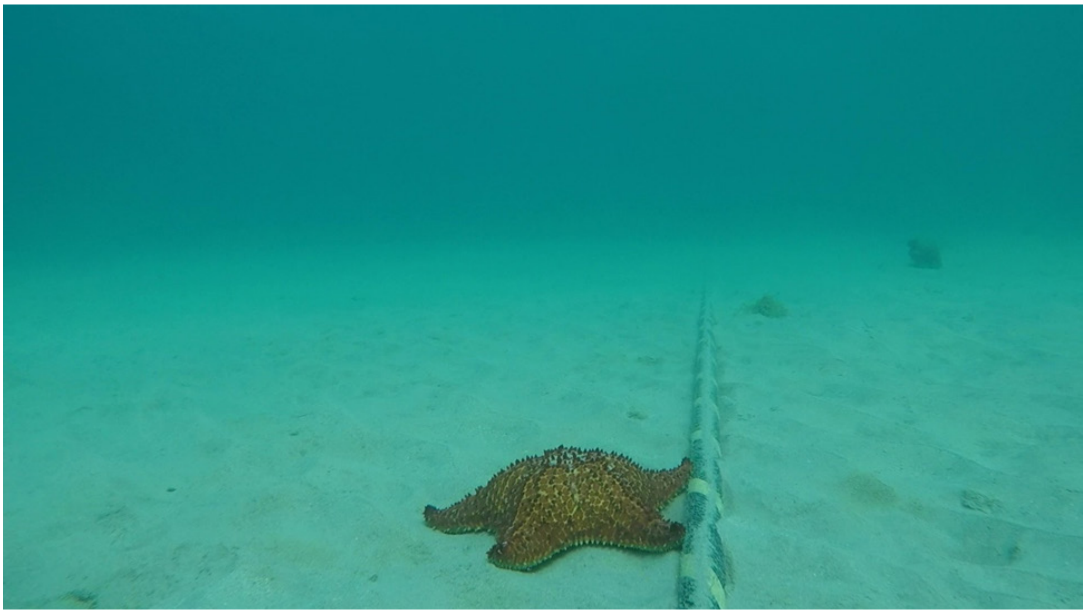
Subsea Cables within the OSPAR Maritime Area: Background document on technical considerations and potential environmental impacts



Environmental Impacts of Human Activites

2023

Subsea Cables within the OSPAR Maritime Area: Background document on technical considerations and potential environmental impacts

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Table of Contents

Figures

1 Executive Summary

This document first sets out the technical principles relating to subsea cables that carry telecommunications and power, and then relates these to their associated environmental impacts.

These topics are set out in two sections within the document, with the technical considerations in Section 4, and the environmental considerations in Section 5.

The principal sectors within the subsea cable industry can be described as:

- Telecommunications cables – fibre optic cables used to transfer communications and digital data from one place to another,
- Power cables used to transfer electricity from one place to another, which may include:
    - International grid interconnection,
    - Transmission from offshore renewable energy generation, including high voltage export cables and medium voltage array cables, and
    - High voltage and medium voltage transmission and distribution links forming part of the national or local grid.

There are key differences between these sectors that use, install and operate subsea cables. This can influence the expected environmental implications – both from the perspective of management of such cable systems, but also in the physical characteristics and methodologies that are used to deploy and maintain them.

Areas where there are differences or similarities have been noted, but in considering the environmental impacts related to subsea cables it is important to consider the context, sector, and activities that are used for installation as well as the location, seabed and other environmental characteristics.

A review of the most up to date available literature has been undertaken to inform this document, and there remain some knowledge gaps that may be addressed by future research or evidence as it becomes available.

There are emerging technological developments using and requiring subsea cables that do not fall within the scope of this document, such as floating offshore wind, and trans-boundary projects such as multi-purpose interconnectors that will require international cooperation and coordination of planning and consenting where they cross between countries.

Section 5, 'Environmental Impacts Associated with Subsea Cables', presents a review of the environmental considerations relating to telecommunications and power cable installation and operation. Each activity is reviewed against the OSPAR Joint Assessment & Monitoring Programme (JAMP) Pressure Table for consistency and a summary of this is presented in Table 1, which is designed to be read alongside the technical and environmental sections of this document.

The impacts on the marine environment associated with the installation and maintenance of subsea cables will vary depending on the type of cable, the nature of installation and protection, and the spatial extent of the disturbance, its duration, background environmental conditions, and the affected habitat(s) and species. Potential impacts range from small-scale, short-term (i.e., minutes to weeks) disturbance of habitats and communities with a high recovery potential, to longer term disturbances with potential habitat loss, albeit over relatively narrow spatial footprints. The following impacts are identified and discussed.

i) Physical loss of habitat due to permanent change of seabed substrate: In instances where it is necessary to protect cables with physical external structures, the seafloor substrate will change permanently although this is restricted to a narrow strip along part of the cable length. The potential for the introduction of non-local, and potentially invasive fauna by the placement of artificial hard substrate (e.g., rock placement) exists, but field studies of cables indicate that where it occurs, colonization of the provided new habitat is by endemic, rather than invasive fauna.

ii) Physical disturbance of the seabed (temporary or reversible): Where cables are buried for their protection, seafloor sediments will be physically disturbed; however, such disturbance has been shown to be temporary and localised. Recovery of the benthic biota relates to seafloor and local environmental characteristics (seabed morphology, sediment composition, currents and sediment supply) which is explained in the supporting literature. In environmentally sensitive areas (e.g., reefs, seagrass meadows) physical disturbance, damage and displacement may have a long-lasting impact on marine biota. Avoidance of such areas along a cable route is preferred.

iii) Changes to hydrological conditions: Surface laid cables and the presence of protective structures may locally alter the near-seafloor hydrodynamic regime; however, these effects are constrained to a small spatial scale around the cable and are considered unlikely to have wider implications for the benthic environment around the cable.

iv) Noise from cables and associated activities: Sound emissions related to cable survey and installation activities generally do not exceed the background levels of shipping and other anthropogenically-induced emissions and are limited in time (i.e., restricted to survey and installation periods). There are no clear indications that noise impacts related to the installation (or removal) and operation of subsea cables pose a high risk of harming marine fauna.

v) Electromagnetic fields: Electromagnetic fields from telecommunications cables are negligible and this topic is only relevant to subsea power cables. At the current scale (number and transmission rates) of subsea power cables, ecological impacts are thought to be very limited or absent. This has potential to change over time with an increase in the number of cables, (raising the likelihood of highly sensitive animals to encounter anthropogenic EMFs) and with an increase in transmission rates (which could arise from stronger magnetic and induced electric fields).

vi) Thermal effects: Power cables emit heat which dissipates into the overlying sediment or water with environmental impacts expected to occur on the long-term, albeit on a small spatial scale and only concern the sediment directly above the cable. Temperature increases in the upper sediment layers strongly depend on the thermal properties of the sediment. Heat emission from the cable should be considered in the planning of the burial depth of a cable to minimize adverse effects on the seafloor environment.

vii) Contamination from the cable itself and due to installation activities: A risk of contamination associated with subsea cables arising from activities causing seabed disturbance is only anticipated for localities that are already heavily contaminated localities (i.e., due to other human activities). Avoidance of such areas or reduction of sediment disturbance is considered to be an appropriate mitigation measure. Subsea cables are typically made from inert materials that are not harmful, and any introduction of contaminants into the environment from the cable itself can only occur if cables are damaged and this would only be at negligible levels.

Table 1 Cable installation activities linked to JAMP which recommends alignment with JAMP and Marine Strategy Framework Directive (MSFD) pressure categories

Phase	Activity	Typical method and/or equipment	Duration	Pressure
Multiple phases	Operation of vessels related to cable works.	Specialized survey vessels, cable ships and barges	Short-term	n/a
Cable routing	Geotechnical sampling	Multipurpose vessels, Drop Core / Vibrocore / Cone Penetrometer Tests / Grab Samples	Short-term	Physical disturbance to seabed (localised)
	Geophysical survey	Vessels equipped with mounted or towed acoustic survey sensors[1]	Short-term	n/a
Route preparation	Horizontal Directional Drilling (HDD) exits & cable pull-in.	Cable installation barges, cable installation vessel	Short-term	Physical disturbance to seabed (at HDD exit)
	Pre-installation works - pre-lay grapnel run (PLGR)	Multipurpose vessels, grapnel train	Short-term	Physical disturbance to seabed
	Pre-installation works - route clearance (clearance of OOS)	Multipurpose vessel, grapnel, ROV with dredge pump	Short-term	Physical disturbance to seabed
	UXO clearance - In-situ detonation of UXO items deemed too dangerous to move.	Multipurpose vessels	Short-term	Input of anthropogenic sound Input of other forms of energy
	Pre-installation works - dredging of mobile bedforms that prevent passage of installation tools.	Dredging vessels, dredge head	Short-term	Physical disturbance to seabed
	Boulder management - removal & relocation	Multipurpose vessels, 'Orange peel' grabber	Short-term	Physical disturbance to seabed
	Boulder management - displacement	Multipurpose vessels, boulder clearance plough	Short-term	Physical disturbance to seabed
	Cable crossings - Protection of surface laid cable by placement of hard materials on seabed[2]	Concrete mattresses, rock placement, rock bags	Long-term	Physical loss
				Changes to hydrological conditions
Cable Installation	Passage of burial tool during burial of cable along route	Jetting tool	Short-term	Physical disturbance to seabed
		Cable plough		

[1] There will be differences in power of acoustic sources used for different activities and this needs to be considered to understand thresholds. It can vary from very small-scale acoustic survey to a more significant towed seismic array.

[2] The type of crossing, location, seabed type will determine whether any additional external protection is required or used.

		Cable burial cutting tool		
	Burial of cable joints at defined locations	Jetting	Short-term	Physical disturbance to seabed
	Cable pull-in into J-tubes (at platforms)	Cable installation vessel	Short-term	Physical disturbance to seabed
	Shore end activities - Civil works between low water mark and high-water mark	Excavator, sheet piling (trench support)	Short-term	Physical disturbance to seabed
Cable Operation	Thermal effects *(relates to power cables only)		Long-term	Input of other forms of energy
	Changes in electromagnetic field *(relates to power cables only)		Long-term	Input of other forms of energy
	Physical damage to cable resulting in chemical contamination		Long-term	Input of other substances

Footnote: It is noted that all installation activities have the potential to create anthropogenic noise – this is addressed within Section 4.

N.B. Not all these activities are relevant to every type of subsea cable or project and are simply to indicate the pressures relating to each specified activity. There are some activities which only relate to power cable activities – and further context is provided later in the report.

Récapitulatif

Ce document présente d'abord les principes techniques relatifs aux câbles sous-marins qui transportent des télécommunications et de l'énergie, puis les relie aux impacts environnementaux qui leur sont associés.

Ces questions sont présentées dans deux sections du document, les considérations techniques figurant à la section 4 et les considérations environnementales à la section 5.

Les principaux secteurs de l'industrie des câbles sous-marins sont les suivants :

- Câbles de télécommunication – câbles à fibres optiques utilisés pour transférer des communications et des données numériques d'un endroit à un autre.
- Câbles électriques utilisés pour transférer l'électricité d'un endroit à un autre, ce qui peut inclure :
    - L'interconnexion des réseaux internationaux,
    - Le transport à partir de la production d'énergie renouvelable en mer y compris les câbles d'exportation à haute tension et les câbles de réseau à moyenne tension, et
    - Les liaisons de transmission et de distribution à haute et moyenne tension faisant partie du réseau national ou local.

Il existe des différences majeures entre ces secteurs qui utilisent, installent et exploitent des câbles sous-marins. Cela peut influencer les implications environnementales attendues, à la fois du point de vue de la gestion de ces systèmes de câbles, mais aussi des caractéristiques physiques et des méthodologies utilisées pour les déployer et les entretenir.

Les différences et les similitudes ont été relevées, mais lorsqu'on examine les impacts environnementaux liés aux câbles sous-marins, il est important de tenir compte du contexte, du secteur et des activités utilisées pour l'installation, ainsi que de l'emplacement, du fond marin et d'autres caractéristiques environnementales.

Une analyse de la littérature la plus récente a été entreprise pour étayer le présent document, et il subsiste des lacunes dans les connaissances qui pourront être comblées par des recherches futures ou des données probantes au fur et à mesure qu'elles deviendront disponibles.

Il existe des développements technologiques émergents utilisant et nécessitant des câbles sous-marins qui n'entrent pas dans le champ d'application du présent document, tels que l'éolien offshore flottant, et des projets transfrontaliers tels que les interconnexions polyvalentes qui nécessiteront une coopération internationale et une coordination de la planification et de l'autorisation lorsqu'ils traversent plusieurs pays.

La section 5, ‘Impacts environnementaux liés aux câbles sous-marins’ présente un examen des considérations environnementales relatives à l’installation et l’exploitation des câbles de télécommunication et des câbles électriques. Chaque activité est examinée par rapport au tableau des pressions figurant dans le Programme conjoint d’évaluation et de surveillance (JAMP) d’OSPAR, pour en vérifier la cohérence. Un résumé est présenté dans le tableau 1, qui est conçu pour être lu en parallèle avec les sections techniques et environnementales de ce document.

Les impacts sur le milieu marin associés à l’installation et l’entretien des câbles sous-marins varieront en fonction du type de câble, de la nature de l'installation et de la protection, de l'étendue spatiale de la perturbation, de sa durée, des conditions environnementales de base, ainsi que des habitats et des espèces concernés. Les impacts potentiels vont de la perturbation à petite échelle et à court terme (c'est-à-dire de quelques minutes à quelques semaines) d'habitats et de communautés ayant un fort potentiel de rétablissement, à des perturbations à plus long terme entraînant une perte potentielle d'habitats, bien que sur des empreintes spatiales relativement étroites. Les impacts suivants ont été identifiés et examinés.

i) Perte physique de l’habitat en raison de la modification permanente du substrat du fond marin : Perte physique de l'habitat en raison de la modification permanente du substrat du fond marin : Dans les cas où il est nécessaire de protéger les câbles par des structures physiques externes, le substrat du fond marin changera de façon permanente, bien que cela soit limité à une bande étroite le long d'une partie de la longueur du câble. Le risque d'introduction d'une faune non locale et potentiellement envahissante par la mise en place d'un substrat dur artificiel (par exemple, la mise en place de rochers) existe, mais les études de terrain sur les câbles indiquent que lorsque cela se produit, la colonisation du nouvel habitat fourni est le fait d'une faune endémique, plutôt qu'envahissante.

ii) Perturbation physique des fonds marins (temporaire ou réversible) : Lorsque les câbles sont enterrés pour leur protection, les sédiments du fond marin seront physiquement perturbés ; toutefois, il a été démontré que ces perturbations sont temporaires et localisées. Le rétablissement du biote benthique dépend des caractéristiques du fond marin et de l'environnement local (morphologie du fond marin, composition des sédiments, courants et apport de sédiments), ce qui est expliqué dans les documents d'appui. Dans les zones écologiquement sensibles (par exemple, les récifs, les herbiers marins), les perturbations physiques, les dommages et les déplacements peuvent avoir un impact durable sur le biote marin. Il est préférable d'éviter ces zones le long du tracé du câble.

iii) Modifications des conditions hydrologiques : Les câbles posés en surface et la présence de structures de protection peuvent modifier localement le régime hydrodynamique près du plancher océanique ; toutefois, ces effets sont limités à une petite échelle spatiale autour du câble et il est peu probable qu'ils aient des implications plus larges pour l'environnement benthique autour du câble.

iv) Bruits des câbles et des activités associées : Les émissions sonores liées aux activités d'étude et d'installation des câbles ne dépassent généralement pas les niveaux de fond de la navigation et d'autres émissions d'origine anthropique et sont limitées dans le temps (c'est-à-dire qu'elles se limitent aux périodes d'étude et d'installation). Rien n'indique clairement que les impacts sonores liés à l'installation (ou à l'enlèvement) et à l'exploitation des câbles sous-marins présentent un risque élevé de nuisance pour la faune marine.

v) Champs électromagnétiques : Des champs électromagnétiques émis par les câbles de télécommunications sont négligeables et ce sujet ne concerne que les câbles électriques sous-marins. À l'échelle actuelle (nombre et taux de transmission) des câbles électriques sous-marins, on estime que les impacts écologiques sont très limités, voire inexistants. Cette situation pourrait changer au fil du temps avec l'augmentation du nombre de câbles (ce qui augmenterait la probabilité pour les animaux très sensibles de rencontrer des champs électromagnétiques anthropiques) et avec l'augmentation des taux de transmission (qui pourrait résulter de champs magnétiques et électriques induits plus intenses).

vi) Effets thermiques : Les câbles électriques émettent de la chaleur qui se dissipe dans les sédiments ou l'eau sus-jacents, ce qui devrait avoir des impacts environnementaux à long terme, bien que sur une petite échelle spatiale et ne concernant que les sédiments situés directement au-dessus du câble. L'augmentation de la température dans les couches supérieures des sédiments dépend fortement des propriétés thermiques des sédiments. L'émission de chaleur par le câble doit être prise en compte dans la planification de la profondeur d'enfouissement d'un câble afin de minimiser les effets négatifs sur l'environnement des fonds marins.

vii) Contamination due au câble lui-même et aux activités d'installation : Le risque de contamination associé aux câbles sous-marins résultant d'activités entraînant une perturbation des fonds marins n'est anticipé que pour les localités déjà fortement contaminées (c'est-à-dire en raison d'autres activités humaines). L'évitement de ces zones ou la réduction de la perturbation des sédiments est considéré comme une mesure d'atténuation appropriée. Les câbles sous-marins sont généralement fabriqués à partir de matériaux inertes qui ne sont pas nocifs, et toute introduction de contaminants dans l'environnement à partir du câble lui-même ne peut se produire que si les câbles sont endommagés, ce qui ne représenterait que des niveaux négligeables.

2 Background and Objectives

The objective of this document is to review currently available information to:

a. Provide a general introduction to the technical aspects of subsea cables; and
b. Describe the environmental considerations relating to subsea cables.

Telecommunications cables have been installed using standard industry practices for decades and remain consistent in their methodology. However, the rapid development of offshore renewable energy and other technologies means that there are different techniques and practices that are used due to the differing sectoral requirements for power cables.

Therefore, as new information/evidence is developed, and infrastructure relying on subsea cables moves forward it is suggested that this document be reviewed periodically to ensure that the information does not become outdated or obsolete and remains relevant to the sectors and associated environmental considerations it describes.

3 Subsea Cables – Technical Aspects

3.1 Introduction

Subsea cables are vital to modern life. Subsea cables serve island communities (remote and domestic) for both communications and provision of energy.

Telecommunications cables facilitate global communications, financial transactions, cloud services, remote work and tele-based applications like e-learning and tele-medicine. Recent studies assess that approximately 99% of global communications are carried by subsea cables, contributing to almost all aspect of modern society.

Power cables allow transmission between countries via interconnectors – balancing energy production and demand across continents, as well as bringing energy ashore from offshore renewable installations.

The physical characteristics of a subsea cable, and the techniques to install them can vary significantly based on the cable's purpose, the location(s) in which it is installed, as well as the different regulatory considerations or requirements imposed on different cable industry sectors or national governance.

Similarly, a cable's impact to the environment can vary depending on multiple factors. Burial of subsea cables has been best practice for decades to protect them from interactions with human activities that disturb the seafloor (e.g., in the region of 70% of all cable damage is attributed to fishing and/or anchoring) as well as natural processes that can damage them (e.g., storms, seafloor erosion).

Subsea cables are an important component of a move towards Net Zero, to mitigate against human-driven climate change through the transmission of energy, data and communications. At the same time, the effects of future climate change have the potential to increase the threats posed to subsea cables (e.g., increased storminess, sediment mobility, coastal erosion); hence, climate change impacts must be assessed and managed for existing and new cable routes (Clare et al., 2023).

Climate Change is considered within the OSPAR cables thematic mini assessment in the OSPAR Quality Status Report (QSR) 2023.

A high-level overview of different cable types and their uses is included in Table-2.

Section 4.2 covers considerations that are specific to telecommunications cables, and Section 4.3 covers topics specific to power cables. Section 4.4 onwards covers topics where there are commonalities, whilst aiming to explain the clear sectoral distinctions.

Table 2 Different Types & Uses of Subsea Cables

Subsea Cables			
Type	**Approx. diameter**	**Typical burial depth**[3] (subject to conditions)	**Comments**
Telecommunications	17-60mm	0-1.5m	Subsea telecommunications cables carry approximately 99% of the world's global communications. They are small in diameter and can be surface laid or buried (typically to 1.5m where feasible) to protect the cable from external aggression and can be installed through ducts near to landfall as well as being protected by articulated pipe. Telecommunications cables can have further external protection applied such as rock or articulated concrete mattressing, but this is mostly seen at crossings of power cables and pipelines and not commonly applied for routine protection.
HVAC Renewable Energy – inter-array cables	33kv – 70-130mm 66kv – 160-185mm	0-1.5m	Inter-array cables connect turbines within a wind farm and can be 33-36kv or increasingly 66kv. These will be contained within an offshore wind farm area. Inter array cables are typically protected through burial. Inter array cables will generally not have additional external protection applied.
HVAC Distribution Cables 132kV	100-300mm	0-1.5m	These cables can serve inter-island connections or be part of a distribution network involving subsea links. Cables may be surface laid, ploughed, jetted, trenched or protected by ducting, mattresses or rock and predominantly include HVAC trefoil construction. Fibre-optics can also be included within the cable to undertake certain functions but would not generally be used for general telecommunications.
HVAC Transmission cables above 132kV	250-300mm	0-1.5m	Predominantly of trefoil construction, these cables may be surface laid, ploughed, jetted, trenched or protected by ducting, mattresses or rock etc.

[3] The table displays typical burial depth. 'Deep burial' can be undertaken for some cable installations but would be on a case-by-case basis depending on the geomorphology and is considered atypical to standard practice. Where deeper burial is used, this can make it more difficult or impossible to repair or recover cables.

Subsea Cables			
Type	**Approx. diameter**	**Typical burial depth**[3] (subject to conditions)	**Comments**
HVDC Transmission cables above 132kV	100-180mm	0-1.5m	Predominantly one pole per cable and laid as a bundle of two power cables and one fibre optic cable. Cables may be separated at landfalls or may be laid as separate cables though this is not common. Cables may be surface laid, ploughed, jetted, trenched or protected by ducting, mattresses or rock etc.
HVDC Renewable Energy Export Cables & Interconnector Cables	130-250mm	0-1.5m	As with Transmission cables – these are bundled cable systems, comprising of two power cables and usually one Fibre Optic cable for transmission of data on operations. Renewable energy export cables carry power to shore from a wind farm or other renewable energy installation. Interconnector cables connect the transmission system of two separate networks. These are also likely to be buried by ploughing, jetting, trenching and are likely to have external protection applied.
Other types of subsea cable	Variable	Variable	Other types of subsea cable may include scientific cables (i.e., tsunami early warning systems, research arrays etc); military cables; cables related to Oil and Gas facilities or extractions; composite cables with combined purpose; legacy cables such as out-of-service telegraph or coaxial cables; legacy fluid/oil filled cables (almost no longer used in OSPAR area).

3.2 *Telecommunications Cables*

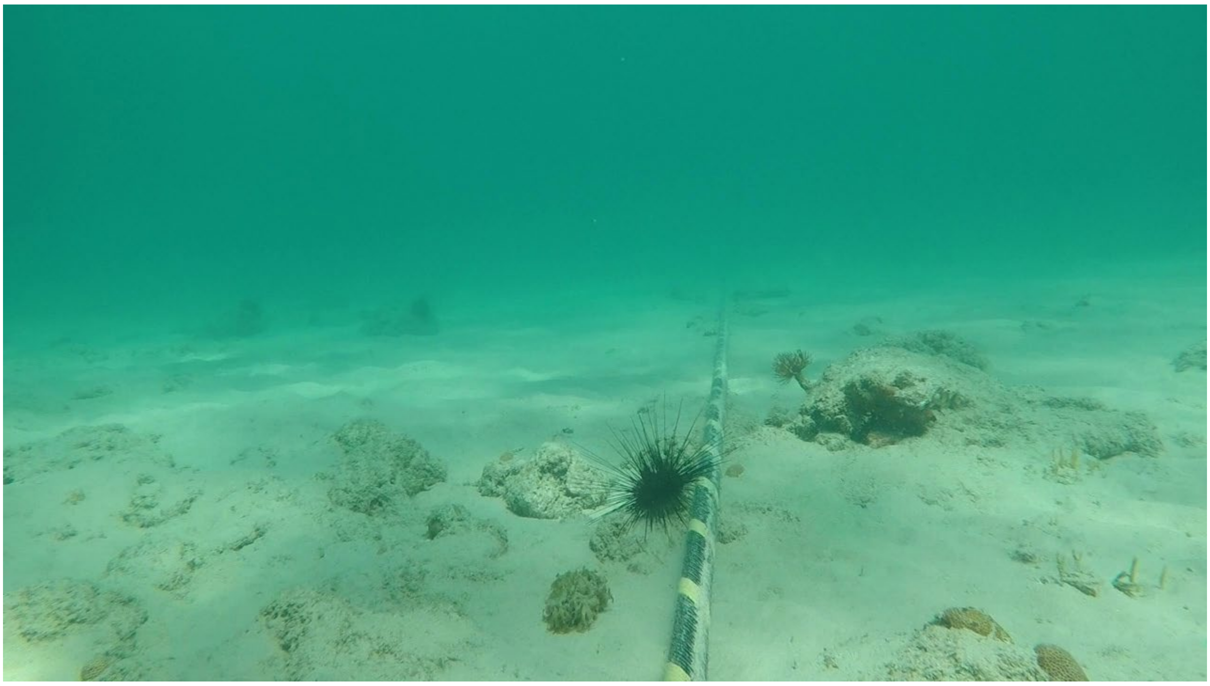


Figure 1 Surface laid fibre optic telecommunications cable (approx. 24mm diameter). Image courtesy of Glenn Lipsham, ESCA.

