Impacts of submarine cables on the marine environment

— A literature review —

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1 Background and Objectives

Subsea cables have a long history in telecommunication services which started at the end of the 19th century with the deployment of the first telegraph cable across the English Channel. Today the demand for fast communication links is still growing rapidly and leads to a flurry of cable laying activities around the globe. But there is a second aspect of subsea cables gaining more importance: transmission of electric power. Power transmission via subsea cables is realized to interconnect terrestrial grids, to supply power to offshore facilities or to feed power supplied from renewable energy sources offshore such as wind and waves into terrestrial grids. Numerous subsea cables can already be found in our oceans and there will be a lot more in the years to come (Fig. 1 and Fig. 2).

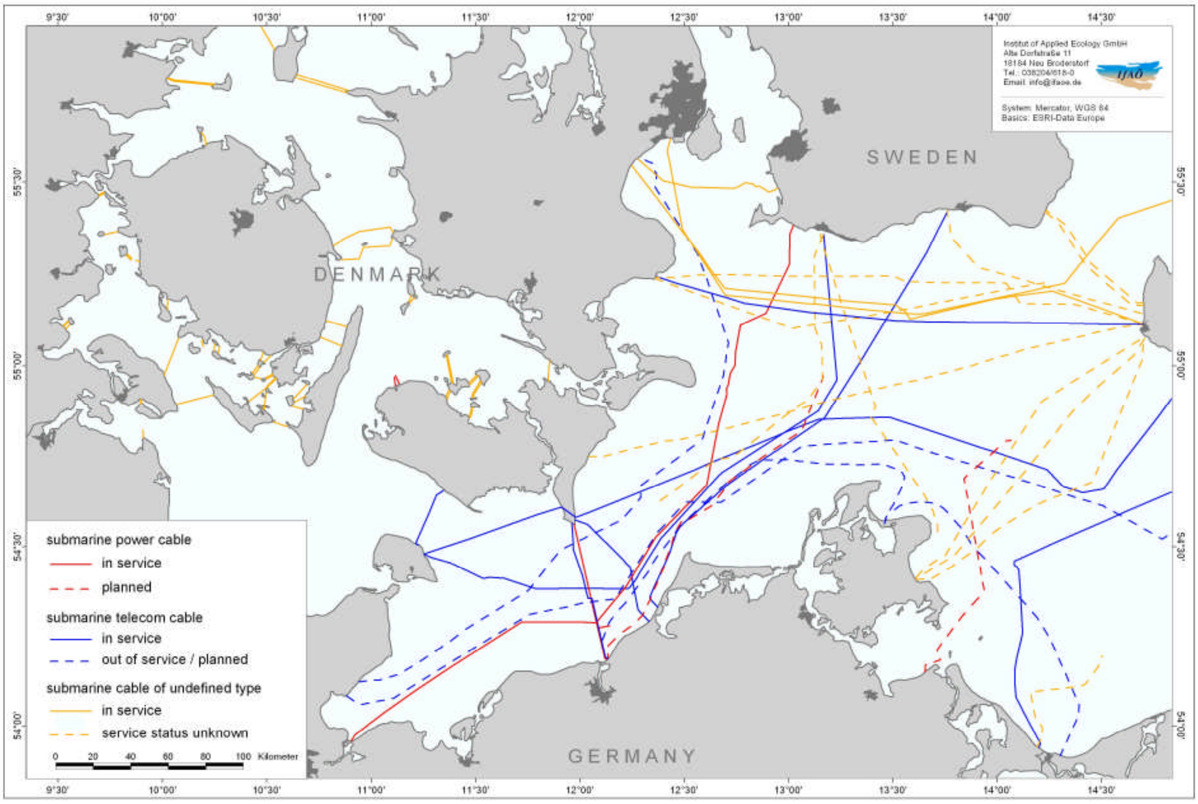


Fig. 1 Subsea cables in the southern part of the Baltic Sea (not complete), sources:

