Guidelines on Best Environmental Practice (BEP) in Cable Laying and Operation

(Agreement 2012-2)

(Source: OSPAR 12/22/1, Annex 14)

Content

1. Background and objectives

In 2008 a background document regarding the influence of laying and operating underwater cables on the marine environment and nature was published in the framework of international cooperation for protection of the marine environment of the North-East Atlantic in line with the OSPAR Convention (OSPAR 2008a). The JAMP assessment (Assessment of the environmental impacts of cables; OSPAR 2009) adopted in 2009 essentially evaluates the environmental impacts of sea cables in terms of their relevance for the area covered by the Convention on the basis of the background document. The assessment served as the technical background document for the 2010 OSPAR quality status report (OSPAR 2010).

Subsequently Germany was requested to submit a proposal for an OSPAR guidance paper on environment and nature compatible construction and operation of underwater cables to EIHA in 2011 (Guidance on Best Environmental Practice on cable laying and operation).

The purpose of this paper is:

- Compilation of possible measures to avoid and mitigate the ecological impacts of construction, operation and removal of underwater cables.

- Differentiation of possible measures regarding various types of sea cables, different burial techniques, burial depths, etc.

- Compilation of possible avoidance and mitigation measures with respect to cumulative effects.

- Identification of remaining gaps in knowledge and the resulting specific research needs. Determining on that basis priorities for future research.

The potential ecological impacts of construction, operation and removal of various types of cable described in current literature and in particular in the above mentioned OSPAR documents as well as the corresponding possible avoidance and mitigation measures form the basis for this guidance paper.

Without any claim to completeness, some proposals are made in the following regarding consideration given to submarine cable laying as a maritime activity. Some of them have already been taken into account in various cable projects, but are not necessarily part of the standard procedures (for telecommunication cables see *e.g*. CARTER et al. 2009).

These aspects should be taken into account both within the framework of the further OSPAR process, and within the development of individual projects.

2. Submarine cable types

As a matter of principle, a distinction should be made between power cables and telecommunication cables on the basis of their different functions, technical characteristics and environmental impacts.

Power transmission cables

Marine power cables are specifically designed to transmit electric currents either as Alternating Current (AC) or Direct Current (DC). Monopolar, bipolar or three-phase systems are different technical solutions in use. Depending on their design the diameter of power cables may be up to 15 cm. Weights vary between 15 to 120 kg/m (OSPAR 2008a).

Alternating Current (AC): There are basically two types of AC sea cable, the **three-conductor cable** and the **single-conductor cable**. The great advantage of the three-conductor cable is that the electromagnetic field of the three conductors is almost neutralised at the surface of the cable, and plastic is used instead of oil as stabilising material to fill the hollow space, preventing broken cables from emitting oil into the sea water. The single-conductor cable is a cable with just one conductor for a single phase, so that three single-conductor cables are required for a three-phase system. The advantage of the latter type of cable is its high transmission capacity, even though the absolute losses rise with increasing transmission capacities.

Direct Current (DC): DC cables have no induced voltages and currents and thus no losses from their metal jackets. To avoid the emission of electromagnetic fields into the environment , the two poles of a DC system, the forward and the return conductor, have to be installed in parallel and as close as possible to each other: such a **bipolar system** again can be designed as a two-conductor cable or as two single-conductor cables. The two conductors thus can be laid either as separate cables, as flat type cables or as coaxial cables. The reduction of the emission of electromagnetic fields ideally reaches 100 % in coaxial cables. **Monopolar systems** consist of only a forward conductor. In such a case the current is fed back via the seawater and the seafloor by means of electrodes in the seawater located at both ends of the forward conductor. In monopolar systems, strong electromagnetic fields are generated along the single cable and electrolysis occurs at the anode and cathode of the return conductor, the seawater. Since monopolar systems with electrodes no longer meet environmental standards of many EU countries (see STEHMEIER 2006) their environmental effects are not addressed in this report.

In general, a DC line can transmit more power than an AC line of the same size. The reactive power flow due to the large cable capacitance will limit the maximum possible AC transmission distance. With DC there is no such limitation, making it the only viable technical alternative for long distance cable links (RAGHEB 2009).

Telecommunication cables

Modern submarine telecommunication systems are fibre optic cables using pulses of light to transport information. However, coaxial cables as the former standard are sporadically still in service (OSPAR 2008a). A fibre optic cable sends information shooting pulses of light through thin transparent fibres usually made of glass or plastics (DREW & HOPPER 2009). The distance over which the optical signal can be transmitted through the fibre without any intermediate undersea signal processing is not unlimited. For that reason fibre optical cables may be equipped with repeaters. DREW & HOPPER (2009) report repeaters to be placed at intervals of 17–34 nautical miles along a fibre optical cable. Repeaters have to be powered via a power cable. The total requirement for a typical 7500 km transatlantic crossing with 100 repeaters would be close to 10 kV (OSPAR 2008a). Outside diameters of fibre optic cables range from 20 to 50 mm (DREW & HOPPER 2009).