3.2.1 Background and Sector Summary

The desire for instantaneous international communications spurred the early development of long-distance subsea cables. Following the installation of the first subsea telegraph cables in the mid-19th Century (1850-1860s), continual advances in cable materials, manufacturing technology and cable laying techniques allowed the construction of telegraph networks throughout the world.

By the early 20th Century, as the telephone supplanted the telegraph, further innovations enabled the development of cables capable of carrying multiple voice channels. This included the replacement of natural insulation materials, such as gutta percha, with polyethylene, the introduction of coaxial cables and the installation of automated repeaters to boost the strength of long-distance signals. The first transatlantic subsea telephone cable came into service in 1956.

Coaxial subsea telecommunication cables remain in sporadic use today, but since the 1980s they have largely been superseded by fibre optic technology. Transmitting information digitally as pulses of light through thin, transparent glass or polymer filaments enables fibre optic cables to offer significantly greater capacity than the most advanced coaxial cables. The first transatlantic fibre optic subsea cable was installed in 1988 and the technology has become the standard for modern subsea telecommunication cables which has been further enhanced over time by significant advances in the land-based electronics that equip a subsea fibre optic cable to transmit data leading to a revolution in global communications, facilitating almost every aspect of modern life that relies on connectivity.

The signal-carrying fibres in modern fibre optic cables are between 9 µm and 125 µm in diameter not dissimilar to a human hair. Fibres are used in pairs to enable two-way communication, and each cable may contain multiple pairs of fibres. The optical fibres at the centre of a subsea cable are surrounded by stranded steel cables for strength and contained within a polythene sheath which provides an electrical insulation layer and waterproofs and protects the cable. Lightweight cables used in deep sea applications (greater than approx. 1000-1500 m water depth) have an outside diameter of 17 mm to 21 mm and a mass of around 0.7 kg per m. Where cables may encounter human activities (e.g., bottom-trawl fishing and ships anchors), high tensile steel wires are used to provide armouring – see Section 4.2.3.

Telecommunications cables are generally buried using a plough to approx. 1000 m water depth. However, this has increased to 1500 m due to human activities, such as fishing activities moving to deeper waters.

3.2.2 Fibre Cable Systems – Repeatered and Un-repeatered Designs

The material used for the fibre is selected for high transparency and minimal losses at the light wavelengths used for data transmission. This high transparency fibre along with the terrestrial transmission equipment that “lights” the fibre allows an optical cable to communicate over distances of 300km or more without the need for additional equipment along the length of the cable to boost the strength of the signal. Such un-repeatered cable is suitable for regional networks among other applications.

To achieve reliable, high-speed communication of distances of hundreds or thousands of kilometres in any kind of cable, the signals require periodic amplification using repeater systems.

Early long-distance fibre optic cables also used electronic repeaters, but modern systems use optical amplification. Fibres doped with erbium are spliced into the cable at intervals. When energised by a laser, these fibres “lase”, amplifying the incoming optical signals with power supplied through a conductor embedded in the cable. Typically, high voltage power feed equipment (PFE) is installed at one or both ends of the cable to create a potential difference along its length. For a transoceanic cable with multiple powered repeaters installed at intervals of around 80km, this power feed equipment may provide a current of 0.8A to 1.3A at a voltage of 10kV to 18kV[4]. Modern powered repeaters are 2m to 4m long and around 300mm in diameter.

[4] https://web.archive.org/web/20200808071549/https://www.suboptic.org/wp-content/uploads/2014/10/255_Poster_EC_04.pdf

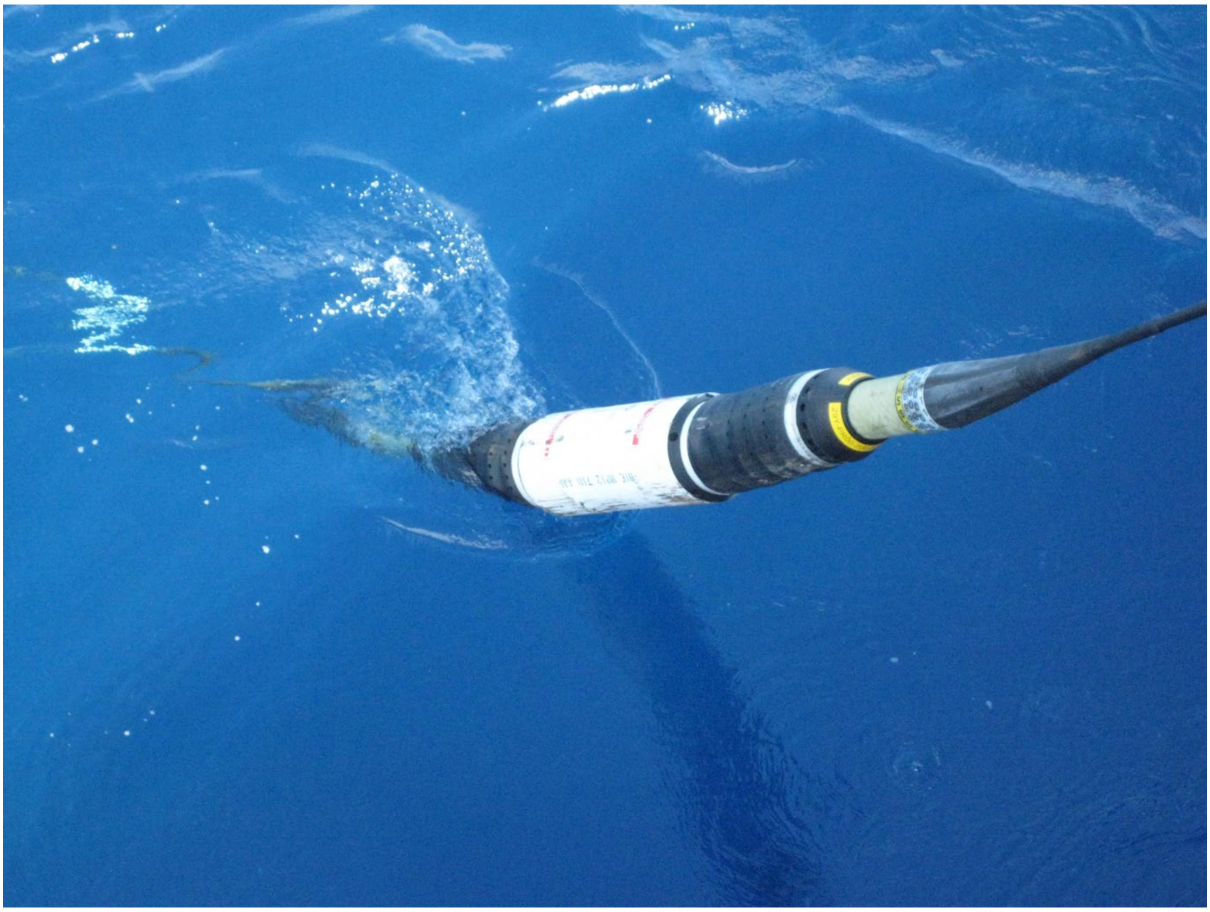


Figure 2 A repeater being deployed from a cable ship. Image courtesy of Glenn Lipsham, ESCA.

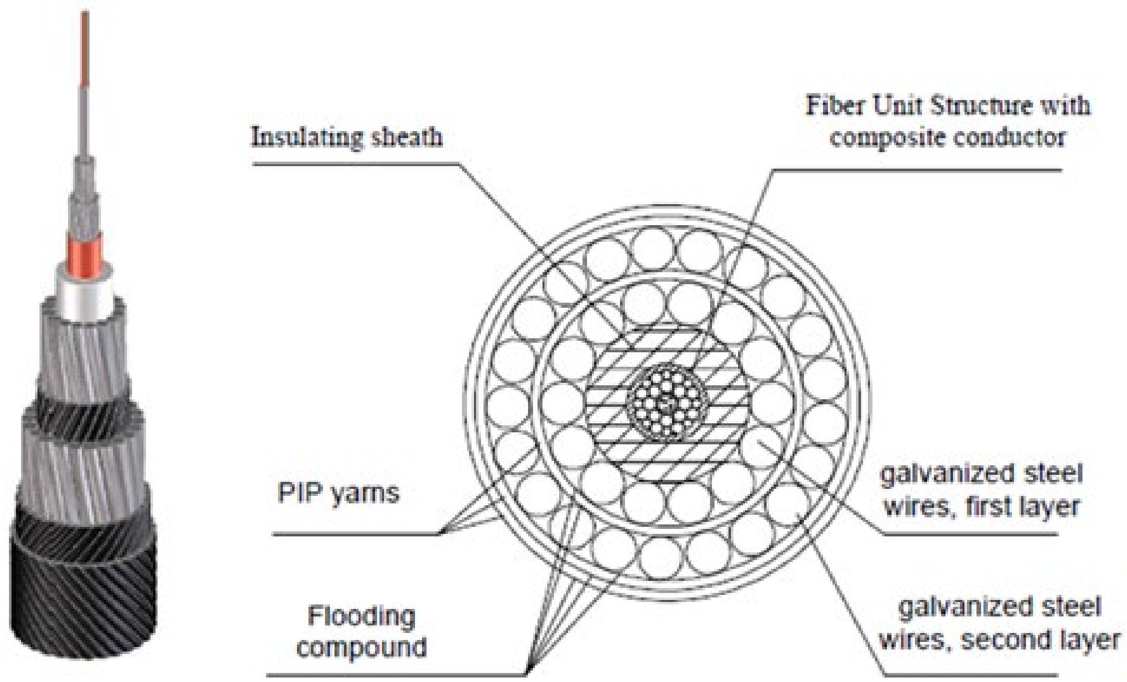
3.2.3 Telecommunication Cables — Armouring Considerations

Subsea telecommunication cables are exposed to various natural and human-made hazards. Natural hazards include the action of underwater currents, the impact of earthquakes, storms and subsea landslides. Human-made hazards include contact with fishing equipment or vessel anchors.

Of the two categories of hazards, it is human activity that has the greatest impact on subsea cables. Between 65 and 75 percent of fibre optic cable faults occur in water depths of less than 200m, with the majority of those the result of damage from ships anchors or fishing gear. The International Cable Protection Committee (ICPC) publishes information to promote good practices for subsea cable resilience for use by Governments[5].

In addition to the other protection measures described in section 4.3.5 below, telecommunication cables laid in shallow water are usually equipped with one or more layers of galvanised steel wire armour, encased in a sheath made of tar-soaked nylon or jute fabric yarns. The addition of this armour increases the outside diameter of the cable to between 28mm (Single Armour) and 50mm (Double Armour) and the mass to as much as 4.8 kg per m.

[5] 'Government Best Practices for Protecting and Promoting Resilience of Submarine Telecommunications Cables' is to assist governments in developing laws, policies, and practices to foster the development and protection of submarine telecommunications cables, the infrastructure of the Internet. https://www.iscpc.org/documents/?id=3733



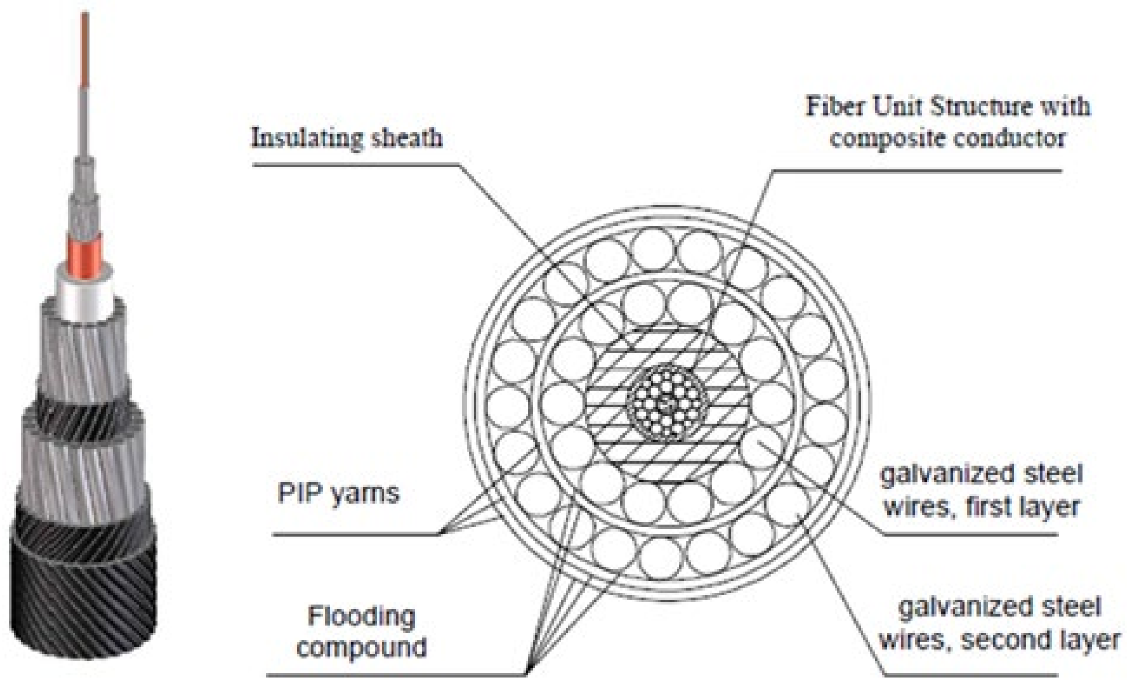


Figure 3 Diagram of Double Armour Telecommunications Cable. Indicative diameter range 37.5mm-50mm dependent on cable type. Image courtesy of Alcatel Submarine Networks.

3.2.4 Telecommunication cable systems and EMF

Repeatered (powered) telecommunication systems do have a live current, but electrical fields are shielded, and currents are markedly lower than power transmission cables (Albert et al., 2020). For context the electromagnetic field (EMF) is less than an average lap-top computer. Given the small diameter of repeatered cables, the magnetic fields induced by fibre optic cable powering are on the order of 30 to 38 microtesla (µT) at the cable surface. These values are lower than the background magnetic field produced by the Earth (60 µT).

At 1 metre from the cable the magnetic field would be 0.30 to 0.38 µT or 1/100th of what it is at the surface of the cable.

Repeatered telecom cable systems produce highly localised magnetic fields if laid on the seabed surface, and if buried the fields would be reduced further.

Unrepeatered telecommunications systems do not produce any EMFs.

Given the very low levels of EMF in a repeatered telecommunications cable, and no EMF produced by unrepeatered telecommunications cables, they do not require further consideration.

3.3 Power Cables

3.3.1 Background and Sector Summary

From the early 19th Century, subsea power cables were used to allow electrical transmission systems to deliver power across waterways or to inshore islands. Early cables used natural rubber to provide electrical insulation and act as a water barrier. By the middle of the 20th Century, synthetic butyl rubber had replaced natural rubber as an insulation material and lead (Pb) extrusion was introduced as a water barrier.

Modern subsea power cables are used in a wide range of applications. As well as extending grid connections to remote locations, they supply energy to offshore installations, and act as interconnectors linking the power grids of islands, nations and continents. One area of particularly rapid growth in the early part of the 21st Century has been the use of subsea cables to bring power ashore from offshore renewable energy installations, most commonly wind farms.

As the range of applications grows, subsea cable technology has evolved to meet new demands. Those demands include longer distances and higher power capacities. As of 2023, the longest subsea power cable in Europe is the 580km NorNed HVDC interconnector between Norway and the Netherlands, and the largest interconnectors have power capacities of 500MW to 2250MW. The expansion of offshore renewable energy has led to the development of multipurpose interconnectors that perform the dual role of grid interconnection and power export from windfarms along the route of the cable.

Other types and uses of subsea cables are being developed with emerging technology. For example, the introduction of floating offshore wind turbines requires the use of dynamic cables that operate in the water column, linking the turbine plant to the seabed, as of 2023 are only at a research and pilot project stage, so are not considered further.

3.3.2 Power Cable Systems - Technology & Designs

Subsea power transmission systems use two different technological approaches: high voltage alternating current (HVAC) or high voltage direct current (HVDC) transmission.

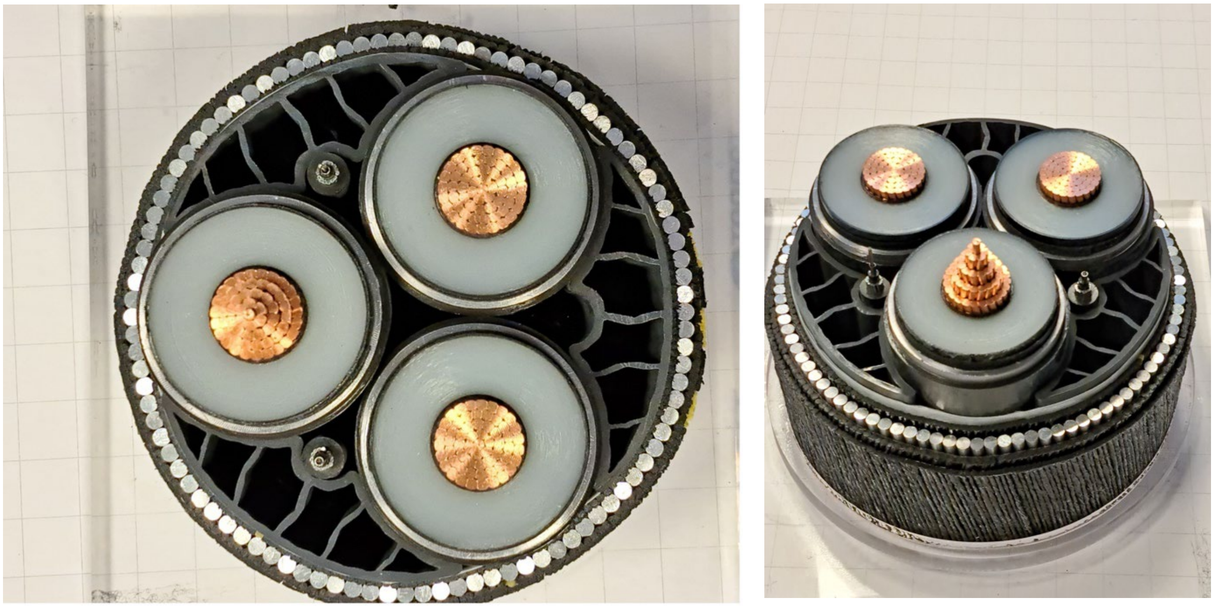


Figure 4 HVAC 155kV Cable – Trifoil Design with 2 integrated fibre cable packages

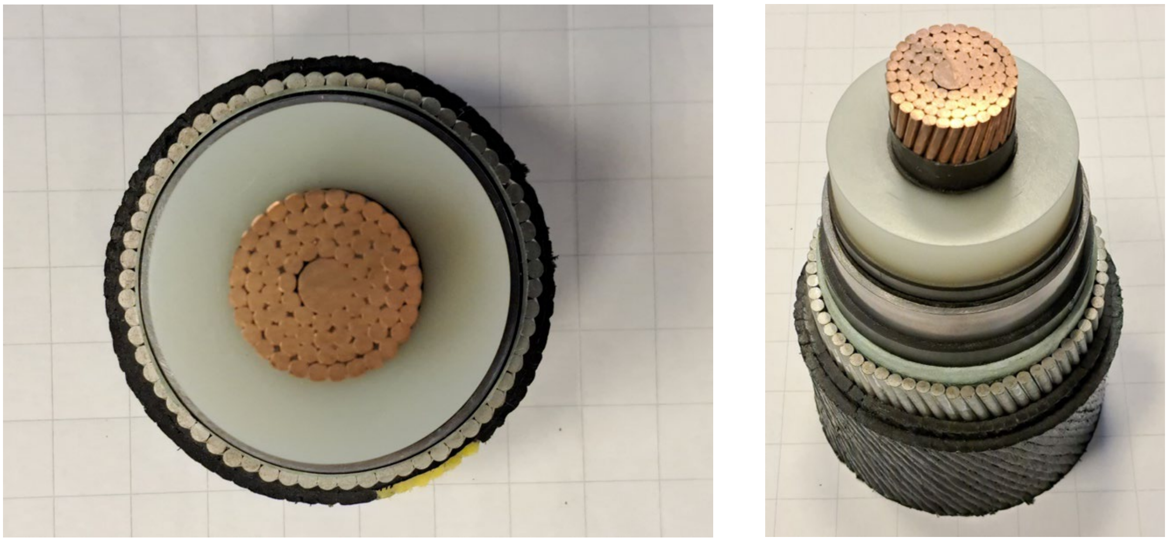
High voltage AC (HVAC) systems are simpler and cheaper to integrate with a single terrestrial grid, which also operate using AC. But AC technology suffers from significant power factor losses when delivering high power and operating over long (in excess of approximately 100km) distances. Additionally, AC cables delivering three phase power require three conductors, which increase the cost and weight of the cable. As a result, AC cables are used for shorter distances and lower power capacity levels.

High voltage DC (HVDC) systems exhibit lower losses than AC systems, allowing the construction of longer, higher capacity cables. They can be configured in monopolar arrangement, using a single conductor with seawater carrying the return current, or in a bipolar design, with a second conductor carrying the return current. Bipolar HVDC systems also allow the bidirectional transmission of power typically using two cables, and they have become the preferred choice for high-capacity international interconnectors.

DC power is converted to AC before it can be exported to the terrestrial grids, and the high cost of the convertors required for this is a perceived disadvantage of such systems, especially for shorter, lower powered cables. For this reason, the first offshore windfarms typically used AC shore connections. As the offshore renewable energy industry has evolved, with larger arrays of more powerful turbines and sites located further offshore, HVDC technology is increasingly being adopted in the sector.

The higher capacity of HVDC cables can also be advantageous to reduce the extent of infrastructure associated with offshore generating assets, since power from multiple turbines or multiple windfarms can be consolidated at an offshore substation and exported via a single cable system to one shore landfall. Future planning for HVDC connections includes the provision for transmission of up to 2 GW.

Figure 5 : Single Core of a Dual 800MW HVDC Export Cable System.



(Cable Diameter is 9cm – Tennet Offshore GmbH)

3.3.3 Power Cable Construction Types

Modern subsea power cables are normally constructed using conductors of stranded copper or more recently cables that use aluminium. Insulation may be an extruded polymer such as cross-linked polyethylene (XLPE) or ethylene propylene rubber (EPR).

XLPE cables are the most commonly provided form for both HVAC and HVDC power cables. This increases the temperature range of the insultation whilst maintaining electrical properties thereby reducing losses (e.g., heat emissions).

