sharks. The Bureau Waardenburg (2020) report set out steps to aid with successful implementation of biodiversity enhancement measures at OWFs. The report considered that the completion of a baseline survey of substrate and biodiversity at the intended site(s) and locating and protecting marine biodiversity hotspots were essential steps. This could be followed by options in the form of the deployment of natural substrates, or the (re-)introduction of reef building species, or the deployment of artificial reefs on soft sediment or OWF scour protection. The Bureau Waardenburg (2020) report also suggested a range of approaches to ecological monitoring e.g., use of remote cameras and imagery for observations or collecting seawater and sediment cores, as well as providing suggested approaches to measuring the success of biodiversity enhancement measures compared with baseline biodiversity.

Hermans *et al.* (2020) outlined key considerations, opportunities and risks associated with optimised forms of cable protection (i.e., NID) that are intended to promote biodiversity enhancement. The authors considered the ability to adapt standardised cable protection measures to NID measures, was a positive. But there are important technical considerations to bear in mind regarding NID protection placement and effects from cable heating, the need for space for cable maintenance, and additional method installation needs associated with NID cable protection measures. With regards to NID cable protection, it was highlighted by Hermans *et al*. (2020) that the adapted cable protection layer should aim to be species-specific, use eco-friendly material as much as possible, and could benefit from randomized patterns in the

[11] The Rich North Sea | Vattenfall (derijkenoordzee.nl)

armour layer. Mollusc shells could also be placed on top of the armour layer to create a stable layer and a calcareous element. Hermans *et al*. (2020) summarised risks including ensuring the NID measures are stable on the seabed, that the NID measures do not damage the cables and that the NID measures do not impinge or disrupt cable maintenance activities. Additional risks included a lack of ecological success of the NID measures, the settlement of invasive non-native species, absence of target species, and competition between target species/lack of food for target species.

Based on workshops with a wide range of stakeholders from Nordic countries, e.g., Norway, Finland, Demark, Iceland, a report was prepared by Nordic Energy Research (2023), highlighting NID research that is ongoing outside of the Nordic countries and considered the potential for NID design in OWFs in Nordic countries. The report highlighted that the appropriateness of NID measures can vary between biogeographic regions, and that NID use should be considered on a case-by-case basis given differences in site environmental conditions, the types of turbine technologies used and potential to use the NID measures for different ecological target species.

A summary report by The Nature Conservancy and INSPIRE Environmental (2021) catalogued NID measures available for OWFs in the United States of America (USA) (Figure 8). Knowledge gaps were identified in the report, including the need to document the marine environmental benefits where NID measures are used. The operation of cables and OSW structures with NID measures in place, and logistical considerations on the placement of NID solutions in relation to other sea users and consideration of what will happen to NID measures (remove or remain in place) during OWF decommissioning (The Nature Conservancy and INSPIRE Environmental, 2021).

Hall *et al*. (2022) noted that at the design phase of developments, there could be consideration of using NID materials to enable structures to be modified for environmental enhancement. Also, in terms of decommissioning options, there is potential for positive reef effects to have a longer lasting impact where structures are strategically left in place (Hall *et al*. 2022).

To date, NID options have primarily been considered and are the process of being trialled at fixed OWFs, such as in the Dutch North Sea. It appears that NID options for floating OSW infrastructure have not been fully explored, although Hermans *et al*. (2020), indicated that inclusive designs could include the use of additional rocks or boulders around floating offshore wind turbine components to reduce scour from mooring lines or cables.