Insulation of power cables

The cable industry today offers various types of mass-impregnated (MI) cables and XLPE (cross linked polyethylene) cables, also self-contained fluid filled (SCFF) or gas filled (SCGF) cables are available (OSPAR 2008a).

Mass impregnated (MI) cables contain a fluid impregnated paper insulation that is not pressurized. XLPE cables are equipped with insulations of a solid dielectric material. SCFF cables have conductors with hollow cores which provide a passageway for insulating fluid under static pressure provided by equipment at the cable terminals (pumping plants at the cable ends, feeding into a hollow conductor core). The insulating fluid saturates the cable insulation (being e.g. polypropylene laminated paper or conventional cellulosic kraft paper), maintaining the electrical integrity of the cable, and preventing damaging ingress of water in the event of an underwater leak. Suitable insulating fluids are refined mineral oils or linear alkylbenzene (LAB). Self contained gas filled (SCGF) cables are similar to SCFF cables except the insulation is pressurised with dry nitrogen gas.

Often cables are designed as composite cables with additional components besides the conductors for power transmission (e. g. optical fibres for data transmission). Cable conductors are usually made of copper or aluminium wires, or may be composite conductors with steel strands at their core. The overall assembly of the cable components may be round or flat.

3. Potential environmental impacts associated with submarine cables

3.1 Introduction

Potential environmental impacts associated with subsea cables are disturbance, underwater noise, heat emission, electromagnetic fields, and contamination (OSPAR 2008a, 2009, 2010) including release of nutrients. Environmental impacts of submarine cables may occur during their laying, operation and removal as well as in the case of accidents. The nature, extent and significance of these potential impacts should be determined on a site-specific basis as part of an assessment of environmental impacts. In the following sections these impacts are briefly discussed taking aspects like spatial extent, timescale (duration, frequency, reversibility) and magnitude of impacts as well as their relevance for the different phases in cable life and for the various cable types into consideration. Possible mitigation measures will be presented on this basis.

3.2 Disturbance by the placement of cables

The laying of cables leads to seabed disturbance and associated impacts (damage, displacement or disturbance) on flora and fauna, increased turbidity, remobilisation of contaminants from sediments and alteration of sediments. Along with noise and visual disturbance, these effects are mainly restricted to the installation, repair works and/or removal phase and are generally temporary. In addition, their spatial extent is limited to the cable corridor (in the order of 10 m width if the cable has been ploughed into the seabed; OSPAR 2009). Such impacts relate both to submarine telecommunications and to power cables. Some mobile benthic species (for example, crabs) are able to avoid most disturbance whereas sessile (bivalves, tubeworms etc.) and sensitive species (such as slower growing or fragile species) will be more impacted.

Though modern equipment and installation techniques can reduce the re-suspension of sediment during cable burial or removal, remaining suspended sediment may nonetheless - depending on percentage of silt fraction and background levels - obstruct the filtration mechanisms of some benthic and pelagic organisms at least temporarily (OSPAR 2009). It can also affect the growth of the macrobenthos and may have a lethal effect on some species. Contamination arising from seabed disturbance is only a risk in heavily contaminated locations (OSPAR 2009, COOPER et al. 2007a, 2007b). Particularly in coastal areas concerned the laying of cables can also lead to increased nutrient releases into the water column and consequently may contribute to eutrophication effects locally.

The application of cable protection (often stones) along the cable route in areas characterized by soft sediments will lead to artificial introduction of hard substrates. The submarine cables themselves, if not buried, will also provide a solid substrate for a variety of species. This ‘reef effect’ has been extensively discussed in literature (see OSPAR 2009) and may lead to the introduction of non-local fauna and thus to an alteration of the natural benthic community. In most cases effects will be localized although long-lasting.

3.3 Underwater noise

There is only little information on potential noise impacts due to the installation (or removal) and operation of sub-sea cables (OSPAR 2008a). Sound emissions associated with the installation, removal or operation of submarine cables are considered as less harmful compared to activities such as seismic surveys, military activities or construction work involving pile driving. Generally, maximum sound pressure levels related to the installation or operation of cables are moderate to low. Only one publication of recordings of noise emissions during cable laying could be found (NEDWELL et al. 2003, North Hoyle). It would be favourable to undertake further field measurements to allow a more profound discussion of potential impacts. Nevertheless, noise associated with the laying of cables adds to the already prevailing acoustical disturbances.Therefore, where appropriate, the timing, duration and method of any cable laying operations should be managed to minimise impacts.