Other types of insulation are noted below for information – but it should be noted that XLPE are the most commonly used for modern subsea cable applications:

- *Mass impregnated (MI) cables are another type of cable design used at the higher operating voltages. MI cables use wrapped paper insulation and can be impregnated with an insulating fluid such as mineral oil and protected from water ingress by an extruded lead or aluminium water barrier.*
- *There are ostensibly two types of MI cables, in the case of these oil impregnated cables, they are normally referred to as Self-contained fluid filled (SCFF) cables. SCFF cables are usually only found in legacy systems as their technology has been generally overtaken by developments of Mass Impregnated Non-Draining (MIND) cables. As such SCFF are almost no longer found within the OSPAR geographic area[6].*
- *Unlike MIND cables, SCFF cables (also known as Low Pressure Oil Filled (LPOF) cables), use pressurised oil in a reservoir at each end of the cable to maintain insulation integrity. Therefore, if such a cable is damaged this can lead to oil leakage into the marine environment.*
- *MIND cables are also paper insulated but impregnated with a very thick substance that resembles a grease. In the case that a MIND cable is damaged, there is very little opportunity for the grease to escape into the surrounding seawater thus they are more environmentally friendly.*
- *Gas filled (SCGF) cables are rare and have conductors with hollow cores which provide a passageway for insulating gas / fluid under static pressure provided by equipment at the cable terminals (pumping stations at the cable ends, feeding into a hollow conductor core). The insulating gas / fluid saturates the cable insulation, maintaining the electrical integrity of the cable, and prevents damaging ingress of water in the event of an underwater leak. Regardless of the type of insulation used, the cable insulation layer is usually surrounded by additional layers of extruded or wrapped EMF (Electro-Magnetic Field) screening materials.*

3.3.4 Power Transmission Method and Cable Design

In an HVAC cable, three conductors are typically bundled together internally in a trefoil arrangement. The complete assembly is surrounded by additional layers of galvanized steel wire armour inside an outer casing of tar impregnated fabric.

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6 Some examples of LPOF cables in operation in OSPAR area, for example, in Norway (mix of oil filled cables (SCFF) and synthetic XLPE cable commissioned in 2014): http://www.jicable.org/TOUT_JICABLE_FIRST_PAGE/2015/2015-B1-6_page1.pdf and Denmark https://www.maritimedanmark.dk/laekage-pa-sokabel-fundet.

HVDC cables use similar construction methods, but the assembly usually contains either a single conductor in a single cable, a concentric pair of conductors in a single cable, or two adjacent 'twin' conductors in a single cable, depending on the system design.

Power cable assemblies commonly incorporate an optical communication package or fibre optic element, which can be used for operational communications, to collect data from monitoring equipment installed on the cable.

3.3.5 Electromagnetic fields in Power Cables

The term "electromagnetic field" (EMF) includes both electric and magnetic fields. Power transmission cables and repeatered telecommunication cables generate electric and magnetic fields, albeit much smaller for the latter. Magnetic fields arise from the current flowing in the cable and the electric fields arise from the voltage. Neither cable types emit electric fields directly, because the metal sheath physically protecting the cable ensures the electric field is entirely confined within the cable. They do emit magnetic fields, of differing magnitudes that can indirectly induce electric fields in sea water and animals.

A key defining characteristic of EMFs is their frequency. They always have the same frequency as the electricity that produced them. Many windfarms array and export cables transmit using Alternating Current (AC) at 50 or 60 Hertz (Hz). Many of the interconnectors connecting the electricity systems of two countries and offshore transmission infrastructure as well as more distant offshore windfarms, will transmit power using Direct Current (DC) technologies (0Hz). DC cables create a steady magnetic field while AC cables induce a rapidly changing magnetic field around the cable; in both cases the field also changes with the load current passing through the cable. The earth's geomagnetic field is a DC magnetic field which is always present in marine environments; in the OSPAR North-East Atlantic area, it varies in the approximate range of 42 -55 microtesla (µT) depending on the geographic location (BGS, 2000).

The EMFs that different cable types can produce and the factors influencing the size and spatial distribution are discussed in the following sections

3.3.5.1 HVDC Power Transmission Cables

HVDC transmission cables produce DC magnetic fields, and the strength and spatial distribution varies depending on:

- Configuration of the HVDC system i.e., bipole or monopole;
- Total distance to the cables - the further from the cable, the lower the magnetic field;
- Separation between the individual HVDC cables in the cable bundle - the closer the cables are, the lower the magnetic field; and
- Current flowing in the cables - the higher the current flow, the higher the magnetic field.

Magnetic fields are always highest closest to the cable and reduce rapidly with vertical and horizontal distance.

The current flow may vary considerably over time, Figure 6 shows the changing power flows on an HVDC interconnector over a 24-hour period and the impact on the magnetic field. These dynamic power flows are also observed in AC systems.

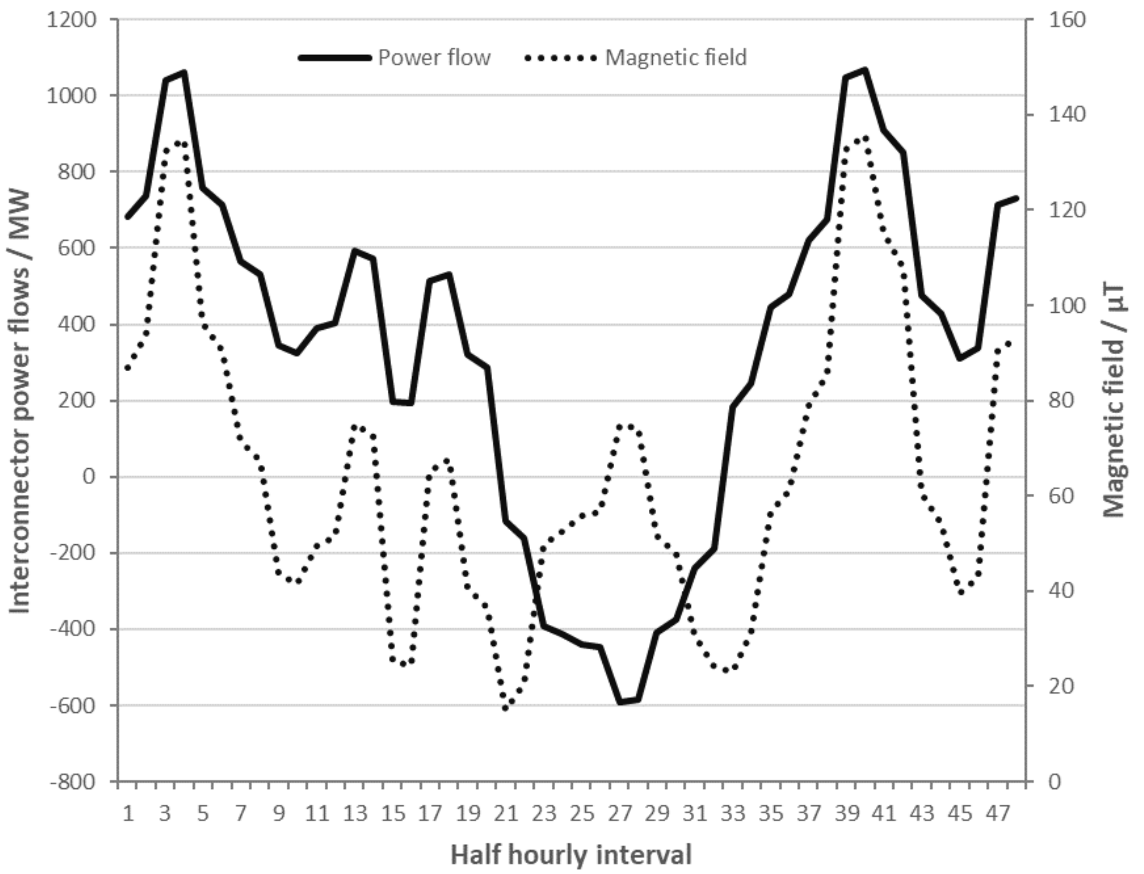

Figure 6 : Power Flow[7] And Magnetic Field Changes Over A 24-Hour Period From A HVDC Interconnector Between the UK And Norway. Cables Buried 1.5m Below Seabed. Calculations Of Magnetic Field at Seabed.

Most HVDC configurations are bipole systems. Where bipole cables are bundled the magnetic fields from each cable cancel each other to a degree – reducing the resultant field magnitude.

If bipole cables are installed at increasing separation, the degree of cancellation decreases, typically once the cables are greater than 8 metres apart the cancellation effect has gone. The maximum calculated magnetic field for a bundled bipole cable, operating at ±500 kilovolts (kV), 2000 megawatts (MW), and buried at 1 metre below ground is 126.8 µT at the seabed - compared to 404.4 µT for cables installed 30 metres apart (NGET & SPT, 2022).

Magnetic fields produced by monopolar systems are highly dependent on how the current return path is designed. For those systems with a metallic return, the magnetic field will mainly depend on the separation of the conductor cable and metallic return and can be treated the same as a bipole system.

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[7] Historic power flow data obtained from Elexon BMRS https://www.bmreports.com/bmrs/?q=generation/avghalfhourIC/historichttps://www.bmreports.com/bmrs/?q=generation/avghalfhourIC/historic.

For monopole systems with a ground / sea return path, calculating fields is more complex, as the return current spreads out over a large area through the sea or ground. A simple upper bound approximation can assume a single cable carrying the total current, with no cancellation from the earth return current. If sea electrodes are used for the return path, other environmental impacts should be considered, such as electrolysis products and high electrical gradients in the water.

The magnetic field from DC cables will combine with the Earth's geomagnetic field, which has a magnitude of about 50 µT in Europe (Figure 2). Magnetic fields from the cable can add and subtract from the earths field and how both fields combine depends on the relative direction of the fields, which in turn depends on the direction of the cable relative to north south.

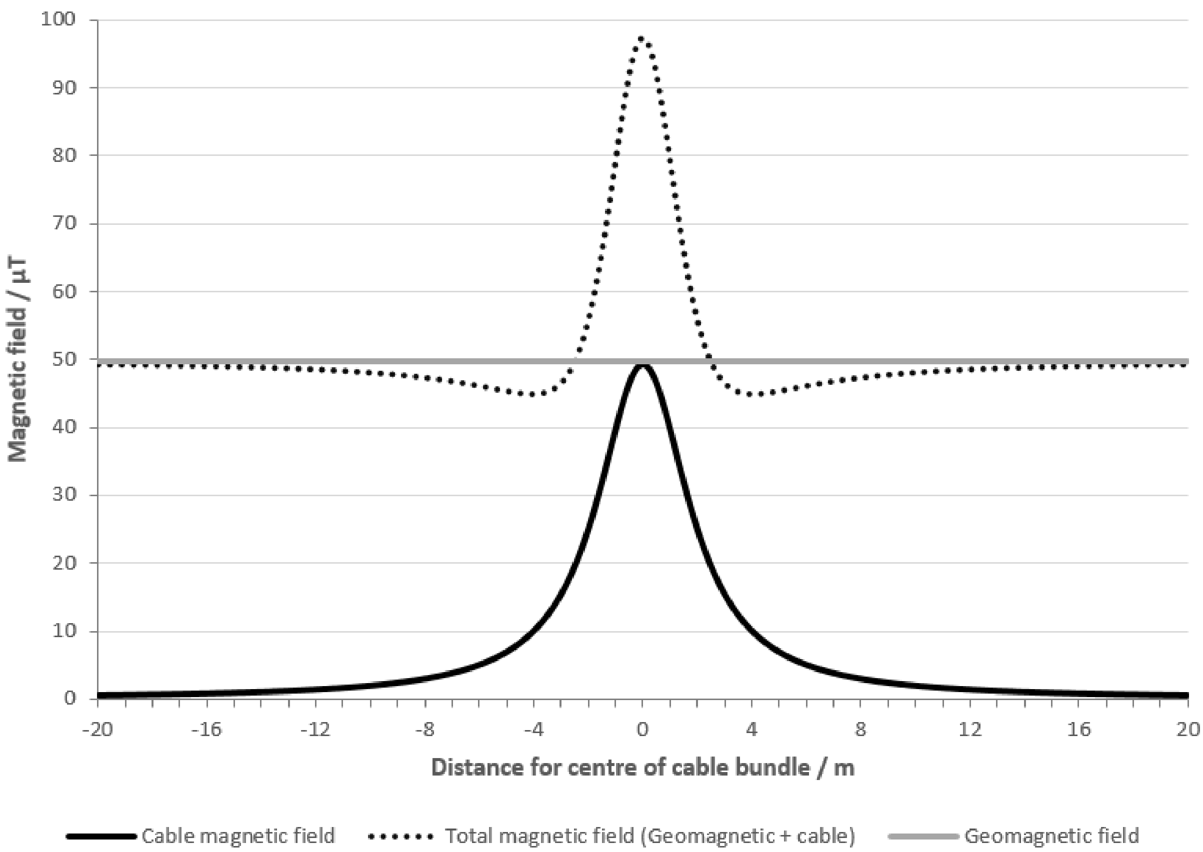


Figure 7: The Calculated Magnetic Field from A Bundled Bipole System With Cables Orientated North South and Its Combination with The Earth's Geomagnetic Field

The interactions of the cable and the Earth's magnetic fields not only alter the magnitude of the combined field but also its direction. This can alter the inclination and declination of the geomagnetic field. One of the effects of this is to cause compasses to deviate from north, when close to cables. The effects on compasses are greatest when a cable is orientated north south and is also dependent on the magnitude of the field from the cable.

Although HVDC cables do not produce electric fields directly, they can induce weak electric fields in conductive bodies that move through the field, such as animals and seawater. The movement of sea water and animals through the magnetic field will result in a small localised electric field being produced, which will be proportional to the magnetic field strength and speed of movement, therefore decreasing rapidly with distance from the cable. This is referred to as a motion induced electric field, as movement in the magnetic field is required for it to occur.

A background motional induced electric field will be present if a tide is flowing in the geo-magnetic field and any local magnetic anomalies present. The electric field induced by movements in the magnetic field is calculated using Lorentz law where:

Induced electric field (µV/m) = Velocity (m/s) **X** Magnetic field (µT)[8]

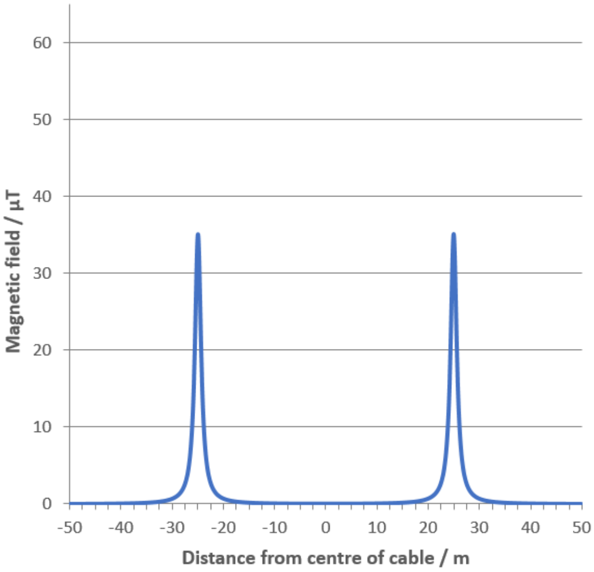
The induced electric field in turn, causes charged ions of salt in the sea water to separate which creates an additional electric field in the water. The marine animal will see the combination of both effects. Modelling them is complex and there are no established ways of presenting these data to date.

An electric field of 25 µV/m is regarded as the natural background in the North Sea (Koops, 2000), although this will vary with the changes in geomagnetic field strengths and tidal velocities. Using the Lorentz approach, the background induced electric field in a geomagnetic field of 48 µT could range between 4.8 and 60 µV/m in tidal velocities ranging between 0.1 m/s and 1.25 m/s. Using this same method, the induced electric fields from a bundled bipole system operating at ±525 kV, 1400 MW would range between 10 to 126 µV/m in the same tidal velocities, reducing to background fields, 5 metres in any direction from the cables.

[8] This is a vector cross product where the velocity and magnetic fields are both vectors with a direction and magnitude. The resulting induced electric field is also a vector which is perpendicular to both v and B.

3.3.5.2 HVAC Power Cables

High Voltage Alternating Current (HVAC) cables for marine environments are predominantly single cables with three individual conductor cores, delivering three phase power. The total magnetic field intensity outside a cable is a function of current flow on the cable conductors, the distance from the cable, and the separation of the conductors within the cable system. Because the phase conductors are near one another, there is a high degree of cancellation and fields are localised, reducing rapidly with distance as shown in Figure 8.



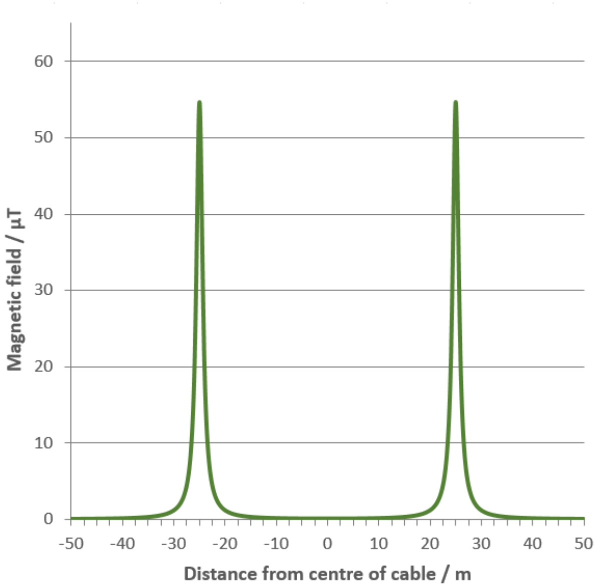


Figure 8: Maximum Calculated AC Magnetic Fields.
At the seabed from two single 3-cored 66 kV AC export cables, 50 m separation carrying 825 A (left); and two single 3-cored 275 kV AC export cables, 50 m separation, carrying 1024 A. Both cables were buried 0.6m below the seabed.

Further attenuation of the magnetic field from the 3-phase currents arises from the following factors:

- twisting of the three conductor cores along the length of the cable – further reduces the magnetic field at distances beyond the pitch of the twist (Del Pino Lopez et al., 2022)
- cable armouring (ferromagnetic shielding) – depending on material can result in a 2-fold reduction in the magnetic field (Del Pino Lopez et al., 2022).

A very small net current, also known as zero sequence current, may also flow in the cable or its sheath depending on earthing arrangements at its ends. The magnetic field resulting from these net currents reduces less quickly with distance[9] than the magnetic field that results from the load currents[10]. Although the net current makes very little difference to the maximum magnetic field close to the cable, once you move away from the cable, it can be the magnetic field from the net current that dominates.

[9] Magnetic field from net currents reduce with the inverse of distance
[10] Magnetic field from 3-phase load current reduce with the inverse of distance squared

Unlike DC fields, AC magnetic fields reverse direction rapidly and so the measured AC field can be considered separately from the measured DC geomagnetic field.

AC magnetic fields, because they are constantly changing direction 50 times a second, will induce weak electric fields in conductive objects, such as seawater and animals. The induced electric fields in seawater and animals through this mechanism can be calculated using numerical methods. The BOEMRE report (Normandeau, 2011) gives an analytical method for calculating the induced electric field within an animal, derived from Reilly (Reilly, 1991), but this is an area where further research is required. This is in addition to the motion induced AC electric field that occurs through movement in the AC magnetic field.

3.3.5.3 Electromagnetic Fields - Summary

Any cable that carries a current will produce a magnetic field which varies in intensity and spatial distribution depending on the cable system design. In addition to a magnetic field, induced electric fields can also occur, via different mechanisms, depending on the frequency of transmission. Table 2 summarises the type of fields that can result from each technology type and should be considered when assessing EMF impacts to the marine environment.

Given the very low levels of EMF in a repeatered telecommunications cable, and no EMF produced by unrepeatered telecommunications cables, they do not require further consideration. Magnetic field emissions are typically only elevated a few centimetres from the repeatered telecommunications cable surface.

Some of the published electric and magnetic field strengths from different power transmission systems are presented in Table 3. The reported values vary in the calculation methodology used. An agreed standardised approach to assessing EMFs in marine environments would improve the overall understanding of these emissions for future research.

Table 3: EMF considerations for different technology types

	Technology type		
	Telecommunication	**DC (Power)**	**AC (Power)**
Magnetic fields	Y	Y	Y
Combination with DC geomagnetic fields	Y	Y	N
Compass deviations	N (too small)	Y	N
Motion induced electric fields	N (too small)	Y	Y
Induced electric fields	N (too small)	N	Y

Table 4 : Data on electric and magnetic field strengths for various power cables obtained by measurement and calculation

Cable type	Design and capacity	Magnetic field	Induced electric field	Reference
DC Bipole	Bipole bundled cables ±550kV, 2047A	5433 µT at cable surface 1248 µT at 0.2 m from cable surface 55 µT at 1 m from cable 14 µT at 2 m from cable	*Assuming a 1.25 m/s tidal flow* 5606 µV/m at cable surface 1288 µV/m at 0.2 m from cable 58 µV/m at 1 m from cable 14 µV/m at 2 m from cable	Western HVDC Link (2011)
	Bipole 50m separation between cables ±550kV, 2047A	5459 µT at cable surface 2047 µT at 0.2 m from cable surface 409 µT at 1 m from cable 205 µT at 2 m from cable	*Assuming a 1.25 m/s tidal flow* 6823 µV/m at cable surface 2559 µV/m at 0.2 m from cable 511 µV/m at 1 m from cable 256 µV/m at 2 m from cable	
	Bipole ±300kV, 354A	Measurement along seabed, cable 2m burial depth Maximum 18.7 µT		Cross Sound Cable (Hutchinson et al. 2020)
DC Monopole	Two balanced monopole systems (four cables in total, conductor and return bundled) 320 kV, 700 MW per pole	0.6 m burial 23 µT at seabed		Fab link (2016)
	Monopole with sea electrode return 1500 A	300 µT at above the cable 55 µT at 5 m from cable 14 µT at 200 m from cable	10^6 µV/m at 10 cm from the cathode $7x10^4$ µV/m at 1 m from the cathode 1-50 µV/m far from the cathode	Koops (2000)

AC Single cable 3-cored	Export cable 132 kV, 745 A	*Parallel conductors* 200 µT at 0.2 m from cable 4 µT at 2 m from cable *Twisted conductors* 200 µT at 0.2 m from cable 0.8 µT at 2 m from cable		Del-Pino-Lopez et al 2022
	Inter-array cable 66 kV, 715 A	1 m burial 6.8 µT at seabed 6.8 µT at 1 m above seabed	1 m burial 1100 µV/m at seabed 100 µV/m at 1m above seabed	Coastal Virginia Offshore Wind Commercial Project (2021)
	Export cable 230 kV, 950 A	1 m burial 11.2 µT at seabed 8.7 µT at 1 m above seabed	1 m burial 1900 µV/m at seabed 200 µV/m at 1m above seabed	

3.3.6 Power Cable Armouring Considerations

Unlike subsea telecommunication cables, which may be used without armour in deep water applications (See Section 4.2), power cables are always armoured. The armour in a power cable is the main mechanism for imparting tensile strength to the cable, as well as protecting it from damage by natural and human hazards. The overall diameter of a subsea power cable may range from 150mm to 300mm or more (See Table 2), depending upon the conductor size, number of conductors and the amount of armour considered appropriate for the installation location. The mass of power cables can range from 60kg to 140kg per metre. Cross sections of examples of power cables can be seen in section 4.3.2.

3.4 Other Types of Subsea Cables

In addition to the uses described above, many other human activities make use of subsea cables. The oil and gas sector uses cables to provide power and communications to offshore facilities, and to link surface and underwater plant for control and monitoring purposes.

The scientific community uses subsea cables to support remote seafloor observatories. Subsea cable sensing technologies are also being developed and in some cases are in use. These technologies include use of the optical fibres within cables to collect underwater data such as acoustic and temperature monitoring, detection of cetaceans, storms and ocean currents and includes the following techniques: i) Interferometry or Phase with High Loss Loop Back (Marra et al., 2022); ii) State of Polarisation (Zhan et al., 2021); iii) and distributed fibre sensing including Optical Time Domain Reflectometry, Distributed Temperature Sensing and, Distributed Acoustic Sensing (Landrø et al., 2022). In addition, sensing using cables may also include bespoke SMART ('Science Monitoring And Reliable Telecommunications') cables that are designed to integrate specialist repeaters with built-in scientific sensor packages (Howe et al., 2019).

Military applications for cables include communications and subsea detection systems.

While the underlying technologies and installation methods for scientific or military cables can be like those used for conventional power and communications cables, other sectors can have their own industry standards and operate under different legal and regulatory regimes.

3.5 Cable Protection

Cable protection is first considered at the design stage - subsea cables play a critical role in communications and energy infrastructure. The failure of these cables can lead to significant cost and inconvenience for users, and the repair of broken cables is a time consuming and expensive process.