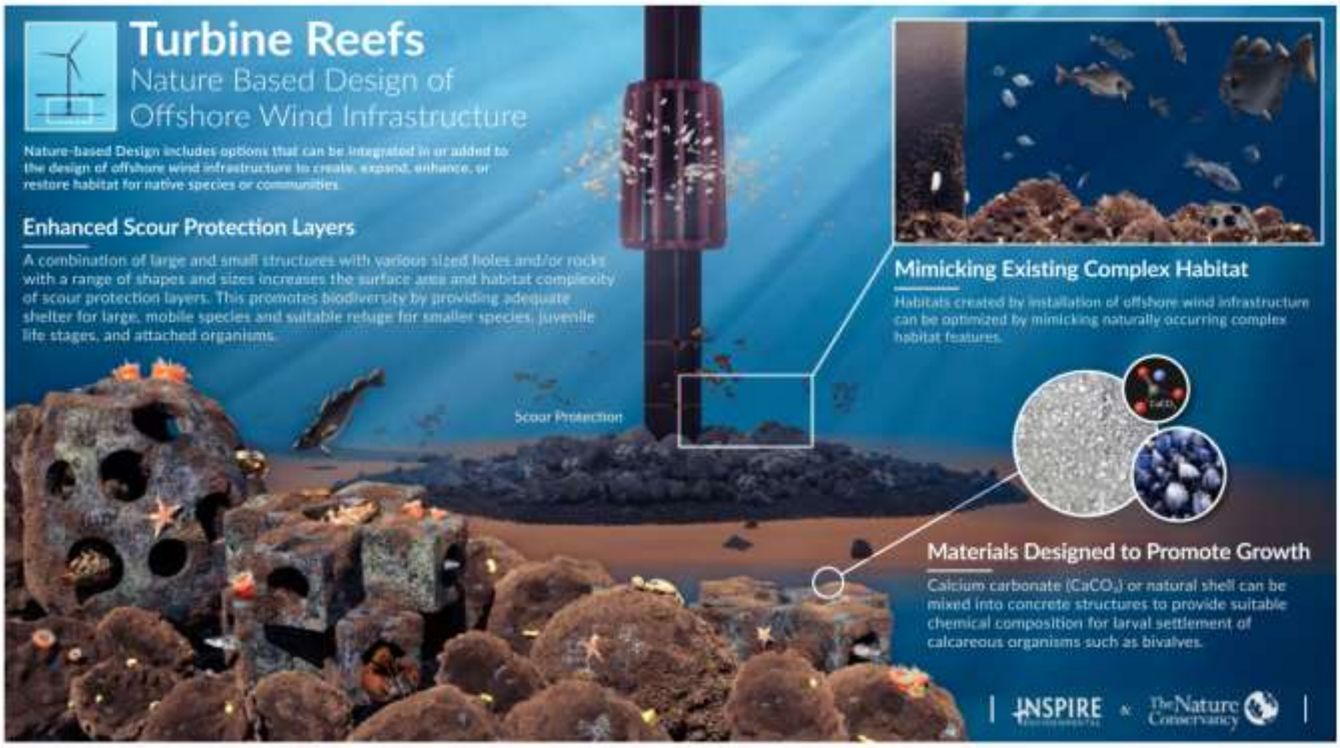


Figure 8: Image of nature-based design of scour protection for offshore wind infrastructure. Sourced from INSPIRE Environmental and The Nature Conservancy (2021).

Notably with the early consideration and piloting of NID solutions in OWFs (either for scour protection, cables or modifications to enhance foundations), it is important to have enough monitoring of the NID structures, to help identify the presence of species of conservation value and support evidence of the ecosystem services associated with the structures.

6. Discussion and Key Findings

The OSW sector is expanding in the UK and internationally, which will result in an increase in subsea cabling and potentially, subject to site needs and consenting requirements, an increase in the presence and spatial footprint of external cable protection measures on the seabed.

This review has summarised the main technical methods used in seabed preparation, cable installation methods and the types of standard external cable protection systems utilised in the OSW, as well as in the oil and gas and interconnector cable sectors.

In relation to the OSW sector, MBIEG (2020) identified that mattresses are in place along a number of OWF export cable routes, with other forms of protection e.g., rock armour, also installed. Previous work by RPS Ltd (2019) estimated that 26.45 km of cables were protected by rock placement, 3.74 km of cables were protected by concrete mattresses, and that 0.05 km of cable was protected by concrete bags.

Several papers documented a range of (direct and indirect) impacts to subtidal benthic ecological communities from subsea cable installation. This included information from post-construction monitoring studies of OWFs in the UK and in Europe, of which key findings have been highlighted in this report. Notably, few studies have focussed on epibenthic colonisation and community development on cable protection, or on scour protection or turbine foundation infrastructure.

In general, key impacts to benthic subtidal communities from cable pre-installation and installation activities relate to changes in habitat structure, seabed disturbance and abrasion, and changes in turbidity through suspended sediment mobilisation, contaminant mobilisation, sediment deposition and potential smothering, as well as water flow changes, including sediment transport considerations.

Additional to cable pre and installation activities, the installation of external cable protection (e.g., rock, mattresses, grout bags) can have potential impacts. These are considered as; changes in seabed type, seabed disturbance / abrasion, changes in suspended sediments, and changes in water flow and sediment transport.