In summary, currently there are no clear indications that noise impacts related to the installation (or removal) and operation of subsea cables pose a high risk for harming marine fauna (OSPAR 2008a). However, it has to be stressed that there are still significant gaps in knowledge in regard to both the characteristics of sound emissions and sound perception by fauna.

3.4 Heat emission of power cables

When electric energy is transported, a certain amount gets lost as heat, leading to an increased temperature of the cable surface and subsequent warming of the surrounding environment. Important factors determining the degree of temperature increase are cable characteristics (type of cable), transmission rate and characteristics of the surrounding environment (ambient temperatures, thermal conductivity, thermal resistance of the sediment etc.). In general, heat dissipation due to transmission losses can be expected to be more significant for AC cables than for HVDC cables at equal transmission rates.

Published theoretical calculations of the temperature effects of operational buried cables are consistent in their predictions of significant temperature rise of the surrounding sediment. The maximum conductor temperature may be 90°C, the maximum cable sheath temperature 70°C. Under specific circumstances a temperature rise of up to 30K directly at the cable is possible while an average temperature rise of 5–15 K cannot be excluded. The corresponding heat gradient then extends over several metres (OSPAR 2008a; BFS 2005).

There is evidence that various marine organisms react sensitively to an even minor increase in the ambient temperature. Nevertheless, field studies on heat related impacts of operational submarine cables appear to be completely lacking. Only one measurement of the temperature increase of the sediment near the cable of the Danish offshore wind farm "Nysted" has been published so far (MEIßNER *et al*. 2007). First laboratory experiments revealed that the polychaete worm *Marenzelleria viridis* shows the tendency to avoid areas of increased sediment temperature whereas the crustacean *Corophium volutator* does not (BORRMANN 2006).

Due to the lack of field data, the effects of artificially increased temperature on benthos are at present difficult to assess. There is the potential that a long-lasting increase of the seabed temperature may lead to changes in physiology, reproduction or mortality of certain benthic species and possibly to subsequent alteration of benthic communities due to emigration or immigration. The temperature increase of the upper layer of the seabed inhabited by the majority of benthos depends, amongst other factors, on the burial depth of the cable.

Other than direct effects on the marine biota, temperature rise of the sediment due to heat emission from the cable may also alter the physico-chemical conditions in the sediment and increase bacterial activity (MEISSNER & SORDYL 2006). Processes set off in deeper sediment layers are likely to finally affect the entire seabed above the cable due to contact with pore water. Alteration of sediment chemistry might possibly exert secondary impacts on the benthic fauna and flora. It should be noted that the content of organic matter in the sediments determines these processes and their ecological relevance. There is still need of further field investigations to assess possible effects of heat dissipation.

3.5 Electromagnetic fields generated by power cables

Electromagnetic fields are generated by operational power cables. Electric fields increase in strength as voltage increases and may be as strong as 1000 µV per m (GILL & TAYLOR 2001). In addition, induced electric fields are generated by the interaction between the magnetic field around a submarine cable and the ambient saltwater (GILL et al. 2005). Magnetic fields are generated by the flow of current and increase in strength as current increases. The strength may reach the multiple of the natural terrestrial magnetic field.

Magnetic fields generated by cables may impair the orientation of fish and marine mammals and affect migratory behaviour. Field studies on fish provided first evidence that operating cables change migration and behaviour of marine animals (KLAUSTRUP 2006, GILL et al. 2009). Marine fish use the earth's magnetic field and field anomalies for orientation especially when migrating (FRICKE 2000). Elasmobranch fish can detect magnetic fields which are weak compared to the earth's magnetic field (POLÉO et al. 2001; GILL et al. 2005).

Marine teleost (bony) fish show physiological reactions to electric fields at minimum field strengths of 7 $mV*m^{-1}$ and behavioural responses at 0.5-7.5 $V*m^{-1}$ (POLÉO et al. 2001). Elasmobranchs (sharks and rays) are more than ten-thousand fold as electrosensitive as the most sensitive teleosts. GILL & TAYLOR (2001) showed that the dogfish *Scyliorhinus canicula* avoided electric fields at 10 $\mu V\ cm^{-1}$ which were the maximum expected to be emitted from 3-core undersea 150kV, 600A AC cables.

3.6 Contamination

Release of harmful substances or nutrients may take place while the cable is laid due to displacement and resuspension of contaminated sediment (see disturbance) or because of damage to cables with subsequent release of insulation fluids. Contamination may also occur due to accidents and technical faults during construction.

3.7 Cumulative effects

Cumulative effects, the combined effect of more than one activity, may reinforce the impacts of a single activity due to temporal and/or spatial overlaps. At present, there are no sufficient data available to address any cumulative effects.