Cable protection can be achieved or enhanced in several stages:

- Through inbuilt design of the cable route in the planning stages to install in areas where there is less risk to the cable.
- Installation according to good practices promoted by the cable industry through the International Cable Protection Committee (ICPC) Recommendations[11].
- Regulatory measures can be considered and taken into account – for example where damaging activities may be excluded from the area where a cable is installed in some countries.
- The ICPC has published Government Best Practices[12] which provide guidance to Governments and regulators on ways in which cable protection and overall resilience can be enhanced. This can in turn have environmental benefits where minimally invasive installation techniques can be deployed, or lesser amounts of external cable protection may be needed. Reduction of other pressures on the seabed in the vicinity of subsea cables can also have environmental benefits.
- Previous sections of this document describe the armouring considerations for telecommunications and power cables.
- In nearshore areas, articulated pipe can be deployed as a form of integrated cable protection that is clamped to the cable itself. See figure 6.
- Where there may be greater need for protection, or at crossing points where further separation between assets is required (e.g., Pipeline or power cable crossings) then external cable protection can be considered – e.g., Rock placement, concrete mattressing, or other forms of external protection. See section 4.5.2.

Since the primary risk posed to subsea cables comes from external aggression caused by human activities, cable protection requirements are usually greatest in shallower waters where those activities are most intense. As a result, cable owners adopt multiple strategies to consider cable protection, and thus minimise risk of damage.

Methods of cable protection are discussed in the following sections.

3.5.1 Cable Route Design and Engineering

The optimal cable route is one that enables the cable connection to be made in the shortest distance whilst avoiding areas that pose a hazard to the cable, such as areas of intensive fishing or shipping activity. Seabed conditions are assessed, and routes adapted to avoid unstable regions and minimize the likelihood of cables becoming suspended across irregularities on the sea floor.

Environmentally sensitive, protected and designated sites are also taken into account in cable routing and avoided where possible.

[11] ICPC Recommendations: https://www.iscpc.org/publications/recommendations/https://www.iscpc.org/publications/recommendations/

[12] ICPC Government Best Practices: https://www.iscpc.org/publications/icpc-best-practices/https://www.iscpc.org/publications/icpc-best-practices/

In accordance with the mitigation hierarchy, subsea cable systems are micro-routed to find the optimal route that avoids or minimises interaction with sensitive habitats from the outset and this is taken into account in the route engineering process.

Many factors are taken into account when routing a subsea cable, and the primary considerations are described in ICPC Recommendations[13]. But there are other factors that are deterministic for cable routes that may prevent optimal routing being achievable, and these can include specific landing points (grid connection points for power cables or backhaul availability for telecommunications cables), presence of other seabed users and infrastructure, unexploded ordinance sites, anchorages, wrecks and obstructions, military practice areas, dumping grounds, and other charted areas or hazards.

3.5.1.1 Defined Landing Points

The requirement for a pre-defined shore landing can prevent optimal routing, in such a case the cable must land at a specific location for reasons other than optimal routing. This can occur where there is existing infrastructure to which the cable must connect.

For telecoms cables the availability of backhaul[14] and terrestrial connection points are a limiting factor when selecting a location for a cable to make landfall.

Routing for marine power cables is heavily influenced by the ability of grid connection points where the power can be integrated into the transmission network. Such infrastructure limits place a constraint on just where the cable can come ashore.

Landing far away from the connection point can be more problematic than a longer marine route. A long land route to reach a connection, with multiple landowners, can also be more challenging in terms of construction than a longer marine cable routing.

Once the route is defined, the design team will select cable types and armouring systems appropriate for the various conditions along its length.

3.5.1.2 Routing Considerations from Marine Spatial Planning

Within and outside the European Union commitments have been to develop Marine Spatial Planning which is described as *"a process by which the relevant … authorities analyse and organise human activities in marine areas to achieve ecological, economic and social objectives"* [15]. MSP is in place across many OSPAR countries and is being further developed and implemented.

[13] ICPC Recommendation #9, Minimum Technical Requirements for a Desktop Study (also known as a Cable Route Study), Issue 10C, 12 June 2022.

[14] Backhaul refers to the land route connection to the Cable Landing Station. (CLS)

[15] https://maritime-spatial-planning.ec.europa.eu/msp-eu/introduction-msp

Some Marine Plans are more prescriptive than others but can have an impact on cable route design and selection, e.g., Germany's maritime spatial plan[16] spatially coordinates various uses (e.g., shipping, offshore wind energy, cables, pipelines, raw material extraction, fisheries, research and defence) to help minimise conflicts and reconcile such uses with the ecological functions of marine space.

Within the EU's MSP process there is generally no differentiation between power cables and telecoms cables as developments, with the same recommendations regarding route planning applying to both. As a result, it is anticipated that this process will evolve over time as the sectoral differences are vital to consider. The EU's Directive for maritime spatial planning came into effect in July 2014, at a time of a growing offshore renewable energy market and the required power cables. Therefore, some existing in-service cables pre-date the commencement of MSP processes, and others have had their routing undertaken within this framework. Future offshore developments will be impacted in terms of routing by Marine Spatial Planning.

3.5.1.3 Subsea Cable Burial

In water depths of less than approximately 1500m where human activities pose a risk to the cable, the preferred cable protection approach from an environmental, technical, and commercial perspective is burial in sediment.

Cables are typically buried to a depth of between 0.5m – 1.5m below seabed where feasible. This depth is determined by the requirement to locate the cable in stable sediment where it will not be subject to movement by natural processes or human activities, such as demersal fishing or ship's anchors.

Seabed density can impact burial, and assessments are undertaken using the Burial Protection Index (BPI) for telecommunications cables or undertaking a Cable Burial Risk Assessment (CBRA) for power cables.

Deeper burial >2m below seabed can be used depending on burial method and seabed type – especially in shipping lanes or harbour areas. Deep burial can impact the ease of recovery and repair and is therefore necessary to consider on a case-by-case basis.

Cables are buried to protect them from human activities such as demersal fishing and ship's anchors. In the past, typically cables were buried (e.g., using a cable plough) to 1000m water depth. As human activities extend into deeper water (such as deep-water fishing activities) this has led to cables being buried in greater depths to approximately 1500m. Beyond 1500m water depth where cables are generally surface laid and unarmoured (approx. diameter 17mm for Light Weight telecommunications cable), because of the low threat of external aggression at this water depth. In water depths greater than 1000-1500m, the risk to a telecommunications cable from human activities is deemed low enough not to warrant any cable protection through burial. Power cables are not generally installed at such water depths (with some exceptions).

[16]https://www.bsh.de/EN/TOPICS/Offshore/Maritime_spatial_planning/Maritime_Spatial_Plan_2021/maritime-spatial-plan-2021_node.htm

New human activities developing and exploiting water depths deeper than 1500m, such as deep seabed mining are likely to increase the threat and risk of cable damage in this area.

Currently, power cables are typically laid in water depths less than 100m, but there are exceptions, such as the Sardinian-Italian connector, which is laid in water depths of 1600m, the deepest submarine power cable in the world.

The burial requirements for power and fibre optic cables differ significantly, and burial requirements for all types of cable will vary depending on sediment type, cohesiveness, and local conditions.

3.5.2 Cable Protection – Integrated and External

The primary method of protection is burial for subsea cables, however additional protection measures can be undertaken in some cases due to:

- Seabed conditions and geology.
- Cable crossing over existing in-service cables or pipelines.
- Where there are additional hazards which present a further risk of cable damage.

In these cases, alternative or supplementary approaches to protection such as integrated or external protection may be used.

Integrated protection systems may be installed onto the cable itself either during or after installation. Common approaches include the use of flexible polyurethane ducting systems or articulated steel pipe which are applied around the cable as shown in Figure 6. Articulated pipe can be installed in the nearshore approaches to a landing where conditions dictate and for the purpose of this report is referred to as integrated cable protection as it is applied directly to the cable.

Figure 9 Articulated Pipe being applied to telecommunications cable. Photo courtesy of Pelagian Ltd.

External protection is laid along and over the cable route after installation. Examples of external protection include scour mats, concrete mattresses and rock placement. These are more commonly seen for protection of power cables.

The only circumstance where telecommunications cables may typically have rock placement or mattressing is where it is used as a method of separation where crossings are undertaken with third parties (pipelines or power cables). Telecommunications cables crossing telecommunications cables do not generally require external cable protection.

External cable protection may be required and laid throughout the lifecycle of the cable or following a repair, although the majority will be installed close to the cable installation phase.

External cable protection is installed to protect cables from external aggression (e.g.,, fishing and ships' anchors) and activities which interact with the seabed that could damage a subsea cable.

3.5.2.1 Seabed Conditions and Geology

Where the required burial protection could not be reached due to the seabed geology (e.g., if rock or hard clay are present), or where sediment conditions may mean that burial alone will not achieve the desired degree of mechanical protection, then additional external protection may be deployed.

3.5.2.2 Cable Crossings

- Telecommunications

  External protection is not usually required for a telecommunications cable crossing another telecommunications cable[17]. Where a level of protection is required then integrated protection can be applied, such as through the use of inter-locking plastic sheaths. These sheaths are placed over and around the cable - for example 'Uraduct'[18] - these provide a level of integrated protection as it is applied directly on to the cable itself.
  Where telecommunications cables cross existing power cables or pipelines external protection such as mattressing may be required and the design of a crossing is agreed with the third-party asset owner.

- Power

  Power cables will use external protection for all crossings, with the application of articulated concrete mattresses over the in-service asset, and then rock placement over the cable that is lying over the mattresses. For power cable crossings, this takes the form of rock berms which can typically be between 0.5 and 2m in height above seabed.

3.5.2.3 Additional Hazards

Power cables are very sensitive to excessive or repeated movement, as this can damage the lead (Pb) layer that lies within the cable. Situations where a power cable is at risk of movement can occur when the cable rises out of burial and into a fixed pipe, or 'J-tube', into a structure, or when the cable is lying across short section of solid rock into which it cannot be buried. To minimise movement of the cable sections of inter-locking articulated metal pipe can be placed around the cable. Like the application of Uraduct for telecoms cables, this integrated protection is applied directly on to the cable itself [19].

If a repair is undertaken during the cable operational phase and reburial is unachievable post-repair, then additional rock protection may be deployed in this area. These methods are most commonly used for power cables as opposed to telecom cables.

3.6 Cable Installation

The installation of a subsea cable is generally a continuous process with associated spatial and temporal effects on the seabed limited to the footprint of the cable installation

[17] https://www.iscpc.org/publications/recommendations/
[18] https://www.crpsubsea.com/products/product-families/impact-abrasion-protection/uraduct/
[19] https://www.protectorshell.com/articulated_split_pipe.html

operation and the duration of the installation activity - which is a function of the progress speeds of the operation.

The complexity and duration of cable installation projects varies significantly with cable type and the installation environment. Installing a fibre optic telecommunications cable may take a few days, weeks or several months depending on the length of the cable which could vary from a short inter-island cable to a large transoceanic system.

Indicative progress rates for telecommunication cable installation are as follows:

- Burial – 15km per day (approx. 0.5-1km per hour)
- Surface lay - >150km per day (4-7km per hour)
- A typical beach shore end landing will take place in one day, with around a week allowed for ancillary preparatory and completion activities.

Installation of a power cable can take from several days to months or may require multiple campaigns spread over several seasons as the vessels are not able to carry the full length of required cable in one campaign.

3.6.1 Cable Route Survey

The telecommunication industry has developed and broadly adopted guidelines on the scope of requirements for cable route surveys. These guidelines are in the form of ICPC Recommendation 18 *"Minimum Technical Requirements for the Acquisition and Reporting of Submarine Cable Route Surveys"* (Issue 1A, July 2020).

Once the proposed route of the cable is known, geophysical and geotechnical surveys will be conducted to assess the selected cable route and the condition of the seabed. These surveys are conducted using vessels equipped with mounted or towed acoustic survey sensors. These 'geophysical' sensors typically include a hull- or pole-mounted multibeam echo sounder (MBES) (150 – 420 kHz in frequency for shallow water and ~12 kHz for deep water) which collects seafloor data to generate bathymetric contours of the seabed, towed side scan sonar (SSS) (<100 kHz in frequency) which collects data to generate seabed imagery showing the contrast in acoustic signature of seabed material used in the interpretation of sediment types, and sub-bottom profiler (SBP) (2-16 kHz in frequency) which collects data to define the shallow stratigraphy of the seabed to a depth of several meters in order to assist with evaluating the feasibility of cable burial. Higher frequency equipment is often used in shallow water less than 1000 m water depth or the limit of cable burial whereas lower frequency equipment (i.e., a 12 kHz MBES) is used to collect data in the deep ocean beyond 1000 m water depth. Beyond the planned end of burial for the cable system, only deep water MBES is collected. The SSS and SBP sensors are typically only deployed in shallow water where burial is planned.

The geophysical survey (acoustic sensor data collection) is accompanied by a geotechnical survey (often from the same vessel) which uses coring techniques (gravity core, piston core, vibrocore, etc), along with grab samples and, where required, cone penetration tests (CPTs). The purpose of the geotechnical survey is to 'ground-truth' the geologic interpretation of sediment types of the seabed, and to assess the geology down to or just past the anticipated depth of burial within the seabed. The geotechnical information aids the selection of appropriate cable burial methods and equipment.

The geophysical and geotechnical data are used to define a final installation route for the cable that targets suitable bathymetry, seabed geology, and is routed along a path where burial is feasible within burial sections.

Outside of MSP areas, a route survey for a telecommunications cable will typically cover a swathe of seabed that is 500-1000m wide along the route depending on water depths. Power cables generally use narrower corridors for survey.

Within some MSP areas (e.g., Germany) routing constraints can reduce the available corridor to smaller distances. Survey planning therefore needs to take into account a multitude of technical and proximity factors.

Currently the most common platform for the deployment of the sensors is from manned vessels that operate 12-hour days for shorter regional cable systems or 24-hour days for larger or transoceanic cable systems. Crews onboard the vessel not only collect data using the geophysical and geotechnical equipment, but they also process the data and develop the necessary deliverables that are utilized during cable installation.

New technologies are emerging such as specialty applications for emerging survey platforms including survey operations using Autonomous Underwater Vehicles (AUVs), remotely operated sub-surface vessels, unmanned surface vessels deployed from a mother ship, or from survey vessels with the crew managing data acquisition from a land-based location. There are, however, some limitations in these emerging methods and equipment, namely that the amount of data collected for any given survey line is often less than from a manned vessel, and the survey durations can often be longer than a conventional manned approach.

In all cases, the acoustic sensors and their frequencies are intended to map the surface of the seabed as well as the first few meters of the subsurface to build a ground model from which an understanding of the seabed conditions can be made. This ground model is used to finalise cable route design, armouring selection, and burial planning.

Where the presence of hazards such as in-service pipelines and cables or unexploded ordnance (UXO) may be a concern along the route, then additional surveys may be required using different sensors appropriate to the survey objectives. It is standard that a survey vessel will have a magnetometer onboard to help identify the presence of existing metallic seabed infrastructure such as cables and pipelines that are not identified in other collected data sets (such as side scan sonar). More advanced magnetometers or gradiometers used for UXO surveys are deployed on a case-by-case basis depending on anticipated conditions.

3.6.2 Route Preparation

Prior to cable installation, work may be necessary to prepare the route of the cable. The complexity and scale of this work varies significantly according to the type of cable and the seabed environment. This involves both the preparation of the seabed to ensure it is clear of debris, and also the installation of any necessary ducting or facilities at the landing location.

3.6.2.1 Horizontal Directional Drilling (HDD)

In nearshore zones (coastal or intertidal area) where cable burial may not be possible due to challenging substrates or the presence of sensitive habitats, horizontal directional drilling (HDD) can be used at the shore end location to install a cable from a beach landing site through the intertidal zone.

This approach involves the subsurface drilling of a hole and placement of a conduit through which a cable is passed during installation. The profile of the HDD emerges on the seabed below the Low Water Mark. This method of cable burial and protection at a shore end location can be used to avoid disturbance of specific features or provide greater protection to the cable. It enables cables to be installed under man-made obstructions, such as sea defences or port berths, without affecting them.

HDD will take place ahead of the main cable installation campaign to ensure that landing facilities are ready in advance for cable pull-in.

3.6.2.2 Pre-Lay Grapnel Run

Seabed preparation for a cable might require a pre-lay grapnel run (PLGR) which is undertaken in areas of anticipated burial to ensure that the route is clear of debris. PLGR is where a vessel tows a grapnel along the cable route to recover, safely dispose of and clear any debris from the route. A grapnel consists of several elements, a grapnel train – in the order of 1m wide - that are linked together and towed by a vessel.

For telecommunications cables PLGR is the typical form of seabed preparation, with Route Clearance (Section 4.6.2.3) taking place where the route crosses Out-of-Service (OOS) cables. PLGR is only undertaken in areas of planned cable burial.

Power cables installation activities may undertake PLGR or may use other techniques to prepare the seabed which are described further in this section.

PLGR is not required where cables are surface laid.

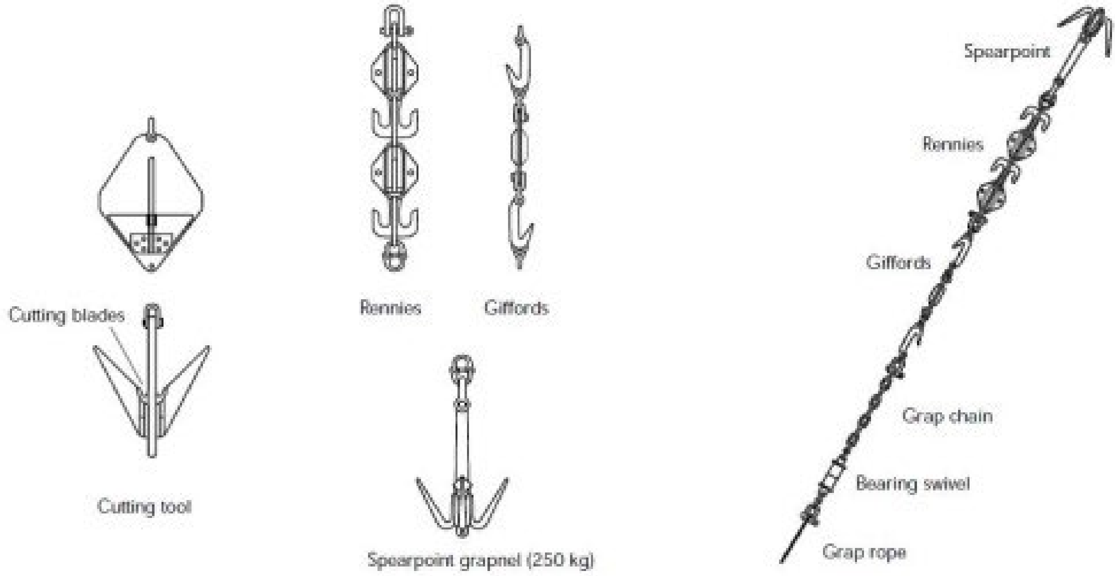


Figure *10* Diagram of Grapnels. Image courtesy of Alcatel Submarine Networks

3.6.2.3 Route Clearance

If Out-Of-Service (OOS) cables are in place along the route, sections of these are usually removed prior to the installation of a new cable, with cable ends made safe in accordance with standard industry procedures[20].

[20] ICPC Recommendation #1 Recovery of Out of Service Cables: https://www.iscpc.org/publications/recommendations/

3.6.2.4 Unexploded Ordnance (UXO)

More complex seabed preparation activities undertaken for large power cables (and potentially for other types of cable) can include UXO identification and clearance. Once an item that is confirmed to be unexploded ordnance is found, national guidance should be followed, and experts deployed to ensure a safe encounter and resolution.

Figure 11 Acoustic Survey of UXO Items (Right). Safely recovered items (Left)
Images TenneT Offshore GmbH

3.6.2.5 Seabed Features

Subsea sand waves and other mobile features on the seabed can be an obstacle to the passage of a burial tool. Where these occur the pre-sweeping and dredging of sand waves can be undertaken to create a more level base for subsequent laying and cable burial operations.

Pre-sweeping is the process to flatten or cap sand waves to avoid future suspension of cables, in order to allow cables to be laid underneath. Some of the tools that can be used to achieve this are describes in Section 4.6.3.

Likewise, the presence of boulders across a cable route corridor may be unavoidable and can block the route. Boulder clearance may be undertaken in certain circumstances to allow the passage of the tool that will bury the cable. Moving of boulders off the route of the cable is typically either undertaken by displacement of them by a plough that clears a corridor, or by pick up and relocation of individual boulders.

It is worth noting, however, that despite the likelihood of having to mitigate the impact of certain seabed features along a cable route, avoidance of the most problematic features is good practice when designing a cable route.

3.6.2.6 12Cable Crossings

Where a cable has to cross an existing in-service cable or pipeline then a survey is firstly undertaken to confirm the actual crossing position and the current status of the in-service asset. Depending on the type of crossing, seabed preparation works can include the placing of articulated concrete mattresses over the in-service asset to ensure a minimum, or positive, separation is kept between the existing asset and the new cable that will be laid over it.

Telecommunications cables crossing telecommunications cables do not commonly require additional protection of this type, and the design of crossings between third party assets is considered on a case-by-case basis.

After cable installation, in order to protect the crossing structure, protective material such as placement of rocks or additional articulated concrete mattresses over the extent is undertaken.

Typically the extent of a power cable crossing will comprise of three elements:

- The grade in and out distances where the cable goes from its burial depth to the seabed surface.
- The placing of the cable over the section of positive separation and the in-service asset.
- The placement of crossing protection over the full extent of the two previous phases.

For a typical power cable crossing this results in a crossing that extends for 80m in length, with a berm height of 1.5m.

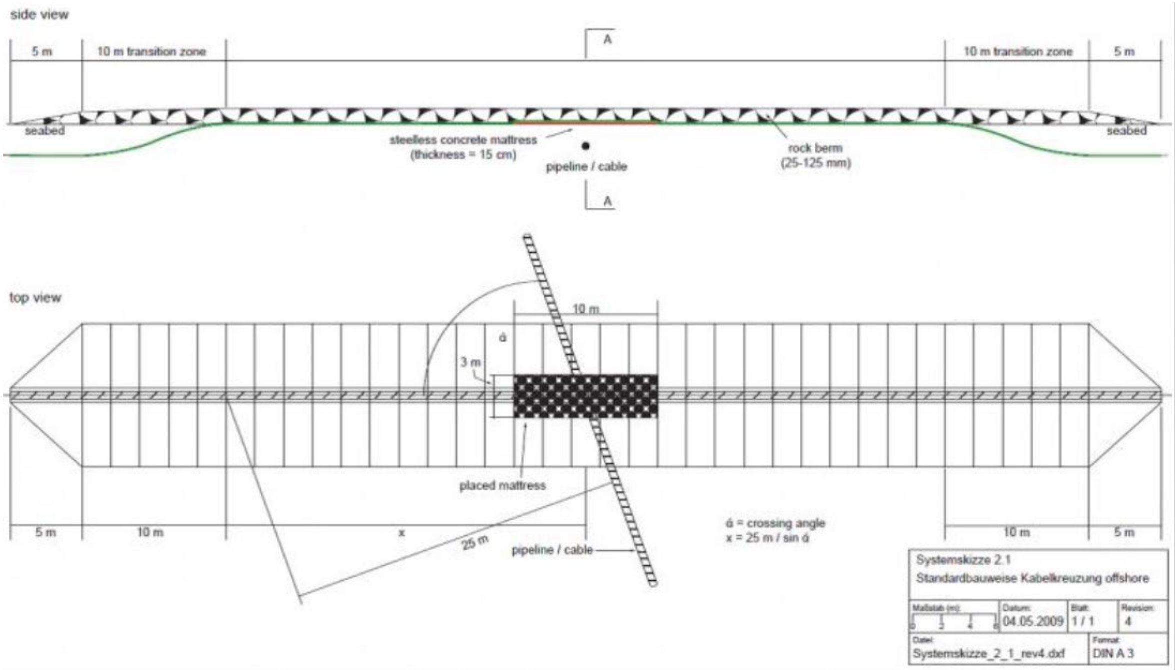


Figure 132 : Example Design of Power Cable Crossing Over Existing Cable: Image TenneT Offshore GmbH.