- Kingfisher Information Service - Cable Awareness (http://www.kisca.org.uk/charts.htm)
- ICPC (International Cable Protection Committee) - Cable Database (http://www.iscpc.org)
- Karten des CONTIS-Informationssystems des BSH für Nord- und Ostsee (http://www.bsh.de/de/Meeresnutzung/Wirtschaft/CONTIS-Informationssystem/index.jsp)
- Informationen zu Kabeln verschiedener Seekarten des BSH für Nord- und Ostsee (http://www.bsh.de/de/Produkte/Karten/Seekarten/index.jsp)
- RLK (2001): Cables in the vicinity of the BalticPipe. Appendix E. BalticPipe OffshorePipeline. Environmental Impact Assessment. RLK joint venture (Rambøll, Hannemann & Høllund A/S, LICengeineering A/S, JP Kennz Ltd.) – DONG – Dansk Olie og Naturgas A/S. Virum October 2001 (http://www.lpa.dk/venstremenuen/Plantyper/Landsplanlaegning/Gastransport/Informationstyper/Arkiv/indholdsfortegnelse.htm)
- Alcatel submarine fiber optic cable (www.alcatel.com)

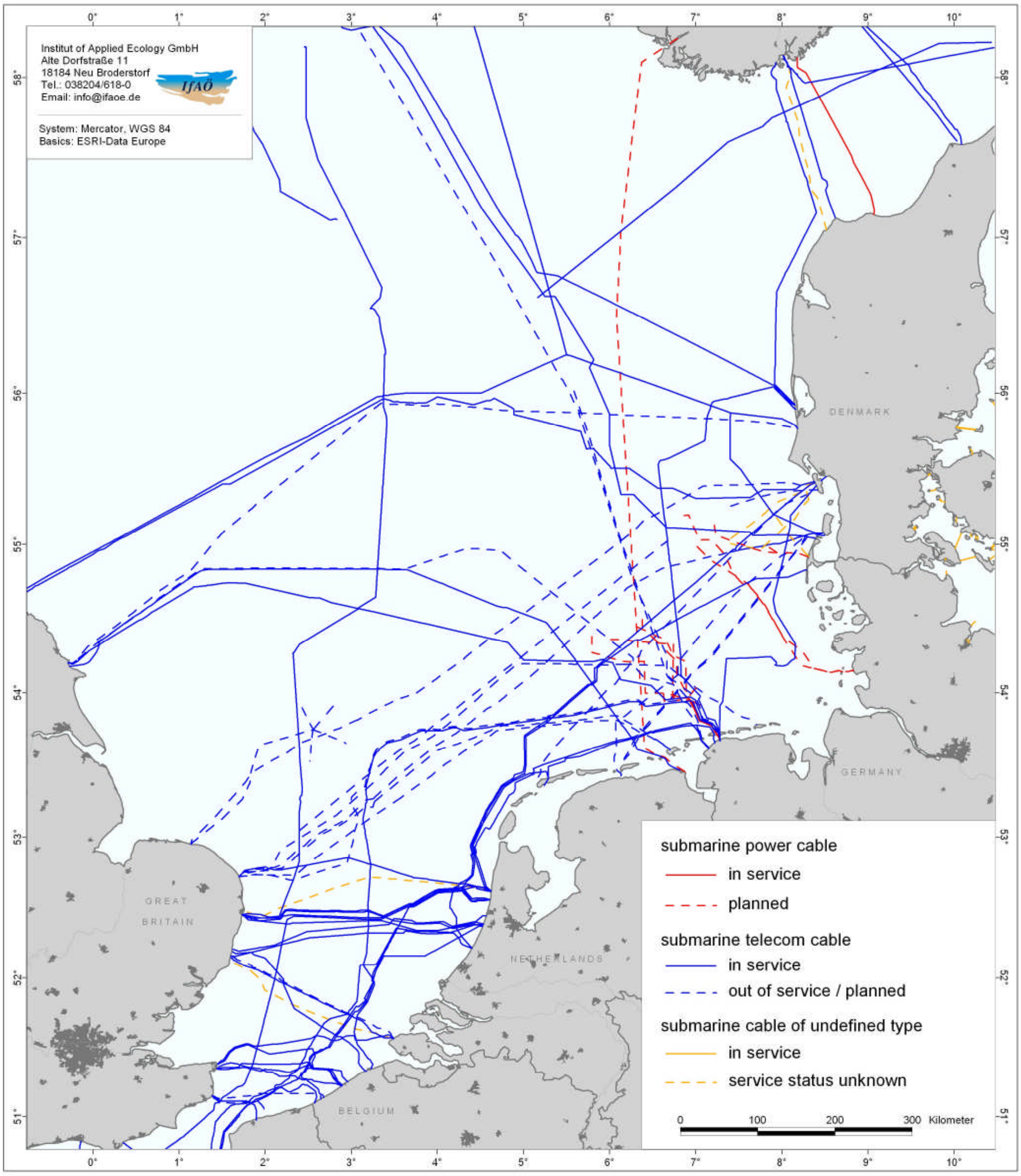


Fig. 2 Subsea cables in the North Sea (not complete); sources see Fig. 1.

Potential problems related to the deployment of subsea cables of different types are raising concerns not only among environmentalists. For that reason, Germany´s Federal Agency of Nature Conservation (BfN) has commissioned this literature review to collect up-to-date information on potential effects of installation, operation and decommissioning of cables in the marine environment. Mitigation measures and requirements of effective monitoring programs are discussed. As a result, a better guidance on development of offshore industries considering environmental aspects and nature conservation issues is expected.

2 Technical aspects of subsea cables

For a better understanding a short introduction into technical aspects of subsea cables with information on cable types, installation methods and cable protection measures is given.

2.1 Fields of application for subsea cables

Cable function often determines the generated effects on the cable environment during installation, operation and decommissioning. Within the scope of this study it certainly is most appropriate to distinguish between cables used for telecommunication and cables for power transmission.