4. Best environmental practice

Best environmental practice (BEP) is defined as *"the application of the most appropriate combination of environmental control measures and strategies"* (OSPAR Convention, Appendix 1). Measures that represent best environmental practice should be adopted during all phases of project planning. Such measures could be used in conjunction with mitigation measures to minimise the magnitude and significance of effects to the local environment (BERR 2008).

Following BERR (2008) and SCHUCHARDT et al. (2006) best environmental practice contains at least the following measures:

- Sound data base and monitoring

- Reducing environmental impacts and risks (by applying Best Available Techniques and mitigation measures)
- Implementation of ecological compensation measures
- Increasing ecological awareness

Sound data base and monitoring

An environmental impact assessment (EIA)[1] should address both the route selection process and further planning steps and should be elaborated on the basis of sound data. However, data should be appropriate for the respective question since a number of possible environmental impacts can be reduced or even avoided by examining alternative routes or installation methods and subsequently fine tuning the selected route.

Monitoring of possible impacts identified in the environmental impact assessment should be carried out especially if there is a forecasting uncertainty regarding certain impacts (e.g. effects resulting from magnetic fields, heat dissipation) or if sensitive areas, identified in the EIA, are affected (e.g. in connection with NATURA 2000 regions).

Reducing environmental impacts and risks

Best Available Techniques: As defined in Appendix 1 of the OSPAR Convention best available techniques (BAT) "means the latest stage of development (state of the art) of processes, of facilities or of methods of operation which indicate the practical suitability of a particular measure for limiting discharges, emissions and waste. [...]"The section on BAT in Appendix 1 of the Convention also specifies: *"Techniques" include both the technology used and the way in which the installation is designed, built, maintained, operated and dismantled."*

Best Available Techniques (BAT) should generally be applied and projects should document their specific choice of BAT.

Since the use of BAT represents a key measure for avoiding environmental impacts, these measures will be described in separate subsections of section 5.

Mitigation measures: see section 5.

Implementation of ecological compensation measures

Where a potential adverse effect is identified and no suitable mitigation measures are available, compensation by means of nature conservation and landscape management measures should be considered. The scale and scope of such compensation measures will be dependent on the site-specific requirements and proportionate to the scale of impact as identified by the environmental impact assessment (see OSPAR 2008b).

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[1] Even though cables are not covered by the EIA Directive, it is recommended that the Contracting Party responsible should assess the environmental impacts of newly planned submarine cables, especially power cables within the OSPAR maritime area through the EIA process (OSPAR 2009).

Increasing ecological awareness

The mitigation of adverse environmental impacts should be a major goal of project management in all project phases. To achieve this, it is necessary to set up an appropriate management structure and a system should be established within the organisation of each project as well as in all companies involved in a project with the aim of supporting ecological awareness at all levels by means of suitable training programmes and at the same time ensuring compliance with environmental standards through checks.

5. Mitigation measures

5.1 Introduction

As already described in section 4, application of best environmental practice (BEP) is a requirement for effective avoidance and minimization of environmental impacts by means of mitigation measures.

Mitigation may be defined as ‘measures envisaged in order to avoid, reduce and, if possible, remedy significant adverse effects’ (European EIA Directive 85/337/EEC). Article 5 (3) requires that Environmental Impact Statements (EISs) include details of proposed mitigation measures. Mitigation should occur as an iterative part of the EIA process, developing and refining measures to address the significant impacts identified during the other stages of EIA (GLASSON et al. 1999). Therefore mitigation measures should be developed within the planning process. This requires early and close cooperation between technical and environmental experts.

Since there is sufficient evidence that the placement and operation of submarine cables may affect the marine environment, the precautionary principle should be applied and appropriate mitigation measures should be taken (OSPAR 2009). In this context any possible impacts should be avoided, reduced or mitigated as far as possible. Impacts that cannot be avoided, reduced or mitigated should be compensated for by means of suitable measures (section 4). Available measures to minimise or even avoid most of the anticipated environmental impacts are shown in the following table:

Table 1: Possible mitigation measures to minimise or avoid environmental impacts of various anthropogenic pressures due to cable laying and operation

	Mitigation Measures					
Environmental impacts	Route selection	Construction times	Burial technique	Burial depth	Cable type	Removal
Disturbance	x	x	x	(x)	(x)	see text
Noise	(x)	(x)	(x)			
Heat emission	(x)			x	x	
Electromagnetic fields				x	x	
Contamination	x		(x)	(x)	x	x
Cumulative effects*	x	x	x	x	x	
x: important measure; (x) less important measure; * knowledge insufficient						

5.2 Mitigating impacts of the placement of cables

5.2.1 Disturbance

Following BERR (2008) the main planning steps where mitigation measures can be applied to reduce sediment disturbance are the selection of the cable route and the cable burial method. The former serves the purpose of avoiding e.g. sensitive habitats, the latter is aimed at reducing impairments occurring during the real cable laying.