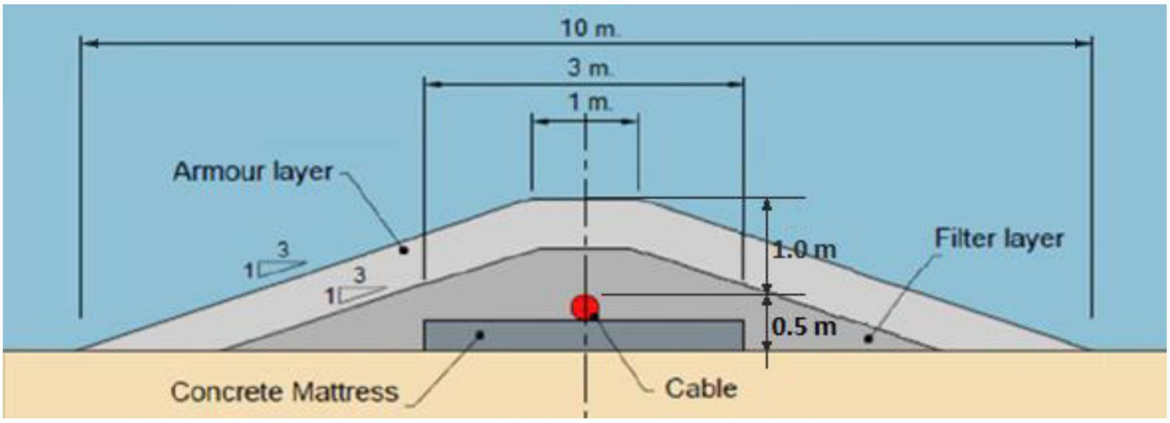


Figure 14 : Typical Rock Berm Profile at Crossing: Image TenneT Offshore GmbH

Due to the smaller impacts that a telecoms cable has when it crosses over a pipeline or power cable, there are minimum requirements for such crossings[21].

[21] ICPC Recommendation #3 Telecommunications Cable and Oil Pipeline / Power Cables Crossing Criteria https://www.iscpc.org/publications/recommendations/

3.6.3 Cable Installation

Different cable installation tools and techniques are available depending on the type of cable being installed, seabed type, conditions and various other factors that determine how a cable will be installed.

For telecommunications cables, the methodology and techniques have been established over decades in accordance with industry good practices and recommendations (ICPC). However, power cables and cables for offshore renewable energy mean that other techniques may be used to achieve burial depths or to accommodate different cable handling requirements.

3.6.3.1 Burial and Surface Lay Methods

While telecommunication cables may be laid directly on the seabed in the deep sea (typically >1500 m water depth), most cable installation operations in shallower water involve burial of the cable where sediment conditions allow protection of the cable from human activities, or other threats and some types of natural hazard. This is achieved in two principal ways, Simultaneous Lay and Burial (SLB) and Post Lay Burial (PLB):

- Simultaneous Lay and Burial (SLB)

In simultaneous lay and burial (SLB) operations, a plough towed by the cable ship creates a trench to the desired depth of burial using the plough shear (also known as a plough share), typically to 0.5m – 2m below the seafloor. The cable passes through the plough and is laid into the excavated furrow. Excavated sediment is then allowed to naturally fall back in and infill the furrow.

The final width (typically 0.4m-0.75m wide) of the excavated furrow depends upon the size of the shear used to bury the cable and sediment type. For example, a 0.45m-wide furrow might widen in poorly consolidated sediments if the sidewalls of the furrow collapse into the furrow itself. In cohesive sediments, the furrow width is likely equal to the width of the plough share, while, in granular sediments the width may be slightly wider.

The plough is stabilised by skids on either side of the furrow, which may up to 0.75m wide. These may compress softer seafloor sediments.

Telecoms cables are generally buried to 0.5-1.5m beneath the seabed to facilitate cable repair and maintenance. Deeper burial can reduce the ability to recover cables in order to repair them and can increase the environmental impact of recovery. Burial requirements are assessed on a case-by-case basis taking into account regional seabed types and conditions, and any requirements for burial within licences should take this into account to fully understand the technical challenges of deeper burial.

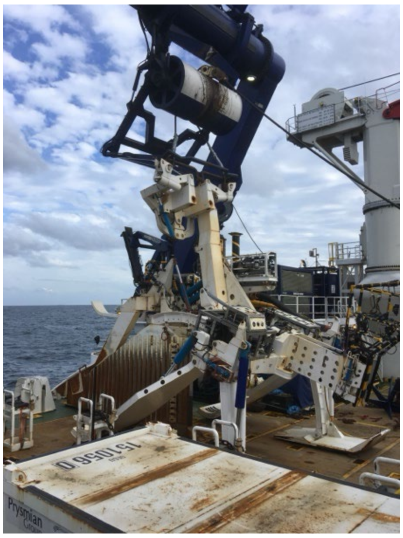


Figure 15 Skid Supported SLB Power Cable Plough - Prysmian's Heavy Duty Plough : Image D. Sinclair TenneT Offshore GmbH

Figure 165Telecommunications cable plough being deployed on an 'A Frame'. Image Global Marine Group.

- Post-lay burial (PLB)

Alternatively, post-lay burial (PLB) is a two-stage process. The cable is first placed on the seabed, then a burial tool follows the cable and cable burial is achieved by two principal methods.

In granular sandy seabed the tool with water jets fluidises sediment either side of the cable allowing it to sink to depth. The fluidised area is typically 0.15m to 0.5m wide and may extend typically to a depth up to 3m below the sea floor. Jetting disturbs the sediment more than ploughing.

Figure 176 Example Of A Power Cable Post Lay Burial Jetting Tool - Canyon's T-1500 : Image D. Sinclair TenneT Offshore GmbH.

In cohesive, clay rich seabed, the tool picks the cable up placing it inside the tool, while a cutting chain creates a trench in hard material. Burial Jetting in cohesive sediments tends to create trenches with steep-sided profiles, while broader profiles are more common in granular sediments. Observed seafloor disturbance widths of the trench are <1m, and typically much narrower. The depth of the trench made by a chain cutter would vary based on the type of tool but can range typically up to 2m deep.

In both PLB methods the cable is covered by sediment that settles out from the fluidised or cut sediment.

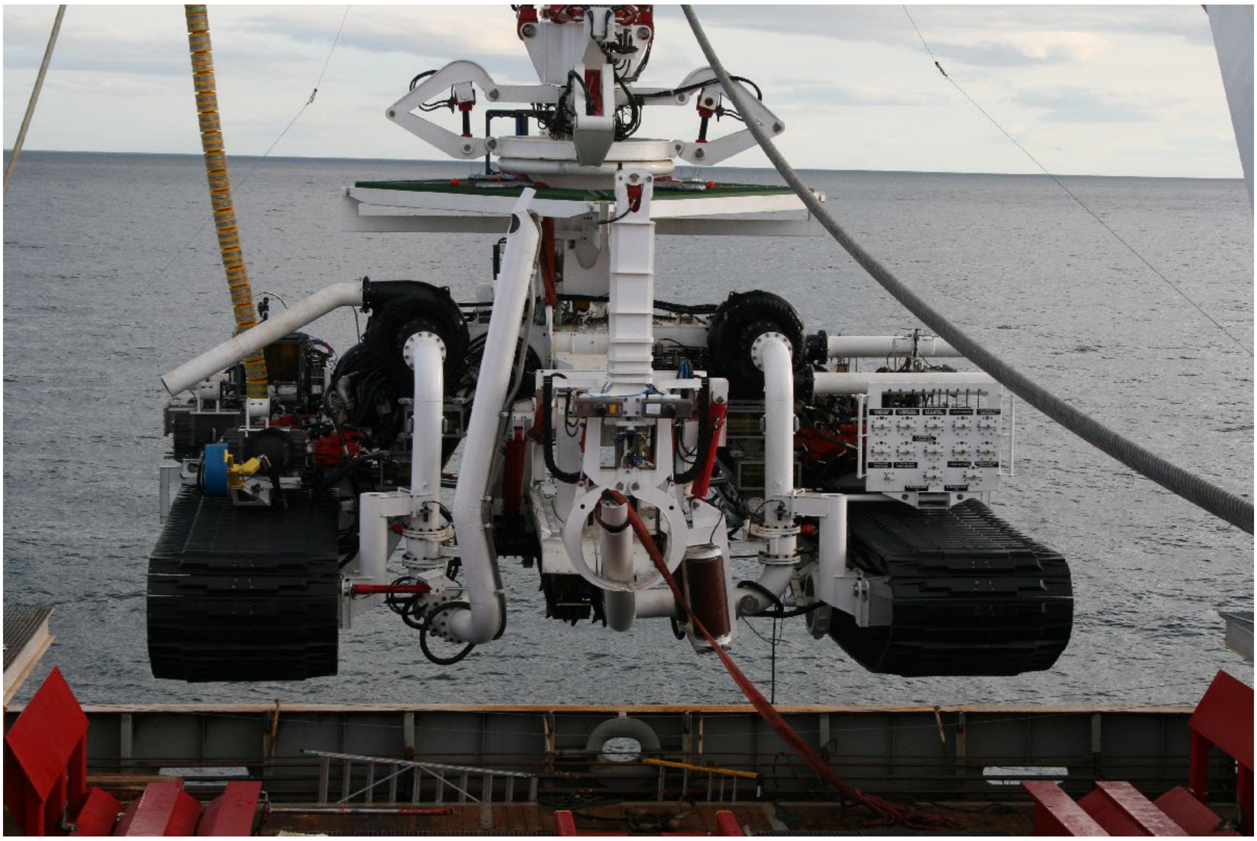


Figure 187 Example of A Post Lay Burial Chain Cutter Tool – Canyon's I-Trencher : Image D. Sinclair TenneT Offshore GmbH.

3.6.3.2 Rock Trenching

Cable routing generally avoids areas of rocky substrate, and given the expense and environmental impacts of trenching, this is a last resort. Where rocky seafloors must be traversed, cables have integral protection applied (e.g., articulated pipe) and are surface laid rather than attempting burial.

3.6.3.3 Power Cable Joint Burial

During power cable installation there may be a requirement for cable joints – either planned due to cable length, or unplanned due to an event which caused the cable to be cut.

Due to the much heavier weight of power cables compared to fibre cables, planned joints are a usual requirement for power cables, with a vessel not able to carry the entire length of cable needed in one go.

The laydown of the joint can be of two arrangements, depending upon the arrangement of the cable ends.

An 'in-line' joint occurs when the cable ship picks up the end of the cable already on the seabed and it has the next length of cable. The cable ends are joined, and the cable ship continues laying the cable in the same direction. This results in a cable and joint on the seabed that is in a straight line.

Figure 208 A Cable Joint In An HVDC Power Cable : Image D. Sinclair TenneT Offshore GmbH.

Figure 19 Cable joint being over-boarded vessel, creating an in-line joint laydown.

'Omega' or arrival joint is when the cable ship approaches from the opposite direction, i.e., it has already laid the cable. The cable ship picks up the end already on the seabed, joins it to the cable end on the ship, and then lays down the cable on to the seabed. Due to the length of cable that is within the water column this means the cable is laid down in a bight, or curve that is a similar shape to the Greek letter omega, Ω.

The joint, and cable bight if present, need to be buried with a post lay burial tool as described earlier.

3.6.3.4 Power Cable Pull-In to Platforms

Some power cables are connected to an offshore structure that is the source of energy transmission. The power cable passes up into the platform through a 'J' tube, an external pipe in the shape of the letter J, with the bend of the pipe just above seabed level.

If this is the start of the cable route, the end of the power cable is pulled directly into the platform from the cable ship. If this is the end of the cable route, then the end from the cable ship is lowered to the seabed, where it is connected to a wire rope that will pull it into the platform.

3.6.3.5 Shore End Activities - Civil Works

Typically, telecommunications cables are pulled into an open trench on the beach and are buried using a mini-digger or excavator. The excavated trench is usually back filled using existing materials, and these activities are of a short duration (approx. 1-2 weeks activity at the beach, and cable pull-in typically undertaken within 1 day).

Power cables are usually installed using Horizontal Directional Drilling (HDD).

Where a power cable does not cross the sea-land interface by HDD, further civil works between the low water mark and high-water mark are required. This usually involves the use of excavator machines, and / or sheet piling to create the access for the cable to shore.

3.6.3.6 Flow Excavators

Mass Flow Excavators (MFE) or Controlled Flow Excavators (CFE) are both tools that use the same principal for remedial burial of cables already on the seabed. The water flow places sediment into suspension and into the water column thus creating a depression into which the cable is lowered under its own weight. Cable protection is undertaken either by blowing sediment back over the cable or leaving the created depression to fill up naturally from material carried into It by tidal / wave currents.

3.6.4 Cable Installation Speeds

The installation rates achieved in cable laying operations are highly dependent on the size and weight of the cable, the chosen burial or external protection strategy, and the seabed conditions along the cable route.

A vessel laying lightweight fibre optic cable on the sea floor may achieve rates of 6000m per hour. A typical installation speed for simultaneous lay and burial of such cables in sands or soft clay sediments is 500m per hour – up to 800/1000m per hour in even softer sediments.

Burial progress rates for large diameter power cables are significantly slower than those achieved for telecommunication cables. Post lay burial operations in in soft substrates using jetting tools may achieve rates of 250m to 400m per hour. Where a chain cutter is used to create the trench for post lay burial in stiff clays or weathered rock, the installation rate may be a low as 50m to 150m per hour.

3.6.5 Vessels and Equipment

Companies engaged in subsea cable installation have developed laying vessels and sophisticated cable laying machinery to optimise cable installation under various laying conditions. Specialist cable ships[22] , appropriate to the type of cable they are installing undertake cable installation activities. Smaller construction vessels and anchor handling barges are used in shallower water (typically less than approximately 15m Water Depth (WD).

Telecommunication cable installation activities can often be completed by a single main lay vessel with small boat support at shore ends, but larger and more complex campaigns such as the installation of inter-array and export cables at windfarms may involve multiple specialised vessels, together with additional general-purpose craft used for the transportation of personnel and materials to the site.

[22] https://www.iscpc.org/information/cableships-of-the-world/

Underwater cable installation equipment includes ploughs, jetting equipment and remotely operated vehicles. Installation tools can be driven by different means; they may be towed by a vessel, or be self-propelled by use of track, be free-swimming or use both methods of propulsion.

The size of the tools used for cable installation activities vary greatly, the ones used for smaller and lighter telecoms cables being smaller than the ones required to manage the larger HVAC and HVDC cable bundles. A smaller tool for burial of a telecoms cable can have a mass of approximately 10 tonnes, with a width of 3.5 - 4.0m. Large tracked ROVs for burial of power cables can have a mass of up to 60 tonnes, and an overall width of 8m.

3.7 Further Reference Sources

There are resources available online to obtain further detailed information on Subsea Cables. Links to useful resources are included below:

- The ICPC (International Cable Protection Committee) publishes Recommendations which are widely used by the cable industry to promote good practices. These are available from the ICPC website as well as other resources and information about subsea cables. https://www.iscpc.org/
- The ICPC also publishes Best Practices for Governments to describe the resilience of subsea cables and the types of regulatory interventions that could be beneficial to promote cable protection and resilience. https://www.iscpc.org/publications/icpc-best-practices/
- ESCA (The European Subsea Cables Association) has observer status in OSPAR and has further resources available on the website. https://www.escaeu.org/
- KIS-ORCA is a not-for-profit cable awareness project which promotes the locations of cables for maritime safety and protection of cables. There are useful resources as well as an online Cables Map showing the locations of subsea cables and OREI (Offshore Renewable Energy Installations) infrastructure in NW Europe. https://kis-orca.org/map/
- CIGRE Technical Brochure: TB883 (2022): The Installation of Submarine Power Cables”

4 Environmental impacts associated with subsea cables

4.1 Introduction

Environmental impacts resulting from subsea cable installation and operation will depend upon the nature of the installation method (e.g., whether surface-laid, buried, or physically protected), the physical setting in which a cable installed (e.g., hydrodynamic conditions, seafloor substrate) and the components of the marine environment with which it interacts. Some impacts are common to all types of subsea cable; however, some impacts will be distinct for different cable types resulting from their different technical designs (e.g., there are key differences between telecommunications, AC and DC power cables). Therefore, in the following section we cross-reference the relevant technical aspects of cable design and installation (Section 4) to ensure that the appropriate context is provided, and discuss the spatial extent, timescale (duration, frequency, reversibility), intensity and their relevance for different components of the marine environment (i.e., sediment, benthic organisms, fish etc).

Environmental impacts that are common to all cable types include: i) permanent changes to seabed substrate in instances where physical protection (e.g., rock placement) is required for cable protection along narrow sections of a cable; ii) temporary or reversible physical disturbance of narrow areas of seabed following the burial of cables where it is necessary to protect them from fishing and anchoring in shallow water; iii) localised changes to hydrological conditions (e.g., influence on seafloor currents) immediately adjacent to seafloor-laid cables or where physical protection structures are installed; iv) short-lived noise arising from cable burial activities (e.g., trenching or ploughing) where cables require burial for protection; v) potential for short-lived release of previously-buried contaminants if cable burial disturbs previously-buried contaminant hotspots (i.e., created by other human activities unrelated to subsea cables). Most of these impacts are relatively short-lived in comparison to the typical 20-30 design life for subsea cables.

Other impacts that are specific only to power cables include: i) long-term electromagnetic fields (although the evidence for ecological impacts is currently considered to be limited); and ii) long-term thermal effects due to heat emission during power transmission. Both of these impacts will be tightly constrained to the power cable and do not relate to telecommunications cables due to fundamental differences in their design. Subsea cables have been shown to be chemically inert and physically stable under typical conditions; hence, release of contaminants (e.g., heavy metals in very small quantities) from a power cable itself would be limited to rare instances of cable damage.

This background document is focused on activities at and close to the seafloor. Disturbances from activities associated with subsea cables above the water surface (e.g., light emission of ships) are not addressed in this document. Furthermore, impacts from activities associated with the construction and operation of other infrastructure such as converter platforms are also not considered. These disturbances are comparable to the construction of other offshore installations which are discussed in existing documents (e.g.,, OSPAR, 2008). As already mentioned in Section 3.3.1, the environmental impact of dynamic cable systems is also not considered in this document.

Table 2 provides an overview of the possible types of disturbances that can arise from activities during various phases from cable routing to cable installation and operation. Activities relating to cable repair and recovery result in disturbances that are similar to those outlined for the cable installation phase. Cable faults are not common during the operational life of the cable, any repairs being limited in extent to the fault location. The intensity and extent of disturbances during cable repair and cable recovery are therefore expected to be of similar or lower impact than disturbances during cable installation. These phases (i.e., repair and recovery) are therefore not explicitly mentioned and discussed.

The disturbances from the various activities related to subsea cables were categorized into pressure categories which are in alignment with the MSFD-pressure categories and the OSPAR Joint Assessment and Monitoring Programme (JAMP) 2014-2023 (OSPAR COMMISSION 2022). Each category is discussed in more detail in the following sections with respect to the impacts on the marine environment and the potential for recovery. The listing of the disturbances is based on the sequence as they appear in the OSPAR JAMP.

As a general note, it is important to note that the specific impact of a disturbance strongly depends on the sensitivity of the particular ecosystem component. Hence, the information provided should be considered as a general description of the potential magnitude of impact and is not a substitute for a case-by-case assessment.

Table 5 Overview of the environmental disturbances associated with different phases and activities related to subsea cables.
Indicative disturbance durations are referenced, wherein "short-term" refers to one-off activities such as the passage of the burial tool during burial of the cable (that may last minutes to weeks), while "long-term" refers to impacts that may occur throughout the design life of a cable.
*Explanation: *Only applies to power cables*

Phase	Activity	Typical method and/or equipment	Duration	MSFD – Pressure (Refer to pressure table)
Multiple phases	Operation of vessels related to cable works.	Specialized cable ships and barges	Short-term	Input of anthropogenic sound (impulsive, continuous)
Cable routing	Geotechnical sampling	Multipurpose vessels, Vibrocore / Cone, Penetrometer Tests	Short-term	Physical disturbance to seabed (temporary or reversible)
	Geophysical survey	Vessels equipped with mounted or towed acoustic survey sensors	Short-term	Input of anthropogenic sound (impulsive, continuous)
Route preparation	UXO Clearance - In-situ detonation of UXO items deemed too dangerous to move.	Multipurpose vessels	Short-term	Input of anthropogenic sound (impulsive, continuous)
	Pre-installation works - dredging of mobile bedforms that prevent passage of installation tools*	Dredging vessels, dredge head	Short-term	Physical disturbance to seabed (temporary or reversible)
	Pre-installation works - pre-lay grapnel run (PLGR)	Multipurpose vessels, grapnel train	Short-term	Physical disturbance to seabed (temporary or reversible)
	Pre-installation works - route clearance of out of service (OOS) cable	Multipurpose vessel, grapnel, ROV with dredge pump	Short-term	Physical disturbance to seabed (temporary or reversible)

	Horizontal Directional Drilling (HDD) exits		Short-term	Physical disturbance to seabed (temporary or reversible)
Cable Installation	Cable pull-in into HDD Cable pull-in into J-tubes (at platforms)	Cable installation barges, cable installation vessel Cable installation vessel	Short-term	Physical disturbance to seabed (temporary or reversible)
	Passage of burial tool during burial of cable along route	Jetting tool; Cable plough; Cable burial cutting tool	Short-term	Physical disturbance to seabed (temporary or reversible)
	Burial of cable joints at defined locations*	Jetting	Short-term	Physical disturbance to seabed (temporary or reversible)
	Shore end activities - Civil works between low water mark and high-water mark	Excavator, sheet piling (trench support)	Short-term	Physical disturbance to seabed (temporary or reversible)
	Cable crossings - Protection of surface laid cable by placement of hard materials on seabed	Concrete mattresses, rock placement, rock bags	Long-term	Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate); Changes to hydrological conditions
Cable Operation	Thermal effects*		Long-term	Input of other forms of energy
	Changes in electromagnetic field*		Long-term	Input of other forms of energy
	Physical damage to cable resulting in chemical contamination		Long-term	Input of other substances

4.2 Physical Pressures

The impacts associated with physical pressures from subsea cables on the marine environment vary in their intensity, depending on the type and spatial extent of the disturbance, the duration, background environmental conditions, and the affected habitat and species. Potential impacts range from small-scale, short-term (i.e., minutes to weeks) disturbance of habitats and communities with a high recovery potential to longer term disturbances with potential habitat loss, albeit over narrow spatial footprints.

There is no standard definition of ‘recovery’, therefore, in this document recovery is referred to as the return of a depleted habitat or community to, or close to, its initial structural and functional state before the disturbance (see LOTZE et al. 2011). In general, recovery of benthic communities, especially of the infauna, is tightly linked to the physical recovery of the seafloor and its properties (sediment grain size, seabed topography, hydrodynamic regime) meaning that biological recovery is hampered if no physical recovery of the seafloor takes place. However, even after physical recovery of the habitat, biological communities may recover more slowly or recovery may remain incomplete. Next to those extrinsic factors, the recovery potential of biological species strongly depends on intrinsic factors such as life-history traits and recruitment, and is generally higher for fast growing, mobile and highly competitive species than for slow growing species with low larval recruitment levels (LOTZE et al. 2011). An extensive review by BIOCONSULT (2019) provides a broad overview of the regeneration potential for different benthic communities in the German EEZ after different types of disturbance, including physical disturbance of the seafloor.

Physical pressures may occur during the phases of cable routing, route preparation and cable installation. The degree of disturbance depends on the technique and equipment used as well as on the substrate type and hydrodynamic conditions on and above the seafloor. Physical pressures from activities associated with subsea cables include physical loss (as a result of potential placement of hard substrates and cutting through hard structures if required in specific circumstances), physical disturbance of the seafloor (as a result of sediment reworking, compaction and displacement, sediment resuspension and resettling of particles) as well as localised changes to hydrological conditions. These pressures may lead to various impacts on the marine environment including the physical properties of the seafloor and marine biota.

The following sections give a brief overview of the environmental impacts from different types of physical pressure on the seafloor as well as the likelihood and approximate time for recovery. However, since benthic recovery depends on many different factors, the assessment of recovery from disturbances related to subsea cables needs to be done specifically on a case-to-case basis (e.g., KRAUS & CARTER , 2018).

4.2.1 Physical loss (due to permanent change of seabed substrate or morphology and to extraction of seabed substrate)

4.2.1.1 Placement Of Hard Substrates

To protect surface-laid cables or cable sections from external damage (for example where cables cross each other) protection may be applied in form of hard material placement on the seafloor, depending on the type of crossing (See section 4.6.2.6). Examples include concrete-mattresses, cable stabilisation, or rock placement. This would be for a small amount of the length of the cable route. These protection measures lead to a physical alteration of the seabed resulting in small-scale habitat loss of the underlying seabed due to the cable itself and the protective structures (also referred to as sealed loss). Sealed soft-bottom habitat may be permanently lost on a small spatial scale without any potential for recovery of the sediment-community. Because of the small spatial extent, substantial negative impacts on the surrounding soft-sediment communities are not to be expected.

An important consideration with regard to the introduction of artificial hard materials is the provision of new habitat which could be colonized by various epifaunal organisms. Next to protective structures, the subsea cables themselves if not buried/covered along the seafloor may provide a solid substrate for a variety of species, including organisms such as anemones (Figure 2).