2.1.1 Telecommunication cables

The first type of submarine telecommunication cables which is sporadically still in service today was coaxial telephone cables. Such cables had been the standard in a period from the 1950´s until the late eighties. They have copper wires carrying analogue electrical signals. The common outside diameters for coaxial telephone cables are reported to range from 40 to 100 mm and they may weigh up to 22 t per mile (DREW & HOPPER 1996). Usually they are protected by coatings of steel components and plastics (polyethylene).

Modern telecommunication cables are fibre optic cables. They were introduced in the 1980´s. A fibre optic cable sends information (including sounds converted to digital signals) by shooting pulses of light through thin transparent fibres usually made of glass or plastics (DREW & HOPPER 1996) (Fig. 3).

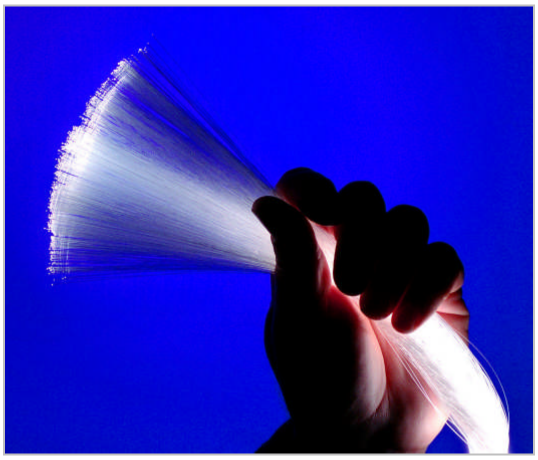


Fig. 3 Fibre optic cable; image source: http://www.sandia.gov/news/resources/releases/2005/images/jpg/light-simple.jpg

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 can be equipped with repeaters. DREW & HOPPER (1996) report repeaters to be placed at intervals of 17 - 34 nautical miles along a fibre optical cable. According to WILLIAMS (2000) repeaters are 100-200 cm long, 30-50 cm in diameter and weigh about 300 to 500 kg each. They have to be powered via a power cable. As an example, each repeater on a four fibre-pair cable requires about 40 W of power (WILLIAMS 2000). The same author states that the standard approach is to send a constant current of about 1 A from one end of the cable to the other, along a copper sheath which lies outside the optical fibres and inside the armour (if present). He calculates that the total requirement for a typical 7500 km transatlantic crossing with 100 repeaters would be close to 10 KV. DREW & HOPPER (1996) also give a voltage of up to 10 kV for powering repeaters.