Route selection

Selecting the route (including landfall) with the lowest environmental impact and highest resource efficiency by comparing different alternative routes on the basis of sound and comparable data (avoiding sensitive areas, etc) is one of the most important steps towards realising best environmental practice of a cable project. Route selection should be carried out within a formal approval procedure (or several if necessary) with integrated environmental impact assessment EIA.

When selecting a route corridor, it is necessary to give consideration to engineering issues as well as environmental concerns, such as existing protected areas and other ecologically important and sensitive areas, and other uses, such as existing cables, offshore wind farms, shipping, dumping sites, natural resources (e. g. sand and gravel extraction sites) and fishery. While taking these aspects into account, the route corridor selected should meet in the most optimal way possible the following conditions in order to minimise or avoid environmental impacts:

- protected areas, environmentally sensitive and/or valuable areas with e.g. habitats and species sensitive to physical disturbance or damage where the cable laying activity or operation would result in adverse effects should be avoided;

- shortest possible length;

- bundling with existing cables and pipelines, where it is safe to do so;

- minimal number of crossings with other cables or pipelines to reduce the number of crossing structures.

After a route corridor has been selected, an appropriate level of site investigation is essential to ensure that the optimum route and burial methods are selected for the cable (see section 4). After analyzing the site investigation data, additional mitigation measures may be necessary and should be considered (e.g. re-routing/micro-siting, see BERR 2008).

Baseline information on the distribution of protected and sensitive habitats and species within the construction area should be used also to plan the positioning of the anchor arrays for the cable-laying ship (BERR 2008). In this way, exclusion zones for anchoring should be established if necessary. (Disturbance due to anchors of the cable-laying ship can be further reduced by using tenders to lift the anchors rather than dragging them across the seabed.)

Burial technique / Burial depth

The burial technique and burial depth are closely related to each other. Two points play an important role in the selection of the burial technique and/or burial depth from an ecological point of view: 1. Reduction of sediment displacement and 2. Avoidance of sediment and morphology changes.

1. Reduction of sediment displacement: Where there are species that are sensitive to increases in suspended sediment occurring close to positions of cable burial, it is recommended that the technique that would result in the lowest release of sediment is utilized whenever this is possible (BERR 2008).

As far as the burial technique is concerned, installation via jetting by means of sledge or ROV or use of a plough involves the lowest environmental impacts. Jetting fluidises the seabed using high power jets, and material may suspend to the water column for prolonged periods (a number of hours), and have the capacity to be transported over longer distances, increasing the number of potential receptors. Ploughing usually entails lifting a wedge of seabed and the seabed backfills over the laid cable. The level of sediment disturbance is, therefore, lower using ploughing compared to jetting techniques. The cable can be laid and buried in one or two separate working steps to achieve the required burial depth. Burying the cable in one step may further minimize the environmental impacts. Another option is to dredge a trench in which the cable is laid and which is subsequently refilled. However, the latter burial method leads to significantly greater sediment displacement.

Horizontal directional drilling may be an appropriate form of mitigation to avoid damage, particularly in the intertidal and landfall areas where habitats may be more sensitive (e.g. chalk cliffs, saltmarsh, etc.; BERR 2008). This method has been proposed for the German "Norderney-Corridor" again because of the presence of saltmarsh habitat and the existing dike (PGU 2006). In tidal flats where large laying vessels cannot operate, laying barges and (self propulsion) vibration ploughs may be used for a "post lay burial". *E. g.,* for the "Norderney-Corridor" the cable laying took place during high tide and the subsequent burial was done at low tides with the barge lying on belly serving as "holding point" for the trenching plough.

2. Avoidance of sediment and morphology changes: Morphological changes of the sediment may under certain circumstances occur when cables are laid in soft substrates. Whenever possible, cable should be buried, also to reduce the impacts of heat dissipation and magnetic fields (see below). At the same time the burial techniques applied should resuspend as little sediment as possible so that the trench closes naturally shortly after burial. Otherwise the trench should be backfilled with on-site or comparable material.

In areas with natural hard substrates and at greater water depths, it is often not possible to bury cables. Because the surface structure is changed to a considerably lesser extent than in the case of soft substrates, however, burial is not absolutely necessary. Should, nevertheless, the cable be buried in a trench that does not naturally refill following cable burial, it is important that, when possible, techniques are used that ensure that no berm is left (BERR 2008). Backfilling the trench will ensure that species recovery occurs quicker and that no obstacles are left on the seabed surface.

If cable protection such as rock-mattress cover is required (e.g. in the case of crossings with other cables or pipelines), inert natural stone material should be used to minimise the degree of impact.