In terms of operational impacts, information from post-consent monitoring of OWFs in the UK, together with studies of OWFs in the Europe (e.g., in Belgium, The Netherlands, Denmark), showed that key operational cabling/cable protection impacts relate to; benthic fauna colonisation and presence on/around artificial hard substrate of the cable and protection system, and a resultant 'reef effect', a potential reserve effect if the cables / cable protection measures prevent or minimise seabed impacting activities e.g., fishing and anchoring, and a potential for the OWF structures to act as stepping-stones for the introduction and spread of non-native invasive species. Although not in scope for this report, several of the papers reviewed had referred to the potential of cable EMF and heat emissions as operational impacts to benthic fauna.

This review identified peer-reviewed articles about benthic community presence and development on external cable protection types, and / or subsea protection systems for pipelines (in the case of the oil and gas industry). Twelve relevant studies were found and reflected the different sectors of offshore wind (fixed and floating wind), tidal energy device, wave energy device, oil and gas, plus a study that compared benthic communities on oil and gas infrastructure with those on fixed offshore wind farms. A limited number of studies specifically investigated the ecological effects of standard external cable protection measures on subtidal benthic communities over time.

From the studies reviewed, it is evident that key ecological metrics (i.e., species density, biomass, relative species abundance, and / or species richness and community composition), have typically been used to evaluate changes (over time and / or space) of epibenthic communities, in relation to presence of artificial structures - cable protection, scour protection, turbine foundations, pipelines, oil and gas platforms. Depending on the datasets, studies were able to characterise the benthic community assemblages associated with the structures.

Of the studies that investigated cabling, few had specified if the subsea cable(s) were live. All but one of the studies reviewed had conducted field research and collected experimental data. A variety of data collection methods were utilised in the respective studies: towed video camera system, ROV, scuba diver surveys and scrape sampling. Aside from visual forms of data collection at monitoring sites e.g., video cameras on ROVs or diver photography, other methods such as environmental DNA (e-DNA), can be used to determine the presence or absence of species and thus potential changes in marine biodiversity in a given study area. There is growing interest in the use of e-DNA to monitor marine biodiversity changes linked to OSW. For example, the BeWild project launched in May 2023[12],includes a component of work on integrating biodiversity monitoring with regular asset inspection at OWFs, using uncrewed surface vessels and ROVs.

Several of the studies investigating benthic ecological impacts of subsea protection systems, used either a Before and After or a Control-Impact sampling design for the monitoring. The difference in the sampling designs is likely related to the monitoring objectives and research questions being addressed, the available monitoring methods and what is practicable to complete at the respective study sites. Notably, some of the studies used historic ROV footage from subsea cable / pipeline asset engineering surveys, which has

[12] BeWild project to measure biodiversity at offshore wind farms launches | Windpowernl

limitations at is not designed intentionally to collect data of a quality needed for benthic ecological monitoring per se.

In addition, it is noted that the studies reviewed were in different geographic localities (e.g., around the UK, Europe and in Australia), conducted at different times, and were located at sites of varying environmental conditions e.g., seabed substrate type, depths, tidal currents. However, these studies provide a general picture of the types of benthic epifaunal communities that can colonise and develop over time, into potentially abundant and diverse epibenthic communities on artificial subsea protection system structures. Notably, Sheehan *et al*. (2020) and Taormina *et al*. (2020a) recommended longer term monitoring i.e., extending beyond 5 years. This could aid scientific understanding of benthic community development, and changes in the long-term regarding ecological succession (as highlighted by Taormina *et al*. (2020a)).

This review identified guidelines detailing options for decommissioning OSW infrastructure, including cables and cables protection, and scour protection systems e.g., see ARUP (2018). Other studies assessed decommissioning options and limitations associated with either full removal of, or leaving in place, different types of external cable protection/scour protection systems e.g., Peritus International Ltd (2022). In terms of decommissioning impacts to benthic communities, Hall *et al.* (2022) summarised a potential range of impacts e.g., habitat loss, disturbance etc, arising from decommissioning of cables and cable protection. It was highlighted in both the Peritus International Ltd (2022) report and Hall *et al.* (2022) study, that future OSW development may wish to consider, at the design phase, the use of NID materials to enable the OSW structures to be modified to support marine environmental enhancement. In turn, this may potentially enable NID optimised forms of cable protection to remain in place at the time of decommissioning the OWFs, but only if there is robust evidence to support this option and a regulatory framework that allows for this.