Outside diameters of fibre optic cables range from 20 to 50 mm (DREW & HOPPER 1996).

2.1.2 Power transmission by cables

There are two general technical solutions for power transmission via subsea cables: Alternating Current (AC) transmission and Direct Current (DC) transmission. The choice of the transmission system is determined by both the capacity and length of the transmission line.

2.1.2.1 Direct current transmission

DC transmission is more commonly used, in particular at large distances and high transmission capacities. For example, all power lines crossing parts of the Baltic Sea to connect power grids of different countries (e. g. Fenno-Skan, Gotland, SwePol Link, Baltic Cable, Kontek, Konti-Skan, Skagerrak) are high voltage direct current (HVDC) lines. Monopolar and bipolar HVDC system configurations are distinguished. In a monopolar configuration the return current is carried by seawater or a separate return conductor whereas in bipolar systems a pair of conductors of opposite polarity is installed providing bi-directional transmission capacity. Monopolar systems without return conductor pass the current into seawater via electrodes, typically graphite anodes and titanium cathodes that are located on the seabed (KOOPS 2000). Tab. 1 gives an overview of current HVDC interconnector systems with subsea links. Usually electric power is generated as AC and delivered as AC to the consumers. Even in most transmission grids (e. g. terrestrial overhead transmission lines < 600 km) electricity is transmitted with three-phase AC (ABB 2006a). For that reason voltage conversation is required if using DC transmission. High costs of HVDC converters are regarded as one of the disadvantages of DC transmission technology. However, considerable line loss and high costs for AC cables set the “break-even” distance at which DC is more attractive than AC at 50-120 km (SÖKER ET AL. 2000).

Tab. 1 HVDC interconnectors with subsea link (from NATIONAL GRID 2000).

Project	Location Converter Stations	Length (km)	Rating (MW)	Voltage (kV DC)	Electrode Current (A DC)	Grounding Electrodes	Electrode Material	Polar Type / Operation
Europe								
Skagerrak 1, 2 and 3. Norway-Denmark	Kristiansand, Tjele	127	1000	± 250 / ± 350	1000	One marine and one land electrode	Graphite / coke	1 cable per pole / Bipole
Gotland 2 and 3. Sweden	Vastervik Vikby	96	260	150	914	Two marine electrodes	Magnetite	2 cables / Bipole
Konti-Skan 1 & 2. Sweden-Denmark	Stenkullen/ Lindome, Vestor Hassing	88	600	285	1050	Two marine electrodes	Graphite / coke	2 cables / Bipole
Baltic Cable Sweden-Germany	Kruseberg, Herrenwyk	250	600	450	1364	Two marine electrodes	Coated titanium, copper	1 cable / Monopole
Fennoskan Sweden-Finland	Dannebo, Rauma	200	500	400	1280	Two marine electrodes	Coated titanium, copper	1 cable / Monopole
Kontek Denmark-Germany	Bjaeverskov, Bentwisch	120	600	400	1500	Two marine electrodes	Coated titanium, copper	1 cable / Monopole
Swepol Sweden-Poland	Starno, Slupsk	230	600	450	—	None	—	1 cable and 1 metal return cable / Monopole
Sacoi Italy, France	Sardinia (I), Corsica (F), Italian mainland	119	200	± 200	1000	Two marine and one land electrode	Copper, Titanium, FeSiCr	2 cables / Monopole
Cross Channel	France, England	86	250	270	—	None	—	8 cables / Bipolar
*Italy-Greece	Galatina, Arachthos	200	500	400	1250	Two marine electrodes	Titanium, copper	1 cable / Monopole
*NorNed Kabel Norway, Netherlands	Feda, Eemshaven	580	600	± 450	—	—	—	2 cables / Bipole hybrid
*Viking Cable Norway	Feda, Brunsbuttel	580	600	500	—	None	—	1 cable and 1 metal return cable / Monopole
*Scotland-N. Ireland	Ayrshire, County Antrim	100	2x 250	± 250	—	None	—	2 cables, 1 metal return cable / Bipole
North America								
Vancouver, Canada	Vancouver, Vancouver Is.	35	682	± 380	1700	One marine and one land electrode	Graphite, Mild steel/coke	2 cables / Bipole
Newfoundland Canada	Gull Island, Soldiers Point	1126	800	—	—	—	—	4 cables
Asia								
Leyte-Luzon	Ormoc, Naga	19	440	350	1260	Two land electrodes	Silicon, iron/coke	1 cable, 1 spare
Haenam-Cheju	South Korea	100	300	± 180	—	Two marine electrodes	Graphite	2 cables / Bipole
Hokkaido-Honshu Japan	Hokkaido, Honshu	43	600	± 250	2000	Two land electrodes	—	2 cables / Bipole
Kii-channel crossing	Japan	49	2800	± 500	—	—	—	4 cables / Bipole
*Leyte-Mindanao, Philippines	Ormoc, Kirahon	23 (cable) 455 (ohl)#	500	± 250	—	One marine and one land electrode	Graphite/ coke, Copper	2 cables / Bipole
Australasia								
*Basslink Australia	Victoria, Tasmania	275	480	400	1200	Two marine electrodes	Graphite/ coke, Copper	One cable / Monopole
Cook Strait, New Zealand	Haywards, Benmore	40	500	± 350	1200	One marine and one land electrode	Mild steel/coke, Silicon iron/coke	2 (+1) cables / Bipole