Where sensitive habitats (e.g. vegetated shingle, saltmarsh, etc.) are present along a cable route and horizontal directional drilling is not possible it may be necessary to remove vegetation prior to installation and replant/enhance following installation (BERR 2008).[2]

Construction times

Once the cable route and burial technique have been selected there are limited further measures that can be adopted to reduce sediment disturbance. The precise timing of the works (e.g. over a spring or neap tide) is crucial for tidal flats, where limited time windows and shallow waters require good synchronisation of laying and burial operations. In these cases burial should take place at low tide with e. g. vibration ploughs whenever possible. Further offshore the speed at which the burial proceeds may have some influence on the sediment disturbance.

Particularly near the coast, including landfall, it is necessary to specify times of the year during which work should not be carried out since many areas are at certain times of the year habitats of species that react sensitively to disturbances. These include resting grounds during bird migration, wintering and moulting areas of e.g. sea ducks, feeding and coastal breeding habitats, spawning grounds of fish and sandbanks where seals give birth to their young.

Visual and other construction related disturbance, in relation to hauling-out of seals, can be effectively mitigated by avoiding cable installation operations in the vicinity of known haul out sites during sensitive periods. Further offshore construction times should consider resting and wintering areas of ducks and seabirds as well as areas known for marine mammals, especially calving sites of harbour porpoise. The definition of time windows for cable laying can thus be a very effective measure for reducing environmental impact where necessary.

5.2.2 Underwater noise

There are no clear indications that underwater noise caused by the installation of sub-sea cables poses a high risk of harming marine fauna. There is a potential for disturbance of fish and marine mammals. However, knowledge gaps still exist (see section 7). The following mitigation measures should be considered and – where necessary - applied as a precaution in sensitive areas.

Route selection and Construction times

If the route selected is crossing areas especially relevant for species sensitive to underwater noise (e.g. harbour porpoise) appropriate scheduling of cable-laying activities to avoid feeding, spawning and/or nursery areas at sensitive times of the year will minimise the potential for noise-related impacts on these species (OSPAR 2008a, 2009, see also section 5.2.1).

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[2] Guidance is available relating to translocation and enhancement for saltmarsh habitat in the Environment Agency/Defra publication 'The Saltmarsh Management Manual' and the Chartered Institute of Water and Environmental Management (CIWEM)/Royal Society for the Protection of Birds (RSPB) document 'The saltmarsh creation handbook: a project managers guide to the creation of saltmarsh and intertidal mudflat' (see BERR 2008).

Information on *e.g.* spawning and/or nursery habitats should be available from published sources or previous surveys. If this is not available then a series of dedicated surveys should be commissioned (BERR 2008).

Burial technique

Burial techniques involving substantial noise generation should not be employed. In particular blasting in rocky subsoil should be avoided. Information on burial technique with the lowest noise emissions is currently not available (see knowledge gaps, section 7).

5.2.3 Contamination

Route selection

Contamination arising from seabed disturbance is only a risk in heavily contaminated locations. Again, avoidance of such areas would be an appropriate mitigation measure (OSPAR 2009). The application of burial techniques with minimized sediment resuspension in areas where sediment is found to have elevated levels of pollutants will minimise pollution risk (BERR 2008).

5.3 Mitigating impacts of operational cables

5.3.1 Heat emission

The reduction of generated heat is by far more important regarding power cables than telecommunications cables. Heat dissipation from fibre-optic cables is supposedly negligible even though modern cables are equipped with electrical power supplies (OSPAR 2008a, 2009). The focus should therefore be laid on heat emission from high and medium voltage power transmission cables. As power losses are higher for HVAC (high voltage AC) cables than for HVDC (high voltage DC) cables during cable operation, heat dissipation can be expected to be minor for DC cables than for AC cables at equal transmission rates.

Route selection

In general a bundled system of comparable capacities or a coherent marine transmission grid will reduce the number of individual power cables (e.g. linking different offshore wind farms together by using sub-sea cables with a high transmission capacity). In this way the overall space used as well as the total area affected by temperature increase and by other possible physical and chemical impacts will be reduced.