Where colonization of sessile, epifaunal species occurs, this may increase the species richness of the area albeit resulting in a less natural biodiversity in soft-bottom dominated areas. Moreover, the ecological relevance is limited as the small surface area does not support high habitat complexity.

The further discussed "reef effect" is, therefore, only considered to apply to larger surfaces of hard substrate such as concrete-mattresses or rock placement at cable crossings. The spatial extent of the protection zone at cable crossings up to 150m².

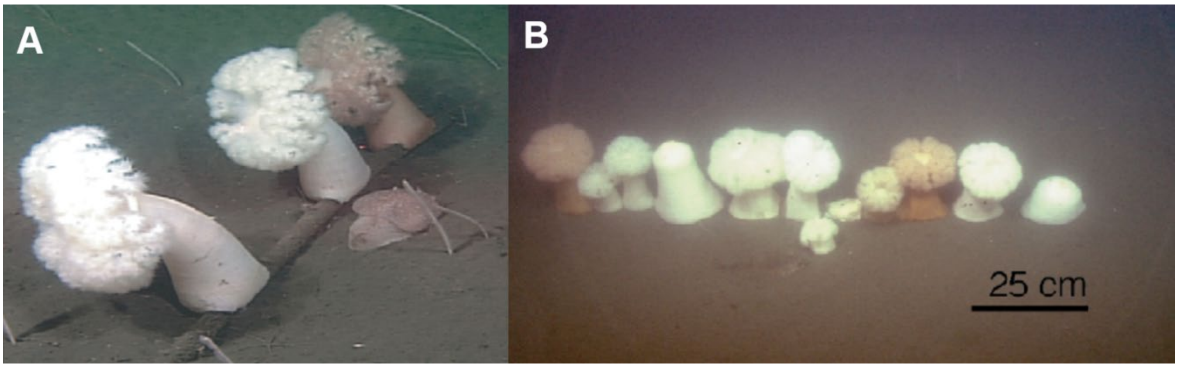


Figure 210: Photographs showing the colonization of the ATOC/Pioneer Seamount cable by Metridium *on exposed sections of the cable, 8 years after installation. A) 134m depth, B) 72 m depth. (modified from KOGAN et al. 2006)*

Generally, artificial hard substrates are rapidly colonized by sessile epifaunal organisms and their associated mobile fauna. The process of colonization of large artificial hard substrates in the marine environment is called the "reef effect" which has been extensively discussed and studied, especially with regard to the foundations of offshore wind turbines and associated scour protection (e.g., DEGRAER et al. 2020, KERCKHOF et al. 2019). After colonization, the epifaunal community goes through several successional stages until it is characterized and dominated by a few competitive species (DEGRAER et al. 2020). In a benthic habitat dominated by soft sediment this fouling community on the artificial hard substrates differs considerably from the local soft-sediment-community which goes along with an increase in habitat heterogeneity and a locally enriched biodiversity which in turn may affect ecological functioning and food-web-dynamics (DANNHEIM et al. 2019). The extent of the reef effect depends on the surface area of the provided artificial hard substrate which is considerably smaller for cables and associated protection structures in comparison to substrates provided by other offshore installations such as the foundations and scour protection of platforms and wind turbines. The reef effect may enhance habitat complexity and biodiversity in the surrounding area and may lead to an increase in the biomass of fish and large crustaceans which are attracted to the area for shelter and predation purposes (TAORMINA et al. 2018). SHERWOOD et al. (2016) reported that already 3.5 year after cable installation the articulated piping cover of the BassLink HVDC cable was densely encrusted and colonized by a community of sessile species which resembled the community of the surrounding reef area. Nevertheless, these reefs are built on artificial, man-made structures and their ecological significance may deviate from that of naturally occurring reefs and, in soft-bottom environments, from the naturally occurring species composition.

A potential drawback of the installation of artificial hard substrates is the introduction and distribution of non-indigenous species (NIS) which may benefit from the provision of new, colonizable habitat that can act as stepping stones for further distribution (DE MESEL et al. 2015, GLASBY et al. 2007). The spread of non-indigenous species worldwide has been acknowledged as a major threat to marine environments as some species can become invasive in very short time spans and may lead to strong alterations of biological communities (PYŠEK et al. 2020). At offshore turbines in the Belgian Part of the North Sea DE MESEL et al. (2015) found that the majority (8/10) of established NIS were located in the intertidal sections of the wind turbines and only two NIS were found in the deep subtidal zones of the foundations. Similarly, COOLEN et al. (2016) report the coexistence of the native shrimp *Caprella linearis* with the invasive *Caprella mutica* because of their different habitat preference where *C. linearis* occurs in subtidal and intertidal habitats whereas *C. mutica* is restricted to intertidal habitats only. The higher proportion of NIS in intertidal zones of hard structures may be explained by the fact that the primary distribution vector (ships) is mainly available to shallow water species. Subsea cables and protection structures are almost exclusively laid in the subtidal water zone which makes them less prone to colonization by NIS. Indeed, SHERWOOD et al. (2016) reported that the metal protection shell around the Basslink cable was colonized by local biota within 3.5 years. Similarly, exposed sections of the MARS system supported local species of sea anemones as opposed to non-indigenous species (KUHNZ et al. 2015). The results of these few studies indicate that the risk of the establishment of NIS on hard substrates in deeper, subtidal areas exists but is lower compared to structures in the upper part of the water column and in the intertidal zone.

4.2.1.2 Cutting through hard substrates

In the process of cable installation, the excavation of trenches through hard substratum such as rock or biogenic reef structures may be necessary in very rare cases; however, avoidance of such reef structures will be the preferred method. When unavoidable, trenching through rocky surfaces is done with cable burial cutting tools, which cut the rock into smaller pieces to create a cable trench (KRAUS & CARTER 2018). The excavated trench is usually down to 1.5 or 3 m deep and <1 m wide (KRAUS & CARTER 2018). Over the width of the trench, the loss of the initial structure of a continuous hard, rocky surface can be regarded as physical loss of habitat. This means that the habitat for sessile epifaunal organisms and associated communities is permanently lost. Through sedimentation from the water column, fine-grained sediment (sand and mud) and organic material may deposit inside the cut trench.

Loss of habitat can be considered the heaviest impact on the environment through physical pressures since recovery of the habitat and biota is unlikely without replacement of the original substrate. Even though new hard substrate may be provided by the cable and/or protection structures (see 4.2.1.2), colonization and succession may lead to different communities compared to the benthic communities of the lost habitat; however, field studies have shown evidence of benthic recolonization in most settings (KRAUS & CARTER 2018).

Nevertheless, loss of habitat due to the cutting through hard substrates usually only concerns a very small area of seafloor along parts of the cable route and impacts on sensitive habitats can be considerably reduced through appropriate cable route designs.

4.2.1.3 Conclusion

Areas along the cable route affected by coverage with protective structures will usually be restricted to a narrow strip along parts of the cable, but the impact will be long-lasting. The same is true for places where cutting through hard substrate such as outcropping rocks along the cable route is unavoidable. The potential for the introduction of non-local, and potentially invasive fauna by the placement of artificial hard substrate exists, but the available field studies of cables indicate a colonization of the provided new habitat by endemic, rather than invasive fauna.

4.2.2 Physical Disturbance of The Seabed (Temporary or Reversible)

During the phases of cable survey, route preparation and cable installation, physical disturbance of the sediment may take place as a consequence of different activities that differ in spatial extent – refer the Table 5 which describes such short-term impacts. These activities include vibrocore sampling, drop cores, grab samples and cone penetrometer tests during cable route survey, dredging of mobile bedforms, pre-lay grapnel run, route clearance and boulder management during route preparation and cable pull-in, passage of cable burial tool and shore end activities during cable installation. The spatial footprint of these activities differs and depends on the specific tool. Similarly, the type of disturbance differs between activities and tools and can include sediment reworking, sediment displacement, sediment compaction, sediment resuspension and displacement of boulders.

4.2.2.1 Sediment Reworking, Displacement and Compaction

Surface-laid cables create the least impact with regard to seafloor disturbance. Usually, the cables are laid or designed in a way that movement across the seafloor is limited in order to prevent breakage or damage of the cable over time. Therefore, the underlying sediment remains intact and undisturbed. KOGAN et al. (2006) describe the state of the surface-laid ATOC/Pioneer cable eight years after installation. Eight years after cable installation the authors found that the cable self-buried itself in some sections of the cable route, particularly along the continental shelf and upper slope. Grooves around the cable in the sediment and rock abrasions were observed at localised nearshore sections of the cable route (2-10 m water depth). The authors hypothesized that these grooves and rock abrasions were created due to strumming of the cable caused by the high wave energy in the area. In such undesired instances, where the cable moves across the seafloor, damage of local fauna by the cable may occur. With the exception of very fragile benthic species like corals or sponges, it is likely that the benthic fauna can avoid damage (especially the mobile fauna) or can recover very quickly from this relatively minor disturbance such that serious harm to benthic fauna is unlikely. Cable movement is undesirable, and it is reduced as much as possible to protect the cable. DUNHAM et al. (2015) studied the recovery of a sponge reef that is crossed by three surface-laid subsea power cables off Vancouver. The authors describe a 55 % mortality of the reef-building glass sponges (*Aphrocallistes vastus* and *Heterochone calyx*) in a 1.5 m-wide corridor along the cable after 1.5 years. In the following two years, thus 3.5 years after installation, sponge cover recovered to 85 % of the initial size (DUNHAM et al. 2015). This recovery following a small-scale disturbance can be considered relatively fast for sponge aggregations. Sponge reefs with a different species composition may show longer recovery rates. Nevertheless, the authors suggest that fragile habitats such as sponge reefs should be avoided whenever possible, that cable movement across the surface should be minimized and that potential damage to sponges should be assessed prior to decommissioning.

Activities associated with buried cables create relatively increased physical disturbance of the seafloor compared to activities related to surface-laid cables. Noting the progress rates listed in Section 4.6, these disturbances are temporary and short term. As such, a higher impact on the benthic environment due to the sediment reworking, displacement and compaction along the cable route can be expected. The passage of the burial tool and the pre-lay grapnel run can be considered as the main activities regarding physical disturbance of the sediment. These activities result in the reworking and displacement of sediment. Minor, but extremely localised, sediment compaction occurs during cone penetrometer tests as part of the cable route survey and also during the passage of the burial tool or, in intertidal areas, by the use of excavators and other heavy gear.

KRAUS & CARTER (2018) summarized the recovery of the seabed and associated marine biota following the burial of several subsea cables worldwide. The results of the investigated case studies suggested that biological recovery is related to the physical recovery of the seabed which took from <1 year after burial in shallow areas with high sediment supply, up to ≥ 15 years in deeper areas (130 – 2000 m) where sediment supply was low. The overall results indicate that the disturbance due to burial of the various cables had only limited, small-scale effect on the benthic biota.

Biogenic habitat structures such as biogenic reefs, maerl beds, coral gardens or sponge aggregations can be regarded as the most sensitive biota/habitats with regard to seafloor disturbance. The high sensitivity is explained by the long time that these habitats need to establish themselves and the slow growth and reproduction of the characteristic species, which is especially true for encrusting species. However, some types of biogenic reefs may also recover relatively fast depending on the species. For example, reefs of *Sabellaria spinulosa* are thought to recover fairly quickly from small-scale physical damage, provided that the worms are not killed or removed from their tubes (BIOCONSULT 2019 and citations within). The natural growth and capacity for repair is such that they can rebuild destroyed parts of their dwellings within a few days (VORBERG 2000 and citations within).

Seagrass meadows represent a highly sensitive habitat with regard to sediment disturbance which may be impacted by the cutting of rhizomes along the cable route resulting in a direct damage of seagrass plants and a loss of connectivity to other parts of the seagrass meadow. Different studies indicate that recovery of the vegetation of *Zostera marina* after cable installation of buried cables takes about 2-7 years (KRAUS & CARTER 2018 and references therein). However, it should be noted that the recovery of seagrass is site dependent and species specific. While *Zostera marina* may recover relatively fast from physical disturbance related to cable activities (AUSTIN et al. 2004), slow-growing species such as the Mediterranean species *Posidonia oceanica* may require more than 100 years to recover from any physical disturbance (DUARTE et al. 2013, TELESCA et al. 2015).

The crossing of biogenic and sensitive habitats by the cable should be avoided wherever possible and the spatial footprint of the disturbance should be minimized by the selection of appropriate tools and methods. Whilst only used in specific circumstances, Horizontal Directional Drilling (HDD) may be used to avoid such habitats in the intertidal zone or to reduce sediment disturbances by the use of mechanical excavators in intertidal zones if there is a particular reason to do so. Seafloor disturbance from HDD only regards a very small area of a few m² of the seafloor at the HDD-exits.

In some instances, the use of heavy mechanical excavators may be necessary to bury the cable in intertidal areas. The disturbance of the seafloor by excavators is higher than that compared with other burial techniques. By digging a trench, the sediment is heavily reworked resulting in a change in sediment morphology and the burial of endobenthic organisms. The sensitivity of benthic organisms to burial is species-specific and depends on different factors such as a species mobility and other adaptations (HENDRICK et al. 2016). In general, recovery of benthic communities after burial can happen via vertical repositioning of the surviving individuals, horizontal colonization of new animals from adjacent areas and via larval settlement (BOLAM 2011). In a meta-analysis, about half of the 32 investigated macrobenthic species were negatively affected by 5.4 cm of sediment burden (SMIT et al. 2008). This is in line with another experimental study which indicated that instantaneous sediment burial of an estuarine benthic community with more than 2 cm sediment induced a high mortality of macrofaunal organisms and reduced the organisms bioturbation and bio-irrigation activity (MESTDAGH et al. 2018).

To conclude, displacement of large amounts of sediment may result in impacts, such as mortality of the endobenthos on the short term which may be visible through changes in community composition and structure. Nevertheless, recovery of the benthos is likely to occur relatively fast due to the similar properties of the deposited sediment and the adjacent areas and the relatively small area that is affected, facilitating a rapid recolonization.

4.2.2.2 Sediment Resuspension and Resettling of Particles

Sediment re-suspension and excess sedimentation may affect benthic biota by smothering, displacement and damage of individual organisms, potentially leading to changes in benthic community composition, species loss and changes in biological parameters. The magnitude of the impact depends on local hydrodynamic conditions, the resilience and recovery potential of the affected species and communities as well as the intensity and duration of the disturbance.

A comparison of burial techniques at multiple cable installation sites worldwide indicated that the use of a jetting tool for cable burial resulted in a stronger disturbance of the sediment compared to the use of a cable plough, especially with regard to sediment resuspension (KRAUS & CARTER 2018). In this comparative study, recovery of the sediment after water-jetted cable burial took more than 5 years, while recovery from ploughing in similar water depths took less than 2 years (KRAUS & CARTER 2018).

With the jetting technique, water is jetted into the sediment to liquify the sediment for the cable to sink into the sediment up to the desired burial depth. Depending on the sediment type, this technique may leave a depression. Refilling of such depressions would depend on the sediment type, its availability and hydrodynamic regime at the site.

Cable burial by jetting generally creates larger sediment plumes than ploughing. While coarser sediment particles quickly settle back at the jetted site, lighter particles may get transported away by currents forming large sediment plumes which typically deposit within approximately 100 m of the site but may spread up to 2 km away from the site in the case of very fine, cohesive mud (KRAUS & CARTER 2018 and references therein). Increased water turbidity can persist for several days depending on the background environmental conditions and the duration of the cable-laying process but at any given location along the cable route, disturbance will typically only persist from a few hours to a few days (see also 4.6.4, TAORMINA et al. 2018).

The impact of the sediment plume on biota depends on the sediment load/deposition thickness and the sensitivity of the affected biota. A temporary increase in turbidity may have an impact on the effectiveness of primary production by phytoplankton in the euphotic zone, reduce foraging success of visual predators and affect zooplanktonic or epibenthic organisms by clogging their filter apparatus (SÖKER et al. 2000, TAORMINA et al. 2018).

At the Nysted offshore wind farm (Denmark), one month was necessary to excavate 17,000 m^3 of sediment with a barge-mounted backhoe for a 10.3 km long, 1.3 m wide and 1.3 m deep cable trench and the excavated material was placed to the side of the trench and was used for backfilling after cable laying (DONG ENERGY 2006). The sediment spill was estimated to be 0.5 – 1 % of the amount excavated and turbidity did not exceed 15 mg/L (DONG ENERGY 2006). Inspection of the excavated trench after backfilling showed that a depression of the seabed was left due to an inadequate filling of the trench. In addition, the lowered seabed acted as a trap for organic material and the trench was filled with detached macrophytes (DONG ENERGY 2006). At some stations close to the trench the silt/clay content of the sediment was higher after the earthwork. This increase was probably caused by a local sedimentation of fine sediment spilled during excavation and back filling. The structure of the benthic fauna had changed significantly at the impacted stations close to the trench. While the abundance of the benthic fauna at the control stations was reduced by 10 %, the abundance at the impacted stations decreased by 50 % (DONG ENERGY 2006). According to the authors, all effects were confined to a narrow zone close to the cable trench (DONG ENERGY 2006). However, with regard to the relatively small area that is affected, the impact on the surrounding environment was considered negligible.

For the Inner Dowsing offshore wind farm (Greater Wash Strategic Area, UK), it has been predicted that 90 % of sediments resuspended during cable laying re-settle within 1 km of the construction corridor (Offshore Wind Power Ltd. 2002 in BAKER 2003). The amount of resuspended material was regarded insignificant in comparison with baseline conditions (Offshore Wind Power Ltd. 2002 in BAKER 2003).

An estimation of sediment deposition and suspended sediment concentrations associated with the Cape Wind Energy Project (Nantucket Sound, Massachusetts, USA) was determined by modelling (GALAGAN et al. 2003). Sediment deposition was determined to occur in a 90-120 m wide corridor (depending on the sediment type). Water quality effects (e.g., increased turbidity) might occur at a distance of more than 0.9 km from the site. The model assumption of GALAGAN et al. (2003) contains a part of 30 % suspended sediments of the total sediment volume and a relocation of the remaining 70 % of the sediment volume within the trench. Increased sediment concentrations in the water column were expected to last only a few minutes to less than one hour.

The results of these case studies and models show that the sediment plume may affect broader areas compared to other disturbances resulting from cable installation operations, particularly in the case of jetting. Nevertheless, while the installation process may take several weeks or months, the disturbance by sediment plumes at any given point along the cable route is short-lived leading to only minor impacts on biota in the water column (fish, zooplankton, phytoplankton) which may either tolerate the temporarily higher sediment load in the water column or avoid the location. Severe, long-term impacts on pelagic biological communities are not expected from a temporary increase in water turbidity if it does not exceed natural levels of turbidity variability (TAORMINA et al. 2018).

After resettling of any suspended sediment, the epi- and endofauna in the area of the sediment plume may be impacted by smothering/blanketing. In general, the recovery of benthic organisms after blanketing/burial depends on the sediment load, sediment type and the individual potential of the animal/species to re-establish its vertical position in the sediment (BOLAM 2011, SMIT et al. 2008). While mobile epibenthic organisms may be able to avoid disturbance, sessile epibenthic animals may be covered with a layer of sediment which can pose a threat especially for filter-feeders and suspension-feeders (HENDRICK et al. 2016). Nevertheless, many species have adapted to natural processes of sediment transport (HINCHEY et al. 2006). During cable installation it can be assumed that the re-settling sediment has similar properties compared to the underlying sediment from the same locality, however, it may be composed of a higher proportion of fine grain sizes as these particles are resuspended more easily. Especially in areas where natural sediment transport takes place on a regular basis or during storm events, it can be assumed that the benthic fauna is tolerant towards low levels of anthropogenically induced sedimentation. In areas with low natural background levels of sediment transport, the fauna may be more sensitive resulting in stronger impacts. For these areas, appropriate mitigation measures should be taken to avoid or minimize sediment resuspension.

Overall, severe impacts from temporary sedimentation during cable installation on the benthic fauna are not expected (TAORMINA et al. 2018).

4.2.2.3 Displacement Of Hard Substrates

In some cases, the clearance of boulders from the cable route as part of the route preparation is unavoidable. During this activity, boulders are pushed to the side or picked up and moved using specialized tools. The boulders with attached fauna may be overturned and displaced potentially resulting in the abrasion and crushing of the attached fauna with damage and/or mortality of the sessile organisms as a consequence. Depending on the type of the local benthic community with regard to standing stock and recruitment, recolonization of the overturned boulders may happen within the time frame of a few months to a few years while recovery of the assemblage to its initial state may take decades, especially when slow growing epifaunal species (e.g.,, encrusting animals, sponges) are affected (ROBERTS et al. 2010).

4.2.2.4 Conclusions

Impacts from physical disturbance of sediments associated with cable laying activities are generally expected to be temporary and localised. Recovery of the benthic biota is tightly linked to the recovery of the seafloor characteristics (seabed morphology, sediment composition) which may take between months and ≥ 15 years. In environmentally sensitive areas (e.g., reefs, seagrass meadows) physical disturbance, damage and displacement may have a significant, long-lasting impact on marine biota. Avoidance of such areas along the cable route should be preferred.

4.2.3 Changes To Hydrological Conditions

The presence of protective structures and exposed sections of surface laid cables may lead to alterations of the hydrodynamic regime in the immediate surroundings of the cable. This might lead to scouring effects around the cable/structure and to an increased deposition of particulate material (KOGAN et al. 2006, KUHNZ et al. 2020). This may indirectly affect biological communities by increasing habitat heterogeneity or food availability. However, as these effects act on a very small scale around the cable they are unlikely to have wider implications for the benthic environment around the cable.

4.3 Substances, Litter and Energy

4.3.1 Input Of Anthropogenic Sound (Impulsive, Continuous)

4.3.1.1 Noise From Subsea Cables and Associated Activities

In contrast to the persistent anthropogenic sound in the ocean caused by dredging, fishing, shipping, large-scale seismic surveys and other noisy activities, cable deployment is a one-off operation.

Sound emission of activities related to subsea cables may occur during multiple phases including cable route surveys, route preparation, cable installation and cable repair and recovery. During installation of surface-laid cables, sound generation will be restricted to the noise generated by the installation ship.

Additional noise is generated by burial tools and other equipment (e.g., sound from the placement of rocks at cable crossings) at or close to the seafloor. The sound generated by the burial tools is comparable to that of a small dredging operation. Geotechnical surveys involve high frequency sonar systems. These high frequency sonar systems have a limited impact on noise sensitive organisms compared to prolonged, mid to low frequency acoustic systems favoured by the hydrocarbon industry and military (e.g., KATES VARGHESE et al. 2020).

The detonation of unexploded ordnance (UXO) as part of the cable route preparation is very unlikely. If unavoidable, very high levels of underwater noise might be generated. Environmental impacts and required mitigation measures need to be assessed on a case-by-case basis and will not be addressed in this document.

Field studies of generation of underwater noise during cable installation are scarce. It should also be noted that surface lay of cables is essentially silent, and passive plough burial has a very low noise impact. One study by NEDWELL & HOWELL (2004) reported a maximal noise emission of 178 dB re 1 µPa (frequency: 0.7 – 50 kHz) at 1 m distance from the source during a cable installation operation. Similarly, BALD et al. (2015) reported average impulsive sound levels of 188.5 dB re 1 µPa (at 11 Hz) during cable installation. This is in accordance with the source levels of marine dredging activities compiled in a review by RAKO-GOSPIĆ & PICCIULIN (2019) who reported source-levels between 160 and 180 dB re 1 µPa (broadband frequency). However, since reported results at least for cable installation possibly include near field effects at distances of 1 m and in lack of standardized methodology for measuring this type of underwater noise emissions, the knowledge base should be considered as rather poor and unreliable due to large uncertainties.

One study investigated the acoustic noise from the operation of subsea cables and reported a measurable, albeit low source level of 100 dB re 1µPa@1 m at a frequency of 120 Hz from a 138 kV AC transmission cable (JASCO RESEARCH LTD. 2006))

4.3.1.2 Environmental Impacts of Noise

Depending on the hearing ability of a species, both the perception and the effect of anthropogenic sound emissions varies. Acoustic information is used by marine animals for different purposes such as communication, orientation, predator avoidance or habitat selection (RAKO-GOSPIĆ & PICCIULIN 2019). Sufficiently high levels of sound are likely to cause various impacts on marine animals including avoidance reactions, changes in behaviour or damage to the hearing abilities of the affected species (POPPER & HAWKINS 2019). Often it is distinguished between acute and chronic effects of underwater noise. Acute effects may induce immediate auditory damage and chronic effects even with low intensities may already induce behavioural changes (RAKO-GOSPIĆ & PICCIULIN 2019). As an example, an overview of potential effects of underwater noise on fish is provided in Table 6.