Footnotes: * Proposed interconnector; #ohl—Overhead line.

A rather recent development in HVDC transmission is insulated-gate bipolar transistor HVDC transmission (HVDC-IGBT, also known as VSC-HVDC (VSC = Voltage Source Converter) or product names like HVDC Light by ABB and HVDCplus by Siemens) (DEUTSCHE WINDGUARD GMBH 2005). In contrast to classic HVDC transmission, IGBTs can be switched within half an AC sine-wave. The advantage of this technology in offshore wind farms is that it is possible to provide voltage and frequency to the turbines without an additional AC connection or diesel generator and to deliver reactive power if desired. For example, provision of AC voltage offshore is necessary to start up the wind turbines. HVDC-IGBT technology is advertised to be particularly suitable for small- and medium-scale power transmission applications and extends the economical power range of HVDC transmissions down to just a few tens of Megawatts. Classic HVDC thyristor systems are the technology of choice when large transmission capacities in the 1,000 MW range are considered.

2.1.2.2 Alternating current transmission

With both decreasing transmission capacity and distance AC transmission becomes an option. High and medium voltage AC transmission is widely used for power supply of offshore platforms and in connection with offshore windfarming. For example, a typical setup for an offshore wind farm (80 turbines) at a distance of less than 100 km from the shore integrates medium voltage AC lines (33-36 kV, maximum capacity 140 MW) for grid connection within the park and high voltage AC lines (150 kV, 280 MW) linking the wind farm to the shore (PÖHLER 2006).

A disadvantage of AC transmission systems is high transmission losses which increase with cable length. However, AC systems have proved successful in numerous applications onshore.