Burial depth

The cable-induced temperature increase of the upper layer of the seabed depends, amongst other factors, on the burial depth of the cable. To reduce temperature rise an appropriate burial depth should be applied. There is evidence that various marine organisms react sensitively to an even minor increase in the ambient temperature. On the basis of current knowledge, however, it is not yet possible to specify at what temperature increase in the sediment significant consequences can be expected for the marine environment (BFS 2005). In Germany, therefore, the Wadden Sea National Park Administrations of Lower Saxony and Schleswig-Holstein have defined the maximum permissible temperature rise in the Wadden Sea as 2 K at a depth of 30 cm below the seafloor (BFS 2005). For German offshore waters the respective Federal Agency for Nature Conservation agreed on a threshold of a maximum tolerable temperature increase of 2 K in 20 cm depth in the sediment. This value was originally established as a precautionary approach in order to protect bottom organisms from harm and benthic communities from change caused by anthropogenic temperature rise. The so called 2 K criterion can be met by an appropriate burial depth of power cables (OSPAR 2008a, BFS 2005). In general an appropriate trenching depth of 1-3 m can limit the rise in sediment surface temperature to prevent macrozoobenthic fauna from harm and benthic communities and processes from changes.

In addition to ecological aspects and technical options regarding cable laying, it is necessary to take into account the thermal properties of the sediment, the type of cable and the transmission capacity when defining the burial depth.

In German waters cable burial depths are proposed to be not less than 1 m in the EEZ and at least 3 m in areas with heavy ship traffic (e.g. shipping channels). Within offshore wind farms, cable burial depth is at least 0.6 m. In tidal channels of the Wadden Sea cables are buried at least 2 m below the seabed. In North America and Southeast Asia typical burial depths for all sorts of cable are between 0.9 and 3.5 m (see OSPAR 2008a). Other sources report about preferred burial depths of 0.6 to 0.9 m in many coastal areas of the U.K. (OSPAR 2008a).

Cable Type

To reduce the environmental impact of thermal radiation, suitable mitigation measures on the choice of cable type can include the use of HVDC transmission systems instead of AC-cables for interconnectors and wind farm-connectors. In addition, the use of a bipolar transmission system instead of two separate monopolar cables will lead to a reduction of the heated area.

5.3.2 Electromagnetic fields

Electromagnetic fields are generated by operational power cables. This effect is much more relevant to power transmission cables than to telecommunications cables, even though modern fibre-optic cables are equipped with electrical power supplies (OSPAR 2009). Although there are specific studies according to which coaxial telecommunication cables also induce electric current in the surrounding area, such current is very low. These aspects are therefore not examined in further detail here.

Cable type

Directly generated electric fields are regarded to be controllable by adequate shielding, e.g. steel plates, sheaths within the cable insulating the conductor etc. However, an induced electric field generated by the magnetic field may occur. In case of high current flows during power transmission the electric fields near the cable significantly exceed values typical under natural conditions.

Occurrence of magnetic fields associated with power transmission is best limited by field compensation to be achieved by using appropriate conductor / cable placement patterns and/or configuration geometry. When using two separate single-conductor cables for a DC transmission, they should be buried in the seabed parallel to and at the shortest distance possible from each other (‘close lying’), so that the magnetic fields would neutralise each other as far as possible. In a two-conductor cable this neutralisation reaches ideally 100 % when using a coaxial-design and no electric field will be induced and should therefore be considered and where suitable applied as avoidance measures.

In case of AC transmission systems the magnetic field is best limited by using three conductor-cables leading to an almost complete field neutralisation at the surface of the cable, since the sum of the voltages and currents of the three phases is zero at any one time. If three single conductor cables are used, again they have to be installed as close as possible and parallel to each other to achieve sufficient field compensation. Nevertheless, due to the phased character of the magnetic field, an electric field will be induced in surrounding conductive materials such as salt water.

Burial depth

Because the strength of both magnetic and (induced) electric fields declines as a function of the distance from the cable, an additional reduction of the exposure of marine species to electromagnetic fields can be achieved by cable burial. The sediment does not have any screening effect, but burial of the cables reduces the exposure of sensitive species to electromagnetic fields by increasing the distance of the animals to the cable.

5.3.3 Contamination

Cable Type

Release of contaminants into the environment from the cable itself can only occur if cables are not removed after decommissioning or if operational cables are damaged, in particular if fluid-filled cables are damaged. Removal of the cable at the end of the operating period and use of cables without fluid components would therefore represent suitable avoidance measures.

Removal

Cables that use oil as an insulating medium may release oil in the event of damage or due to ageing. To avoid this release, the cables can be removed after decommissioning. Removal after decommissioning should be stipulated in the approval, as has already been implemented for cables in the German exclusive economic zone (EEZ) and the territorial waters. However, cable removal involves additional environmental impacts that roughly correspond to those during construction. Removal may not take place, or should be restricted, if it generates greater adverse environmental impacts than would be the case if the cable were left in the seafloor.

5.4 Cumulative effects

Generally all mitigation measures applied for individual cables also contribute to reduction of cumulative impacts. They will thus not be repeated here. Above and beyond the measures for individual cables, coordinated route selection and the coordination of the construction times are suitable measures to reduce cumulative impacts.