Table 6: Overview of the potential effects of underwater noise on fishes by POPPER & HAWKINS (2019)

Effect	Description
Death	Sound exposure results in instantaneous or delayed mortality.
Physical injury & physiological changes	Physical injury results in temporary or permanent impairment of the structure and functioning of some parts of the body. Physiological changes result in increased stress or other effects that can lead to reduced fitness.
Hearing threshold shift	Loss of hearing, temporarily or permanently, results in decreased ability to respond to biologically relevant sounds.
Masking	Noise results in a decrease in detectability of biologically relevant sounds (e.g.,, sounds of predators and prey, sounds of conspecifics, acoustic cues used for orientation).
Behavioural responses	Behavioural responses include any change in behaviour from small and short-duration movements to changes in migration routes and leaving a feeding or breeding site. Such responses are likely to vary from species to species, depending on numerous factors such as the animal's normal behavioural repertoire, motivational state, time of day or year, age of the animal, etc. Some changes in behaviour, such as startle reactions, may only be transient and have little consequence for the animal or population.
No obvious behavioural responses	Animals may show transient or no responses, even if they detect the sound (e.g., to a very low-level sound) or habituation may take place. However, even if there is no response, there is always the possibility that physical injury and physiological changes may take place without the animal showing overt changes in behaviour

There is a large body of research on the effects of noise from human activities such as shipping noise or construction of offshore structures on marine animals. These anthropogenic impacts are elaborately described and discussed in OSPAR (2009).

There are only few field studies which specifically aimed at measuring the impact of cable laying on marine animals. One of these studies is a field study by NEDWELL et al. (2003) investigating the noise created during cable installation at the North Hoyle offshore wind farm and possible impacts on the fauna. Cable installation activity in this study resulted in a source level of 178 dB re 1 µPa at 1 m and the calculated sensitivities of locally occurring species (dab, cod, salmon, bottlenose dolphin, harbour porpoise, harbour seal) indicated that sound levels during cable installation were below the species perceived level at which a behavioural reaction would be expected.

The Sakhalin II Phase 2 Project, an integrated oil and gas project in Russia´s Far East, investigated noise impacts from the construction phase of both pipelines and cables (SAKHALIN ENERGY INVESTMENT COMPANY 2005). Focus of the environmental impact assessment was laid on the possible impacts of the noise from pipeline/cable installation on grey whales migrating through the project area and using it as feeding grounds. In the respective report it was mentioned that some individuals were observed avoiding areas in which noise levels were greater than 120 dB. Unfortunately, no more detailed information about the setup of the field studies and their results were given in the report.

4.3.1.3 Conclusions

Although impacts of anthropogenic sound on marine animals is a well-studied topic, there is only little information on potential noise effects due to the installation (or removal) and operation of subsea cables. Compared to activities such as seismic surveys, military activities or construction work involving pile hammering, maximum sound pressure levels related to the installation or operation of cables are moderate to low. In most cases modelling approaches were chosen to get an idea of the expected sound pressure levels since field studies of noise from cable laying activities are largely missing. It would be favourable to undertake further field measurements accompanied by experimental studies to allow a more profound discussion of potential risks. If seismic surveys are necessary before cable laying, their impact has to be assessed carefully on a case-by-case basis.

In conclusion, sound emissions from activities associated with subsea cables (other than geophysical surveys for cable routing) generally do not exceed background shipping noises and other anthropogenically induced sound emissions and are limited in time, refer Section 4.6.4. Currently, there are no clear indications that noise impacts related to the installation (or removal) and operation of subsea cables pose a high risk of harming marine fauna (TAORMINA et al. 2018).

4.3.2 Input Of Other Forms of Energy – Electromagnetic Fields

Magnetic and electric fields are tightly connected with each other and naturally occur in the Earth's environment. The dominant natural magnetic source on earth is the Earth's magnetic field (geomagnetic field) which is a constant and directional magnetic force, refer to section 4.2.4.

Because of the differences in electromagnetic fields between telecommunication cables and power cables outlined in section 4.3.5, this section is focused on the impacts of EMF related to power cables, only.

Electric fields, measured in millivolt/metre (mV m^{-1}), originate from voltage differences while magnetic fields are created from the flow of an electric current and are expressed as microtesla (µT). The electric field directly created by modern power cables is completely shielded off by the insulation of the cable while the magnetic field extends outside of the cable. If an animal or water body passes through a magnetic field (including the earth's magnetic field), motionally induced voltage is generated (GILL et al. 2014) resulting in an induced electric field.

4.3.2.1 Reception Of Electromagnetic Fields by Marine Organisms

As described above, relevant electromagnetic fields from power cables to be discussed are the magnetic field (B-field), the direct electric field (E-field, AC only) and the induced electric field (iE-field). A schematic overview of the different magnetic and electric fields (natural and anthropogenic) is given in Figure 22.

It is undebated that many animal groups in the marine environment possess the ability to sense electromagnetic fields. Most of these animal groups are magneto-receptive, meaning that they can sense magnetic fields, an ability that enables them to make use of differences in field direction, intensity and inclination of the geomagnetic field for orientation and navigational purposes (FORMICKI et al. 2019, KLIMLEY et al. 2021). Animal groups that display magneto-reception include cetaceans, marine turtles, elasmobranchs (sharks and rays), bony fish, crustaceans and molluscs (ALBERT et al. 2020, TAORMINA et al. 2018). A comprehensive review about magneto-reception in fish with regard to natural and anthropogenic magnetic fields is presented in FORMICKI et al. (2019).

Some animal groups have evolved specialized organs with electrosensitive cells (e.g.,, Ampullae of Lorenzini in elasmobranchs) that allow them to sense electric cues in the environment. NEWTON et al. (2019) provide a detailed review of electro-reception in fish, particularly the well-studied elasmobranchs. While magneto-reception is mainly thought to be used for orientation, navigation and behavioural purposes, electro-reception serves as a means to locate the bioelectric field of other organisms and is, therefore, used for a wide range of behavioural purposes such as prey detection and capture, finding a mate, avoidance of predators or learning and habituation. It is important to note that there is a close link between magneto- and electro-reception. Elasmobranchs for example are able to use the induced electric field that is generated by water current (passive) or their own body movement (active) passing through the geomagnetic field for orientation in space. Early research has shown that through this mechanism, elasmobranchs are able to detect even small changes in the geomagnetic field, e.g.,, the thorny skate (*Amblyraja radiata*) can detect changes of the vertical component of the geomagnetic field of one nanotesla per second (BROWN et al. 1979).

The capacity of some animals, and especially marine animals to detect small differences of electric fields is striking. ENGLAND & ROBERT (2022) provide a thorough review of existing information about electro-reception in animals with an overview of sensitivity thresholds. The highest sensitivity can be found in elasmobranch fishes, due to their specialized electro-receptive organs. Their threshold to sense electric fields and induce a behavioural response lies in the region of around 5 nV cm^{-1} which is a widely accepted sensitivity threshold for this group of animals. Some authors argue that this value may be even lower. For comparison, the sensitivity threshold for humans is in the range of 40 kV m^{-1} (ENGLAND & ROBERT 2022). This means that their threshold for sensitivity and behavioural response is well in the range of electric fields created in the proximity of subsea cables (see chapter 3.3.5).

Several studies indicate that marine animals are not only able to sense very small differences in electric and magnetic fields but that they are using these small differences in geomagnetic fields to receive map-like information for orientation and migration (e.g., KELLER et al. 2021, LUSCHI et al. 2007, NEWTON & KAJIURA 2020a, NEWTON & KAJIURA 2020b, WALKER et al. 2003).

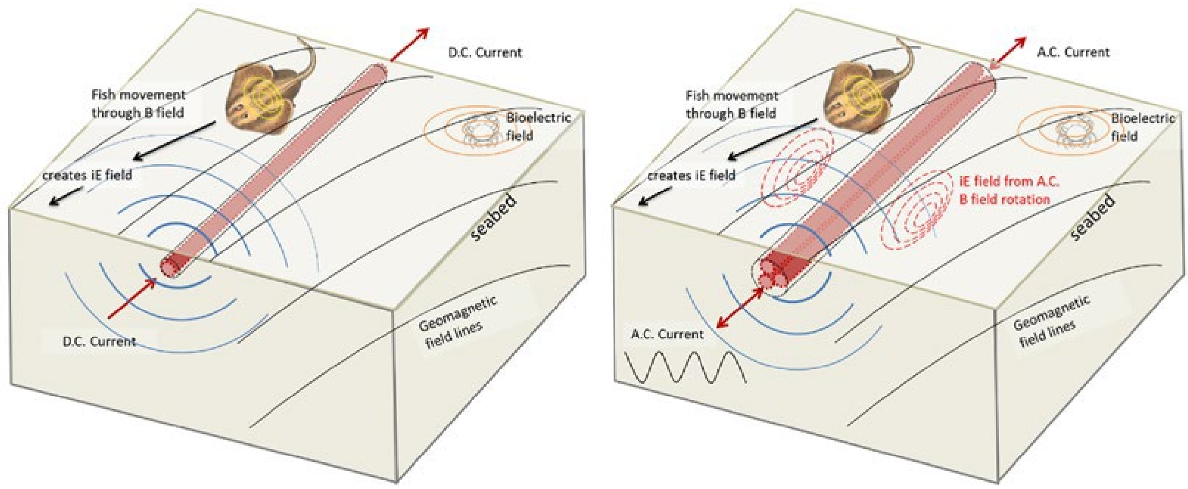


Figure 21: Schematic diagrams of natural and anthropogenic electromagnetic fields including magnetic (B-fields), electric (E-fields) and induced electric fields (iE-fields). This figure is intended to show differences in the electric fields and their spatial footprint related to DC and AC cables (as also illustrated in Figure 7 and 8). Left: DC-cable, right: AC-cable. From GILL & DESENDER (2020) (adapted from NEWTON et al. 2019).
It is important to note that DC cables are typically bundled together (unlike the image shown on the left which shows a cable in isolation), and the magnetic fields cancel each other out to a large degree, reducing the resultant field magnitude (Section 4.3.5.1).

4.3.2.2 Environmental Impacts of Anthropogenic Electromagnetic Fields

As outlined above, many marine species are able to detect magnetic and electric fields. It also becomes evident that some species may not be able to differentiate between anthropogenic and natural EMFs, and increased electromagnetic fields could lead to significant behaviour changes such as increased exploration behaviour or the focus on more concentrated areas when searching for prey (GILL et al. 2009, HUTCHISON et al. 2020a). Therefore, the introduction of anthropogenic EMF by power cables has become a relevant topic with respect to the marine environment, especially in light of the expansion of offshore renewable energies.

The investigation of the effects of anthropogenic EMF on the marine environment is a relatively new field of research and new insights are generated over time. For example, a literature review by SVENDSEN et al. (2022) found that the number of empirical studies investigating the effect of EMF from offshore wind farms on fishes has increased rapidly since 2014. The authors also provide an overview of the major findings of these empirical studies on fish ecology. The 17 reviewed empirical studies lead the authors to conclude that current research does not indicate negative effects of anthropogenic EMFs on fish movement and migratory behaviour or fish community metrics, which is in line with conclusions formulated by GILL & DESENDER (2020). It has been suggested that anthropogenic EMFs may negatively impact early life-stages and fish development; however, most of the studies performed to data were laboratory-based studies that consider unrealistically high EMF emissions that are not necessarily representative of those related to power cables. In the State of the Science report by GILL & DESNDER (2020), the authors summarize the findings of relevant studies (field and laboratory studies) regarding the effects of anthropogenic EMFs on marine organisms, they describe the development of the scientific knowledge and provide guidance on measurements of EMF from cables. GILL & DESENDER (2020) conclude that although current research shows evident effects and responses of individual species towards anthropogenic EMF the ecological impact of EMF from subsea cables at the current scale is probably only weak or moderate.

Nevertheless, most authors note the scarcity of empirical studies and emphasize the need for further research to reduce the current uncertainty (e.g.,, ALBERT et al. 2020, GILL & DESENDER 2020, HUTCHISON et al. 2020b, SVENDSEN et al. 2022, TAORMINA et al. 2018). Furthermore, with a growing number of cables being deployed and an increase in their transmitted power, the extent and intensity of EMF from subsea cables will increase which may lead to stronger ecological impacts.

4.3.2.3 Conclusions

EMFs are created during the entire operational phase of a subsea cable and can, therefore, be considered a long-term disturbance of the marine environment. EMFs from telecommunications cables are considered negligible and this is only a topic relevant to subsea power cables.

Although research about the impacts of EMF from subsea power cables on marine animals has increased in recent years, the current knowledge base is still quite limited. At the current scale (number and transmission rates) of subsea power cables, ecological impacts are thought to be very limited or absent. This may change with an increase in the number of cables and thus likelihood of animals to encounter anthropogenic EMFs and with an increase in transmission rates which will result in stronger magnetic and induced electric fields. Furthermore, our understanding of environmental impacts from EMF may change in the light of new emerging research. Sensitive receptors such as elasmobranch fishes should receive particular attention in the assessment of environmental impacts, especially because many species of these groups are already listed in the OSPAR List of Threatened and/or Declining Species and Habitats.

4.3.3 Input Of Other Forms of Energy – Heat

When electric energy is transported, a certain percentage of energy is lost in form of heat. Therefore, operating power cables are a source of heat to the seabed and water column. The heat emission of telecommunication cables and other types of cables is very low or absent and out-of-service cables do not emit heat. Therefore, this section only relates to high and medium voltage power cables.

Heat emission from cables is an important issue in the considerations of environmental impacts related to subsea cables. The topic became a standard to be discussed in the scope of Environmental Impact Assessment studies for offshore power cables leading to a number of publications on seabed temperature modelling (e.g., BRAKELMANN 2012, BRAKELMANN & STAMMEN 2006, MÜLLER et al. 2016, STAMMEN 2020b). The most important factors determining the degree of sediment temperature increase include cable characteristics (type of cable), average load, burial depth and sediment characteristics (thermal conductivity, thermal resistance)(BÜCKING & KALTSCHMITT 2018).

In German waters the “2 K-criterion” is applied as a regulative measure for heat emissions of subsea power cables. This criterion stipulates that the maximum temperature increase of the sediment should not exceed 2 K at a sediment depth of 20 cm which aims to limit potential adverse environmental impacts on the benthic ecosystem.

4.3.3.1 Heat Emission of Power Cables

The magnitude of warming around the cable strongly depends on the emission of heat by the cable and the thermal conductivity of the surrounding environment. In water, heat will dissipate very fast and, therefore, major heat impacts from surface laid cables on the environment are not to be expected. Sediment on the other hand possesses a lower heat conductivity depending on the type of sediment. As such, the thermal conductivity of gravel is highest with 2.00 – 3.30 W/(K*m) and the thermal conductivity of very dense sediments such as clay is lowest with 0.90 – 1.67 W/(K*m) (BÜCKING & KALTSCHMITT 2018).

The heat emission of cables and temperature increase of the sediment under different conditions can be modelled quite accurately if all above mentioned factors for the specific environment of the cable are known. As such, MÜLLER et al. (2016) determined thermal parameters (e.g.,, conductivity, diffusivity) of the seabed based on measurements using the VibroHeat method and modelled the heat dissipation from a stable heat source using these parameters. Theoretical base parameters consisted of a power cable buried at 1.5 m sediment depth with a constant power loss of 50 W/m starting at day 1. Results indicated that the maximum temperature difference between the cable and the reference site was between 0.9 K and 2.3 K at 20 cm depth for a scenario of heterogenous sediment with high and low diffusivity, respectively.

In another modelling study, the maximum temperature increase at a sediment depth of 30 cm was predicted to be 1.68 K for a 525 kV HVDC cable (conductor diameter: 60 mm) with a burial depth of 1.5 m (STAMMEN 2020a).

Field measurements of seabed temperature near power cables have been published from the Nysted offshore wind farm (Denmark, Baltic Sea, MEIßNER et al. 2007), where the maximum temperature increase at a sediment depth of 20 cm was 1.4 K.

These modelling and field studies indicate that for currently used power cables, the threshold of 2 K temperature increase at a sediment depth of 20 cm will only be exceeded in rare cases and for short periods of time.

4.3.3.2 Environmental Impacts of Heat Emission

Generally, natural variability of seabed temperatures is high, and temperature varies seasonally depending on depth and bottom water temperature. Water temperature differs throughout the year naturally and the range of temperature variation greatly exceeds the cable-induced net temperature increase of the sediment. Nevertheless, cable-induced heat adds to the natural temperature variability and, therefore, may result in even higher thermal maxima inside the sediments.

Potential impacts of an increase in temperature of the sediment from a buried cable include changes in the biogeochemical processes inside the sediment, especially in deeper layers as they are closer to the heat source, changes in bacterial/microbial activity and changes in the spatial distribution and community composition of benthic organisms. All of these potential impacts are poorly studied with respect to heat emission from subsea cables while much more information is available on impacts from bottom water temperature increase. While the power-cable-scenario describes a heat source from below with respect to the upper 20 cm sediment, the heat source in the latter scenario comes from above (the seawater) which may result in very different impacts on the sediment and biota. This poses a considerable knowledge gap and conclusions about ecological impacts from heat emission by buried cables cannot be drawn (TAORMINA et al. 2018).

Nevertheless, if the benthic community would be severely affected by disturbances arising from buried cables, this would become visible in differences regarding community structure, density or biomass between cable sites and control sites. These differences were not detected in available field studies comparing cable sites and control sites (ANDRULEWICZ et al. 2003, KOGAN et al. 2006, SHERWOOD et al. 2016).

4.3.3.3 Conclusions

Power cables lose part of their energy in the form of heat which then dissipates into the sediment or water. Published calculations of the temperature effects of operating cables are consistent in their predictions of temperature rise in the vicinity of the cables. Whether these predictions hold true under operational conditions still has to be examined and depends on the thermal characteristics of the sediment.

With regard to the ecological consequences of heat emission from cables, knowledge gaps remain, and further research is needed. Nevertheless, impacts can be expected to occur on the long-term but on a small spatial scale and only concern the sediment directly above the cable. Because field studies considering the effect of heat emissions in the sediment on fauna are scarce, the 2 K-criterion could be used as a threshold value within a precautionary approach as applied in Germany. However, there is insufficient evidence to justify this to be the appropriate value in other areas. However, measuring/monitoring of sediment temperature above a cable in the field is challenging, and more effort on the monitoring of thermal effects from buried cables might be desirable.

The temperature increase in the upper sediment layers, which depends on the thermal properties of the sediment, and the heat emission from the cable should be considered in the planning of the burial depth of a cable in order to minimize adverse effects on the seafloor environment. This is especially true with regard to newer cable systems that transport more energy than today.

4.3.4 Input Of Other Substances

The impacts of anthropogenic contamination on the marine environment is an intensively studied field. A review of the huge amount of available information would be beyond the scope of this background document. For that reason, the following sections focus on information directly related to cable projects. For more detailed analyses of contaminants in the North-East Atlantic, OSPAR's Hazardous Substances and Eutrophication Committee (HASEC) are responsible for work to identify, monitor, assess and take action on sources, pathways and sinks. Regarding the effects of contaminants on fauna it is referred to existing data sources (web portals) which can be searched for detailed information.

A risk of contamination associated with subsea cables arises from activities causing seabed disturbance (e.g., passage of burial tool) in areas where contaminant load in the sediment (associated with other human activities) is high and from the release of contaminants associated with the cable itself due to cable damage. Hence contamination could become an environmental issue during cable installation. Nevertheless, the temporal and spatial scale of activities related to subsea cable installation is significantly much smaller compared to other, more frequent and larger scale occurring activities such as active demersal fishing activities and, therefore, needs to be assessed in perspective to those activities.

4.3.4.1 Contamination By the Cable Itself

A recent study investigating the physical stability of surface laid cables showed that cables were physically intact and well-preserved 38 and 44 years after installation (CARTER et al. 2019). The cable outer sheaths were undamaged and the stranded steel that provides strength to the cable was free of corrosion. This meets the intentions of the companies installing and operating the cable since the high-grade plastic, steel and copper components are also valuable targets for recycling.

Chemical analysis in the laboratory that subjected cables to different environmental conditions also found that deep-sea cables were chemically inert (CARTER et al. 2019). Intentionally damaged sections of cables with protective metallic armour were found to temporarily release low concentrations of zinc (<11 parts per million) in a laboratory experiment (CARTER et al. 2019). Such low concentrations recorded in the small, contained experiment would be significantly further diluted within the open ocean, particularly due to the action of currents that sweep across the seafloor. Dilution effects would be lower in sediments, in the case of buried cables, however, the risk of damage is far lower for buried cables than for surface-laid cables.

Potential contamination by the cable would therefore only include very small concentrations of heavy metals (e.g., lead extrusion if applied as a water barrier) if cables are damaged, for short periods of time until the cable is repaired and there is no specific contamination relating to the cable itself. Contamination by oil-filled cables depicts a worst-case scenario but is unlikely as these types of cables are almost no longer in use (see Table 2 different types & uses of subsea cable in section 4.1).

4.3.4.2 Contamination Associated with Cable Installation and Route Preparation

The risk of contamination related to seabed disturbance is restricted to the potential release of harmful substances from sediments with a high load of contaminants into the water column because of cable installation of buried cables. Usually, sediment quality is assessed before a cable is laid and a cable route is designated which avoids so-called “toxic hotspots”. Typical potential contaminants that these areas are screened for are arsenic, cadmium, copper, lead, mercury, nickel, selenium, silver, zinc and total polycyclic aromatic hydrocarbons (PAH). However, there may be circumstances in which areas with contaminated sediments cannot be avoided. Of special concern are areas in the vicinity of major ports, oil and gas industrial areas (drilling/exploration sites, platforms), areas which have historically been used for industrial, sewage or ammunition disposal, or localities which have acted as a natural sink for oil or chemical contamination. In such cases mitigation measures to minimize potential risks of contaminant release could include the use of tools causing the least sediment disturbance or to schedule the work to coincide with slack tides to minimize potential for tidal currents and wave action from carrying the suspended sediments away from the work area.

4.3.4.3 Environmental Impacts of Contamination

Contamination effects on fauna have been intensively studied under laboratory conditions and in the field. There are several web portals providing very detailed information on toxicity of chemicals for aquatic and terrestrial life. These sources inform about the expected effects on different species to be expected as a result of contaminant exposure of defined dosages.

When dealing with toxicity it always needs to be considered whether the compound under investigation is a single compound or a multi-compound mixture. The toxicity of several compounds together may be different than the sum of the single-compound-effects potentially resulting in additive, synergistic or antagonistic effects. Furthermore, the type of exposure (chronic vs. acute), the measured endpoint (e.g., sublethal/lethal effects, effects on behaviour/life-history-traits, etc.) and duration of exposure need to be considered when conducting and interpreting ecotoxicological studies.

Results of field studies from subsea cable laying activities regarding ecotoxicology are quite rare. There are, however, some field studies from dredging activities that might give an indication of similar impacts. A study conducted at the Oskershamn harbour in Sweden measured the leaching of heavy metals from contaminated sediments following dredging

(FATHOLLAHZADEH et al. 2015). The authors highlighted the potential release of copper (Cu), lead (Pb), zinc (Zn), manganese (Mn), and nickel (Ni) to the environment. Of these metals, Cu and Pb were found to be in ionic form, which is the bioavailable form of the metals, thus posing a risk to the local biota. However, after a short recovery period, the water quality returned to pre-disturbance levels. In a long-term study on the effects of sediment dredging on cobalt (Co), Zn and Ni contamination, CHEN et al. (2019) reported an increase of up to 69 % (Co) and 166 % (Zn) into the overlying water after dredging. The authors also noted that there were considerable seasonal differences in the release of these compounds from the sediment.

Dredging operations are expected to have a stronger impact on sediment disturbance than cable laying activities meaning that results of existing field studies from dredging operations cannot be directly transferred to the context of cables. Project-specific assessments will be needed when disturbance of contaminated sediment along the route cannot be avoided. These assessments should consider the contaminant concentrations inside the sediment, the environmental conditions (e.g., anoxic conditions, differences in pH) that could affect bioavailability of the released compounds, and the species composition of the local benthic community.

4.3.4.4 Conclusions

A risk of contamination associated with subsea cables arising from activities causing seabed disturbance can only be anticipated for heavily contaminated localities. Avoidance of such areas or reduction of sediment disturbance would be an appropriate mitigation measure. Introduction of contaminants (at negligible levels) into the environment from the cable itself can only occur if cables are damaged.

5 References

ALBERT, L., F. DESCHAMPS, A. JOLIVET, F. OLIVIER, L. CHAUVAUD & S. CHAUVAUD, 2020: A current synthesis on the effects of electric and magnetic fields emitted by submarine power cables on invertebrates. - Marine Environmental Research 159: 104958.