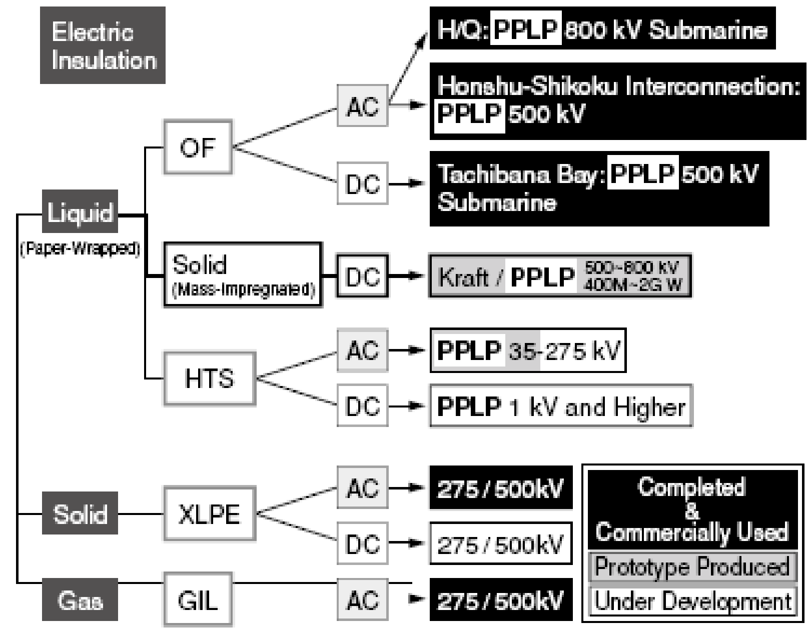
2.1.2.3 Cable types

The variety of cables an investor can choose from seems enormous. Sizes, materials, and types of modern power cables can be particularly adapted to its uses (Tab. 2). The cable industry today offers various types of mass-impregnated (MI) cables and XLPE (cross linked polyethylene) cables (Fig. 5 - Fig. 7), also self contained fluid filled (SCFF) or gas filled (SCGF) cables are available (JACQUES WHITFORD LIMITED 2006a) (Fig. 8). 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 prevents 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 pressurized 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 aluminum wires, or may be composite conductors with steel strands at their core. The overall assembly of the cable components may be round or flat. Outer diameters are usually less than 15 cm. Weights vary between 15 to 80 kg/m.

Tab. 2 Information on recent submarine cable projects (taken from Jacques Whitford Limited 2006a).

Project	**Description**	**Contract Status**	**In-Service Date**
Hong Kong Submarine, Lamma Island	275/550 kV AC , two circuits, 2.7km (SCFF PPLP)	J-Power	2005/6
Gibraltar 2nd link (Spain – Morocco)	400kV AC, 30 km (SCFF Kraft Paper)	Pirelli / Nexans	Dec 2005
Norwalk Ct. (USA) Replacing circuit 1385	3x138 kV circuits, 3x17.6 km (XLPE)	Tender in progress	2007
Hainan Crossing (China)	500kV AC, 31 km (SCFF Kraft Paper)	Tender in progress	2007
Norway, Gossen Island	415 kV AC, 2.7km (XLPE)	Nexans	2006
EstLink, Gulf of Finland	150 kV HVDC, 80 km (XLPE)	ABB	2006
Saudi Arabia - Bahrain	420 kV AC , 42km (SCFF Kraft Paper)	Nexans, Prysmian	2007
Thailand, Khanom (mainland) - Ko Samui Island	115 kV AC , 24 km (XLPE)	Nexans	2007
VITR	242 kV AC, 30km (SCFF PPLP or Kraft Paper)	Tender in Progress	2008



Abbreviations:

OF	oil-filled
PPLP	polypropylene laminated paper
XLPE	cross linked polyethylene
HTS	High Temperature superconducting
GIL	gas-insulated transmission line

Fig. 4 Latest technical trends in underground and submarine cables after HATA (2006).