It is noted that interest in the use of NID for OSW is generally linked with the potential for exploring habitat enhancement and habitat recovery within the OSW sector. This in the context of the proposed expansion of the OSW sector and the drive towards net zero in the UK and internationally. With the expansion of the OSW sector, there will be a substantial increase in the spatial footprint of OSW hard substrata and cabling. This could provide an opportunity to introduce NID principles to OSW to help achieve a net positive impact on marine biodiversity. However, more evidence and data collection are needed (and is underway in the case of research in The Netherlands), to address questions on NID use in OSW.

This report covered the potential optimisation of OSW structures with NID features, including the shape, structure, and material composition, of the NID based solutions / measures. Information on ecological and technical considerations, opportunities and risks associated with optimised forms of cable protection, have been mentioned, based on studies that have drawn on expert knowledge including some comparative experiences in artificial reef research outside of the OSW sector. We have also provided a synopsis of the types of NID measures in use/ being considered in the OSW sector, with reference to catalogues of NID measures that have been collated for OSW research in the Dutch North Sea and for work on NID options for OSW in the USA.

This report highlighted some of the evidence gaps regarding NID measures in OSW, including the importance and need for monitoring studies related to the practical use of NID measures in OWFs. Knowledge gaps are recognised and these apply to the operation of cables and OSW structures with NID measures in place, logistical considerations on the placement of NID solutions in relation to other sea users, plus consideration of what will happen to NID measures (remove or remain in place) during OWF decommissioning. The incorporation and application of NID solutions for OSW and associated research on potential ecological impacts (whether positive, neutral or negative) is ongoing, and over time this should help increase the scientific evidence base.

Knowledge gaps

Knowledge gaps were identified in terms of understanding ecological impacts of different types of cable protection (including NID types), in connection with marine benthic species settlement and community succession over time. This includes knowledge of impacts to higher trophic levels arising from benthic artificial reefs forming on the NID and non-NID protection systems, at both individual and regional scale OWFs.

Relatively few ecological monitoring studies have focussed on cable protection systems and undertaken repeated monitoring over long time periods (i.e., > 5 years). Also, relatively few studies were found that used a biological traits-based approach to derive meaningful data on ecological functional changes, due to the cable protection. Indeed, Taormina *et al.* (2022) highlighted the potential merits of using indicators to help assess epibenthic community ecological changes (from biological traits or functional diversity analyses) in relation to artificial structures, as well as to use a multi-metric index to help assess ecological quality of epibenthic communities on artificial structures.

It has been noted that studies have not routinely been undertaken using ROVs and imagery to assess biomass and ecological functional changes, as a result of epifauna changes over time. This includes keystone species presence and shifts in species assemblages, which can in turn modify the reef-effect from epifauna to higher trophic levels. Longer-term research should be encouraged, which could use approaches such as assessing ecological functional changes using ROV imagery data from repeated ecological monitoring surveys. This could help address gaps by answering research questions about the introduction of the external cable protection artificial structures (including NID types) and the significance and consequences of the changes (positive, negative, or neutral) in benthic ecological communities, framed in terms of potential changes to marine biodiversity, marine ecosystems and potentially also associated ecosystem goods and services. This in turn would help support evidence needs behind the expansion of OSW, as well as decommissioning of OSW infrastructure.

There are gaps in terms of documented studies of NID features at OWFs and associated monitoring data from these NID focussed studies, to help address questions and understanding about whether NID features for subsea external cable protection, can potentially enhance marine biodiversity, and contribute to a net positive impact. Evidence is, however, being acquired through research being undertaken to date, such as various OSW environmental research programmes in the Netherlands and in other countries, that may add to the knowledge base over time.

7. Concluding Remarks

The following objectives of this Phase 1 review have been achieved, and have been presented in this report:

- A summary of methods for pre-cable installation work, subsea cable installation methods and types of external cable protection in use, primarily within the OSW cable sector.
- Providing a summary of the review of evidence for direct impacts to benthic fauna (epifauna) and infauna from the cable and external cable protection installation, operation, and decommissioning.
- Providing a synopsis of types of NID measures in use / being considered in the OSW sector.
- Bringing together evidence from the synopsis with broader concepts and questions for potentially using external methods of NID cable protection as an option for marine nature enhancement. This includes highlighting applicable knowledge gaps from the literature.

Information including survey methods, indicators and metrics of benthic community change, and recommendations identified during this review, will help to shape the study design and analyses to be conducted in the Phase 2 / 3 of the NICE project. The information and discussion points about benthic ecological impacts of cabling / cable protection, NID options of cable protection, information on cable/ cable protection decommissioning and evidence gaps identified during the review, will feed into the content of the Phase 3 report for the NICE project.

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