Strategic planning and route selection

In general a bundled system of comparable capacities or a coherent marine transmission grid will reduce the number of individual power cables (e.g. linking different offshore wind farms together by using sub-sea cables with a high transmission capacity). As a result, cumulative impacts are reduced (SCHREIBER et al. 2004). Overlapping of electromagnetic fields is already avoided by virtue of the necessary safe distances between the cables.

Construction times

By coordinating construction times, it is possible to avoid reinforcement of impairments due to the burial of several cables either simultaneously or immediately after each other.

Other measures

Avoidance of impacts in specific projects will also mitigate or entirely eliminate possible cumulative impacts. This applies to the burial technique, the burial depth as well as the type of cable.

6. Environmental Impact Assessment EIA

In general the installation and operation of submarine cables should follow a formal approval procedure that includes the elaboration of an environmental impact assessment EIA. *Inter alia*, the EIA should provide sufficient information about the technical design of the project as well as the occurrence of species and habitats within possible cable corridors. The environmental impacts expected and the choice of suitable mitigation measures should be based on this information.

6.1 Data Base

As a minimum, the following data should be available for the EIA as well as for the selection of appropriate mitigation measures:

- sediment and habitat structure;
- benthic communities;
- habitat structure relevant for fish fauna;
- occurrence of breeding and resting birds in the landfall areas;
- occurrence of marine birds and mammals in coastal areas as well as offshore;
- occurrence of hazardous waste (e.g. munitions) and cultural heritage sites;
- other activities e.g. dumping at sea, aggregate extraction, fishing, archaeological features – wrecks.

This can essentially be based on existing data but collection of new field data will be necessary in many cases.

6.2 Monitoring and assessment phase

Monitoring to evaluate the predicted environmental impacts of the construction and operation of a cable should be carried out especially if the pressure-impact relationship is not known sufficiently.

For example, there is still need of further investigation and research regarding various aspects for a comprehensive evaluation of the impacts of cables, for further developing "best available techniques", for derivation of new mitigation measures and the evaluation of their effectiveness. This includes (without any claim to completeness):

- distribution and effects of temperature rise due to heat dissipation;
- distribution and effects of electromagnetic fields;
- distribution and effects of noise during installation.

6.3 Access to Data

If possible and not infringing the confidentiality of commercial information, environmental data regarding individual marine regions and collected in connection with the cable project as well as the respective monitoring reports should be made publicly accessible.

As already proposed in section 4, the data collected in connection with the project should be fed into a database which is accessible to the public as far as possible and in which all data relevant to the environment for individual marine regions are compiled and updated.

7. Knowledge gaps

Gaps in knowledge essentially exist in four areas:

- The impacts of the **temperature increase** of the sediment on benthic species and communities are known only to a basic degree at present. Relevant field studies are almost completely lacking.

- Considerable forecast uncertainty still exists with regard to the impacts of weak **electromagnetic fields** on fish and marine mammals. Studies on this topic are rare and resulted in contradictory results in some cases. For this reason, extensive investigations are still necessary. Apart from field studies it appears expedient to conduct experimental investigations. Experimental mesocosm studies (GILL et al. 2009) are an example of this. Laboratory tests may also furnish important supplementary information.

- Gaps in knowledge also exist with respect to the **regeneration** period and regeneration capacity of sensitive habitats like *Posidonia* meadows, mudflats and reefs.

- Further study is required to assess the **noise levels** produced by the range of available cable burial devices and tools in the various types of seabed sediments encountered in the OSPAR region. This can be achieved through real time monitoring during cable installation.

The gaps in knowledge mentioned can be closed only in part by means of customary monitoring of individual projects. In some areas further basic research is necessary.

8. Conclusion

Since there is sufficient evidence that the placement and operation of submarine cables may affect the marine environment, the precautionary principle should be applied. Appropriate mitigation measures are available and should be taken:

- Choice of appropriate cable routes to reduce or avoid impairment of protected or sensitive areas (e.g. areas of sensitive species and habitats, areas with contaminated sediments);

- Selection of suitable conductor / cable placement patterns and/or configuration geometry (cable type) to limit the emission of electromagnetic fields;

- Burial of the cables to an adequate depth in order to reduce the cable induced temperature rise of the upper layer of the sea bottom and to avoid impairment of marine species by electromagnetic fields;

- Selection of suitable burial techniques to minimise disturbance effects of benthic species and habitats and the release of contaminants;

- Scheduling of the cable laying to reduce disturbances in sensitive areas (*e. g.* feeding, resting, moulting, spawning or nursery areas) at sensitive phases of the year (*e. g.* moulting times of seals, breeding times of harbour porpoises as well as resting, moulting and wintering times of ducks and seabirds).

Cable laying and operation therefore requires a comprehensive and sound planning phase and approval procedure taking account of the mitigation measures presented in this Guidance document.

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