ANDRULEWICZ, A., D. NAPIERSKA & Z. OTREMBA, 2003: The environmental effects of the installation and functioning of the submarine SwePol Link HVDC transmission line: a case study of the Polish marine area of the Baltic Sea. - J. Sea Res. 49: 337-345.

AUSTIN, S., S. WYLLIE-ECHEVERRIA & M. GROOM, 2004: A Comparative Analysis of Submarine Cable Installation Methods in Northern Puget Sound, Washington. - Journal of Marine Environmental Engineering 7: 173-184.

BAKER, E. T., 2003: Offshore Wind Energy Generation: Phase 1 Proposals and Environmental Report. - BMT Cordah Limited, Penicuik, UK: 219 S.

BALD, J., C. HERNÁNDEZ, A. URIARTE, J. CASTILLO, P. RUIZ & N. ORTEGA, 2015: Acoustic characterization of 26 submarine cable installation in the Biscay Marine Energy Platform (BIMEP). - Bilbao Energy Week 27: 2015.

BIOCONSULT, 2019: Gutachten zum Regenerationspotenzial benthischer Biotoptypen in der AWZ der Nordsee nach temporären anthropogenen Störungen. - (i. A. des Bundesamtes für Seeschifffahrt und Hydrographie (BSH), Hamburg) 110 S. https://www.bsh.de/DE/PUBLIKATIONEN/_Anlagen/Downloads/Projekte/Gutachten_Regenerationspotenzial_benth_Biotoptypen.pdf?__blob=publicationFile&v=4, 19.01.2021.

BOLAM, S. G., 2011: Burial survival of benthic macrofauna following deposition of simulated dredged material. - Environmental Monitoring and Assessment 181: 13-27. https://doi.org/10.1007/s10661-010-1809-5, 2011/10/01.

BRAKELMANN, H., 2012: Studie 600-kV-Gleichstrom-Leitung DolWin3 Thermische Felder der Seetrasse. - Rheinberg: 41 S. http://www.tennet.eu/de/fileadmin/downloads/Netz-Projekte/Offshore/PFV_BorWin4/11_Materialband_und_Quellen/11.1_Sonstige_Untersuchungen/10.1_01_ThermischeFelderSeetrasse_ErgebnisberichtDolWin3_20121019.pdf, 28.9.2015.

BRAKELMANN, H. & J. STAMMEN, 2006: Thermal Analysis of Submarine Cable Routes: LSM or FEM? - First International Power and Energy Conference PECon 2006 Putrajaya, Malaysia: 560-565 S.

BRITISH GEOLOGICAL SURVEY (2020) World Magnetic map www.geomag.bgs.ac.uk/data_service/models_compass/wmm_calc.html [accessed Feb 2023]

BROWN, H. R., O. B. ILYINSKY, V. M. MURAVEJKO, E. S. CORSHKOV & G. A. FONAREV, 1979: Evidence that geomagnetic variations can be detected by lorenzinian ampullae. - Nature 277: 648-649. https://doi.org/10.1038/277648a0, 1979/02/01.

BÜCKING, L. M. & M. KALTSCHMITT, 2018: Verlustwärme von Offshore-Gleichstrom-Seekabelsystemen – Entstehung und Übertragung. - Zeitschrift für Energiewirtschaft 42: 299-314. https://doi.org/10.1007/s12398-018-0238-y, 2018/12/01.

CARTER, L., K. COLLINS, C. CREESE & G. WATERWORTH, 2019: Chemical and physical stability of submarine fibre-optic cables in the Area Beyond National Jurisdictrion (ABNJ). - SubOptic 2019 6 S.

CHEN, M., S. DING, S. GAO, S. XU, C. YANG, Y. WU, M. GONG, D. WANG & Y. WANG, 2019: Long-term effects of sediment dredging on controlling cobalt, zinc, and nickel contamination determined by chemical fractionation and passive sampling. - Chemosphere 220: 476-485. https://www.sciencedirect.com/science/article/pii/S0045653518324731, 2019/04/01/.

CLARE, M.A., YEO, I.A., BRICHENO, L., AKSENOV, Y., BROWN, J., HAIGH, I.D., WAHL, T., HUNT, J., SAMS, C., CHAYTOR, J. AND BETT, B.J., 2022. Climate change hotspots and implications for the global subsea telecommunications network. *Earth-Science Reviews*, p.104296.

COOLEN, J. W. P., W. LENGKEEK, S. DEGRAER, F. KERCKHOF, R. KIRKWOOD & H. J. LINDEBOOM, 2016: Distribution of the invasive Caprella mutica Schurin, 1935 and native Caprella linearis (Linnaeus, 1767) on artificial hard substrates in the North Sea: separation by habitat. - Aquatic invasions 11:4: 437-449.

DANNHEIM, J., L. BERGSTRÖM, S. N. R. BIRCHENOUGH, R. BRZANA, A. R. BOON, J. W. P. COOLEN, J.-C. DAUVIN, I. DE MESEL, J. DERWEDUWEN, A. B. GILL, Z. L. HUTCHISON, A. C. JACKSON, U. JANAS, G. MARTIN, A. RAOUX, J. REUBENS, L. ROSTIN, J. VANAVERBEKE, T. A. WILDING, D. WILHELMSSON & S. DEGRAER, 2019: Benthic effects of offshore renewables: identification of knowledge gaps and urgently needed research. - ICES Journal of Marine Science 77: 1092-1108. https://doi.org/10.1093/icesjms/fsz018,

DE MESEL, I., F. KERCKHOF, A. NORRO, B. RUMES & S. DEGRAER, 2015: Succession and seasonal dynamics of the epifauna community on offshore wind farm foundations and their role as stepping stones for non-indigenous species. - Hydrobiologia 756 (1): 37-50.

DEGRAER, S., D. A. CAREY, J. W. COOLEN, Z. L. HUTCHISON, F. KERCKHOF, B. RUMES & J. VANAVERBEKE, 2020: Offshore wind farm artificial reefs affect ecosystem structure and functioning: A synthesis. - Oceanography 33: 48-57.

DEL PINO LOPEZ JC. et al (2022). Evaluation of the power frequency magnetic field generated by three-core armored cables through 3D finite element simulations, Electric Power Systems Research, 213, 108701

DOMINION ENERGY (2021) Appendix AA: Offshore electric and magnetic field assessment: Coastal Virginia Offshore Wind Commercial Project. https://www.boem.gov/sites/default/files/documents/renewable-energy/state-activities/Appendix-AA-Offshore-EMF.pdf

DONG ENERGY, 2006: Review Report 2005. The Danish Offshore Wind Farm Demonstration Project: Horns Rev and Nysted Offshore Wind Farm Environmental impact assessment and monitoring. - 148 S.

DUARTE, C. M., A. BORJA, J. CARSTENSEN, M. ELLIOTT, D. KRAUSE-JENSEN & N. MARBÀ, 2013: Paradigms in the Recovery of Estuarine and Coastal Ecosystems. - Estuaries and Coasts 38: 1202–1212.

DUNHAM, A., J. R. PEGG, W. CAROLSFELD, S. DAVIES, I. MURFITT & J. BOUTILLIER, 2015: Effects of submarine power transmission cables on a glass sponge reef and associated megafaunal community. - Marine Environmental Research 107: 50-60.

ENGLAND, S. J. & D. ROBERT, 2022: The ecology of electricity and electroreception. - Biological Reviews 97: 383-413.

FATHOLLAHZADEH, H., F. KACZALA, A. BHATNAGAR & W. HOGLAND, 2015: Significance of environmental dredging on metal mobility from contaminated sediments in the Oskarshamn Harbor, Sweden. - Chemosphere 119: 445-451. https://www.sciencedirect.com/science/article/pii/S0045653514008583, 2015/01/01/.

FORMICKI, K., A. KORZELECKA-ORKISZ & A. TAŃSKI, 2019: Magnetoreception in fish. - Journal of Fish Biology 95: 73-91. https://onlinelibrary.wiley.com/doi/abs/10.1111/jfb.13998,

GALAGAN, C. H., T. ISAJI & C. SWANSON., 2003: Results of model simulations of sediment deposition from cable burial operations in Lewis Bay, MA. Narragansett. - In: www.nae.usace.army.mil/projects/ma/ccwf/deis.htm (Hrsg.),

GILL, A. & M. DESENDER, 2020: Risk to Animals from Electro-magnetic Fields Emitted by Electric Cables and Marine Renewable Energy Devices. - In: COPPING, A.E. & L.G. HEMERY (Hrsg.), OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). 86-103. DOI: 10.2172/1633088,

GILL, A., Y. HUANG, I. GLOYNE-PHILIPS, J. METCALFE, V. QUAYLE, J. SPENCER & V. WEARMOUTH, 2009: COWRIE 2.0 Electromagnetic Fields (EMF) Phase 2: EMF-sensitive fish response to EM emissions from sub-sea electricity cables of the type used by the offshore renewable energy industry. Commissioned by COWRIE Ltd (project reference COWRIE-EMF-1-06). - 68.

GILL, A. B., I. GLOYNE-PHILIPS, J. KIMBER & P. SIGRAY, 2014: Marine Renewable Energy, Electromagnetic (EM) Fields and EM-Sensitive Animals. - In: SHIELDS, M.A. & A.I.L. PAYNE (Hrsg.), Marine Renewable Energy Technology and Environmental Interactions. Springer Netherlands, Dordrecht: 61-79. https://doi.org/10.1007/978-94-017-8002-5_6,

GLASBY, T. M., S. D. CONNELL, M. G. HOLLOWAY & C. L. HEWITT, 2007: Nonindigenous biota on artificial structures: could habitat creation facilitate biological invasions? - Marine Biology 151: 887-895. https://doi.org/10.1007/s00227-006-0552-5,

HENDRICK, V. J., Z. L. HUTCHISON & K. S. LAST, 2016: Sediment burial intolerance of marine macroinvertebrates. - PLoS ONE 11(2): e0149114. doi:10.1371/journal.pone.0149114.

HINCHEY, E. K., L. C. SCHAFFNER, C. C. HOAR, B. W. VOGT & B. L.P., 2006: Responses of estuarine benthic invertebrates to sediment burial: the importance of mobility and adaptation. - Hydrobiologia 556: 85-98.

HUTCHINSON, ZL et al, (2020). Anthropogenic electromagnetic fields (EMF) influence the behaviour of bottom-dwelling marine species, Nature: Scientific Reports, 10: 4219

HUTCHISON, Z. L., A. B. GILL, P. SIGRAY, H. HE & J. W. KING, 2020a: Anthropogenic electromagnetic fields (EMF) influence the behaviour of bottom-dwelling marine species. - Scientific Reports 10: 4219. https://doi.org/10.1038/s41598-020-60793-x, 2020/03/06.

HUTCHISON, Z. L., A. B. GILL, P. SIGRAY, H. HE & J. W. KING, 2021: A modelling evaluation of electromagnetic fields emitted by buried subsea power cables and encountered by marine animals: Considerations for marine renewable energy development. - Renewable Energy 177: 72-81. https://www.sciencedirect.com/science/article/pii/S0960148121007175, 2021/11/01/.

HUTCHISON, Z. L., D. H. SECOR & A. B. GILL, 2020b: The Interaction Between Resource Species and Electromagnetic Fields Associated with Electricity Production by Offshore Wind Farms. - Oceanography 33: 96-107. https://www.jstor.org/stable/26965753,

KATES VARGHESE, H., J. MIKSIS-OLDS, N. DIMARZIO, K. LOWELL, E. LINDER, L. MAYER & D. MORETTI, 2020: The effect of two 12 kHz multibeam mapping surveys on the foraging behavior of Cuvier's beaked whales off southern California. - The Journal of the Acoustical Society of America 147: 3849-3858. https://doi.org/10.1121/10.0001385, 2020/06/01.

KELLER, B. A., N. F. PUTMAN, R. D. GRUBBS, D. S. PORTNOY & T. P. MURPHY, 2021: Map-like use of Earth’s magnetic field in sharks. - Current Biology 31: 2881-2886.e3. https://www.sciencedirect.com/science/article/pii/S0960982221004760, 2021/07/12/.

KERCKHOF, F., B. RUMES & S. DEGRAER, 2019: About "Mytilisation" and "Slimeification": A decade of succession of the fouling assemblages on wind turbines off the Belgian coast -In: DEGRAER, S., R. BRABANT, B. RUMES & L. VIGIN (Hrsg.), Environmental impacts of offshore wind farms in the Belgian part of the North Sea - Marking a decade of monitoring, research and innovation. Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management,, Brüssel: 73-84.

KLIMLEY, A. P., N. F. PUTMAN, B. KELLER, A & D. NOAKES, 2021: A call to assess the impacts of electromagnetic fields from subsea cables on the movement ecology of marine migrants. - Conservation Science and Practice e436.

KOGAN, I., C. K. PAULL, L. A. KUHNZ, E. J. BURTON, S. VON THUN, H. GARY GREENE & J. P. BARRY, 2006: ATOC/Pioneer Seamount cable after 8 years on the seafloor: Observations, environmental impact. - Continental Shelf Research 26: 771-787. https://www.sciencedirect.com/science/article/pii/S0278434306000355, 2006/04/01/.

KOOPS, F. B. J. (2000). Electric and magnetic fields in consequence of undersea power cables. In: ICNIRP: Effects of Electromagnetic Fields on the Living Environment, pp. 189 – 210

KRAUS, C. & L. CARTER, 2018: Seabed recovery following protective burial of subsea cables - Observations from the continental margin. - Ocean Engineering 157: 251-261. https://www.sciencedirect.com/science/article/pii/S0029801818303020, 2018/06/01/.

KUHNZ, L. A., K. BUCK, C. LOVERA, P. J. WHALING & J. P. BARRY, 2015: Potential impacts of the Monterey Accelerated Research System (MARS) cable on the seabed and benthic faunal assamblages. - Monterey Bay Aquarium Research Institute: 33 S.

KUHNZ, L. A., K. BUCK, C. LOVERA, P. J. WHALING & J. P. BARRY, 2020: Potential impacts of the Monterey Accelerated Research System (MARS) cable on the seabed and benthic faunal assamblages 2020. - Monterey Bay Aquarium Research Institute: 38 S. DOI: 10.13140/RG.2.2.12907.57122,

LANDRØ, M., BOUFFAUT, L., KRIESELL, H.J., POTTER, J.R., RØRSTADBOTNEN, R.A., TAWEESINTANANON, K., JOHANSEN, S.E., BRENNE, J.K., HAUKANES, A., SCHJELDERUP, O. AND STORVIK, F., 2022. Sensing whales, storms, ships and earthquakes using an Arctic fibre optic cable. *Scientific Reports*, *12*(1), p.19226.

LOTZE, H. K., A. M. MAGERA, P. WARD, C. & L. AIROLDI, 2011: Recovery of marine animal populations and ecosystems. - Trends in Ecology and Evolution 26: 595-605.

LUSCHI, P., S. BENHAMOU, C. GIRARD, S. CICCIONE, D. ROOS, J. SUDRE & S. BENVENUTI, 2007: Marine Turtles Use Geomagnetic Cues during Open-Sea Homing. - Current Biology 17: 126-133. https://www.sciencedirect.com/science/article/pii/S0960982206025826, 2007/01/23/.

MARRA, G., FAIRWEATHER, D.M., KAMALOV, V., GAYNOR, P., CANTONO, M., MULHOLLAND, S., BAPTIE, B., CASTELLANOS, J.C., VAGENAS, G., GAUDRON, J.O. AND KRONJÄGER, J., 2022. Optical interferometry–based array of seafloor environmental sensors using a transoceanic submarine cable. *Science*, *376*(6595), pp.874-879.

MEIßNER, K., J. BOCKHOLD & H. SORDYL, 2007: Problem Kabelwärme? - Vorstellung der Ergebnisse von Feldmessungen der Meeresbodentemperatur im Bereich der elektrischen Kabel im Offshore-Windpark Nysted Havmollepark (Dänemark). - In: Bundesamt für Seeschiffahrt und Hydrographie (Hrsg.), Meeresumwelt-Symposium 2006. 153-161.

MESTDAGH, S., L. BEGAÇO, U. BRAECKMANN, T. YSEBAERT, B. DE SMET, T. MOENS & C. VAN COLEN, 2018: Functional trait responses to sediment deposition reducemacrofauna-mediated ecosystem functioning in an estuarine mudflat. - Biogeosciences 15: 2587-2599.

MÜLLER, C., R. USBECK & F. MIESNER, 2016: Temperatures in shallow marine sediments: Influence of thermal properties, seasonal forcing, and man-made heat sources. - Applied Thermal Engineering 108: 20-29. https://www.sciencedirect.com/science/article/pii/S1359431116312364, 2016/09/05/.

NATIONAL GRID ELECTRICITY TRANSMISSION AND SCOTTISH POWER TRANSMISSION (May 2022) Scotland England Green Link 1 / Eastern Link 1- Marine Scheme: Environmental Appraisal Report https://marine.gov.scot/sites/default/files/environmental_appraisal_report_v2_-_chapter_2_project_description_-_redacted.pdf [accessed Feb 2023].

NATIONAL GRID & SCOTTISH POWER, Western HVDC Link Environmental Report: Marine Cable Route, September 2011. http://www.westernhvdclink.co.uk/doc-marine-cable.aspx

NEDWELL, J. & D. HOWELL, 2004: A review of offshore windfarm related underwater noise sources. - (commissioned by COWRIE) 57 S.

NEDWELL, J., J. LANGWORTHY & D. HOWELL, 2003: Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore windfarms, and comparison with background noise. - (commissioned by COWRIE) 68 S.

NEWTON, K. C., A. B. GILL & S. M. KAJIURA, 2019: Electroreception in marine fishes: chondrichthyans. - Journal of Fish Biology 95: 135-154. https://onlinelibrary.wiley.com/doi/abs/10.1111/jfb.14068,

NEWTON, K. C. & S. M. KAJIURA, 2020a: The yellow stingray (Urobatis jamaicensis) can discriminate the geomagnetic cues necessary for a bicoordinate magnetic map. - Marine biology 2020 v.167 no.10: pp. 151-151. https://dx.doi.org/10.1007/s00227-020-03763-1, 2020-10.

NEWTON, K. C. & S. M. KAJIURA, 2020b: The yellow stingray (Urobatis jamaicensis) can use magnetic field polarity to orient in space and solve a maze. - Marine Biology 167: 36. https://doi.org/10.1007/s00227-019-3643-9, 2020/02/06.

NORMANDEAU, EXPONENT, TRICAS T, AND GILL, A. (2011). Effects of EMFs from Undersea Power Cables on Elasmobranchs and other Marines Species. U.S.Dept. of the Interior, Bureau of Ocean Energy Management, Regulation and Enforcement, Pacific OCS Region, Camarillo, CA. OCS Study BOEMRE 2011-09.

OSPAR, 2008: Assessment of the environmental impact of offshore wind-farms. - Biodiversity Series 385, 31 S.

OSPAR, 2009: Overview of the impacts of anthropogenic underwater sound in the marine environment. - Biodiversity Series 133 S.

OSPAR COMMISSION, 2022: OSPAR Joint Assessment and Monitoring Programme (JAMP) 2014 – 2023. - (OSPAR Agreement 2014-02) 78 S.

POPPER, A. N. & A. D. HAWKINS, 2019: An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. - J Fish Biol. 2019; 94: 692–713. DOI: 10.1111/jfb.13948,

PYŠEK, P., P. E. HULME, D. SIMBERLOFF, S. BACHER, T. M. BLACKBURN, J. T. CARLTON, W. DAWSON, F. ESSL, L. C. FOXCROFT, P. GENOVESI, J. M. JESCHKE, I. KÜHN, A. M. LIEBHOLD, N. E. MANDRAK, L. A. MEYERSON, A. PAUCHARD, J. PERGL, H. E. ROY, H. SEEBENS, M. VAN KLEUNEN, M. VILÀ, M. J. WINGFIELD & D. M. RICHARDSON, 2020: Scientists' warning on invasive alien species. - Biological Reviews 95: 1511-1534. https://doi.org/10.1111/brv.12627, 2020/12/01.

RAKO-GOSPIĆ, N. & M. PICCIULIN, 2019: Chapter 20 - Underwater Noise: Sources and Effects on Marine Life. - In: SHEPPARD, C. (Hrsg.), World Seas: an Environmental Evaluation (Second Edition). Academic Press, 367-389. https://www.sciencedirect.com/science/article/pii/B9780128050521000231, 2019/01/01/.

REILLY, P. (1991). Magnetic field excitation of peripheral nerves and the heart: a comparison of thresholds. Ned. & Biol. Eng. & Comput., 28: 571-579.

ROBERTS, C., C. SMITH, H. TILLIN & H. TYLER-WALTERS, 2010: Evidence: Review of existing approaches to evaluate marine habitat vulnerability to commercial fishing activities. - Environment Agency report No SC080016/R3. 150 S.

RTE (2016), FAB Link: Offshore Environmental Report, December 2016 https://www.fablink.net/wp-content/uploads/2016/12/FAB_Link_Offshore_Environmental_Report_V02.pdf

SAKHALIN ENERGY INVESTMENT COMPANY, 2005: Executive summary of the phase 2, Environmental and social impact assessment process. - S.

SHERWOOD, J., S. CHIDGEY, P. CROCKETT, D. GWYTHER, P. HO, S. STEWART, D. STRONG, B. WHITELY & A. WILLIAMS, 2016: Installation and operational effects of a HVDC submarine cable in a continental shelf setting: Bass Strait, Australia. - Journal of Ocean Engineering and Science 1: 337-353.

SMIT, M. G. D., K. I. E. HOLTHAUS, H. C. TRANNUM, J. M. NEFF, G. KJEILEN-EILERTSEN, R. G. JAK, I. SINGSAAS, M. A. J. HUIJBREGTS & A. J. HENDRIKS, 2008: Species sensitivity distributions for suspended clays, sediment burial, and grain size change in the marine environment. - Environmental Toxicology and Chemistry 27: 1006-1012. https://doi.org/10.1897/07-339.1, 2008/04/01.

SÖKER, H., K. REHFELDT, F. SANTJER, M. STRACK & M. SCHREIBER, 2000: Offshore wind energy in the North Sea: technical possibilities and ecological considerations: a study for Greenpeace. - S.

STAMMEN, J., 2020a: Magnetische und thermische Eigenschaften der Seekabeltrassen BorWin4 und DolWin4. - sta-fem GmbH, 51 S. + Anhänge.

STAMMEN, J., 2020b: Magnetische und thermische Eigenschaften von 525 kV-HGÜ-Seekabeltrassen in der Nordsee. - Bocholt: 62 S.

SVENDSEN, J. C., B. IBANEZ-ERQUIAGA, E. SAVINA & T. WILMS, 2022: Effects of operational off-shore wind farms on fishes and fisheries. Review report. -

TAORMINA, B., J. BALD, A. WANT, G. THOUZEAU, M. LEJART, N. DESROY & A. CARLIER, 2018: A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions. - Renewable and Sustainable Energy Reviews 96: 380-391. https://www.sciencedirect.com/science/article/pii/S1364032118305355, 2018/11/01/.

TELESCA, L., A. BELLUSCIO, A. CRISCOLI, G. ARDIZZONE, E. T. APOSTOLAKI, S. FRASCHETTI, M. GRISTINA, L. KNITTWEIS, C. S. MARTIN, G. PERGENT, A. ALAGNA, F. BADALAMENTI, G. GAROFALO, V. GERAKARIS, M. LOUISE PACE, C. PERGENT-MARTINI & M. SALOMIDI, 2015: Seagrass meadows (Posidonia oceanica) distribution and trajectories of change. - Scientific Reports 5: 12505. https://doi.org/10.1038/srep12505, 2015/07/28.

VORBERG, R., 2000: Effects of shrimp fisheries on reefs of Sabellaria spinulosa (Polychaeta). - ICES J. Mar. Sci. 57: 1416-1420.

WALKER, M. M., C. E. DIEBEL & J. L. KIRSCHVINK, 2003: Detection and Use of the Earth's Magnetic Field by Aquatic Vertebrates. - In: COLLIN, S.P. & N.J. MARSHALL (Hrsg.), Sensory Processing in Aquatic Environments. Springer, New York, NY:

ZHAN, Z., CANTONO, M., KAMALOV, V., MECOZZI, A., MÜLLER, R., YIN, S. AND CASTELLANOS, J.C., 2021. Optical polarization–based seismic and water wave sensing on transoceanic cables. *Science*, *371*(6532), pp.931-936.

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Our vision is of a clean, healthy and biologically diverse North-East Atlantic Ocean, which is productive, used sustainably and resilient to climate change and ocean acidification.

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