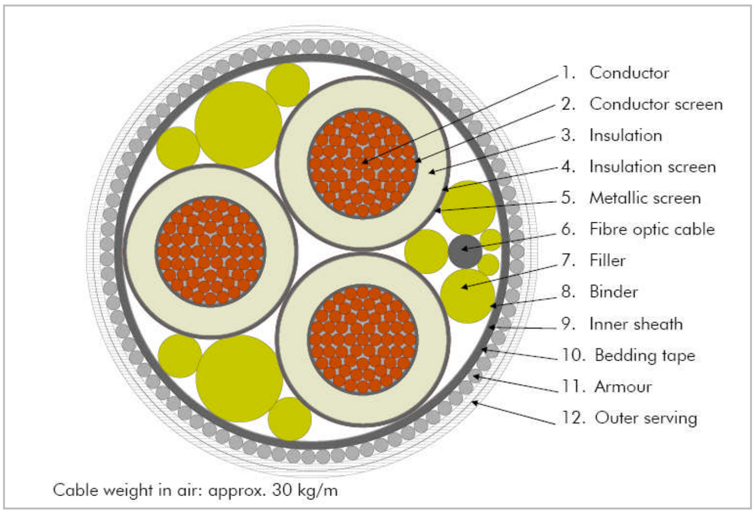
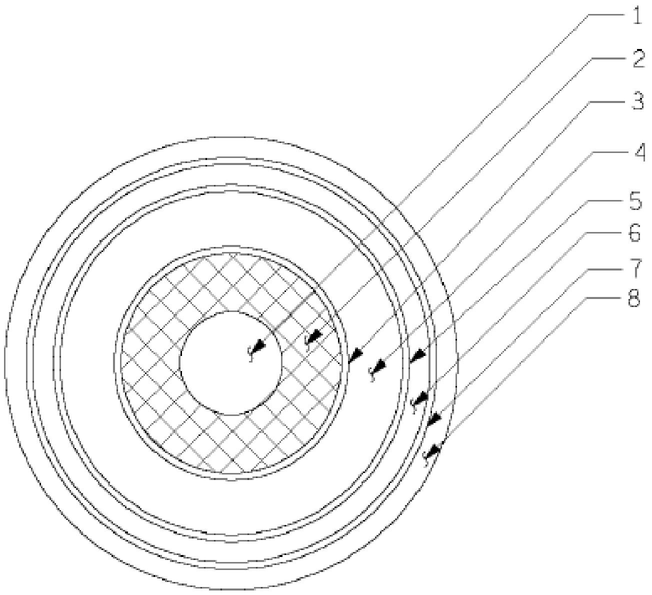


Fig. 5 Example for a standard 3-core submarine cable manufactured by Nexans Norway AS (NEXANS NORWAY AS 2006): TFRA 36 kV 3x1x500 mm² (AC).

Fig. 6 Cables manufactured by Nexans Norway AS; Left: 52 kV XLPE insulated composite power and fibre optic cable employed at the Troll field in the Norwegian sector of the North Sea (AC), right: HVDC 250 kV/250 MW cable with integrated return conductor and fibre optic element (Nexans Norway AS 2005).

Fig. 7 Submarine power cables manufactured by ABB; left: polymeric HVDC Light cable for DC and paper-insulated mass-impregnated cable for HVDC, right: XLPE-insulated three-core and single core-cable for AC (ABB 2006b).



ITEM	COMPONENT	DESCRIPTION
1	INSULATING FLUID DUCT	
2	CONDUCTOR	CROSS SECTION SELF SUPPORTING SEGMENTAL STRIPS OF COPPER
3	CONDUCTOR SCREEN	CARBON BLACK PAPERS
4	INSULATION	IMPREGNATED PPL PAPER TAPES
5	CORE SCREEN	CARBON BLACK PAPERS COPPER WOVEN FABRIC TAPE
6	LEAD OR ALUMINUM SHEATH	EXTRUDED LEAD ALLOY OR ALUMINUM
7	REINFORCEMENT (LEAD ONLY)	BRONZE, COPPER OR STAINLESS STEEL TAPES
8	ANTI-CORROSION JACKET	EXTRUDED POLYETHYLENE SHEATH

Fig. 8 Cross section of a self contained fluid filled cable (SCFF-cable) (taken from JACQUES WHITFORD LIMITED 2006).

2.1.3 Electrical heating of subsea flowlines (oil and gas pipelines)

Another application of electrical devices in the marine environment to be mentioned in the in the scope of this study is electrical heating of subsea flowlines (oil and gas pipelines). Pipeline heating allows active hydrate and wax control by controlling thermal conditions inside the pipeline. The pipeline inner wall is kept above the wax and hydrate formation temperature, and thus, flow reduction and blocking are prevented.

GILL ET AL. (2005) give a short summary of methods for electrical heating of pipelines:

“Electrically heated pipelines operate either by direct heating or induction. With induction heating, a conductor is coiled around the pipeline, the current in the conductor sets up a magnetic field which induces a current directly into the wall of the (metallic) pipeline. The current flowing through the pipeline then has a heating effect due to the resistance of the pipe material. With direct heating a voltage is applied directly to the pipeline, the resulting current returns to the source by flowing through either a combination of the seawater and the pipeline, or a separate cable." The same authors continue: "…Voltages and currents are understood to vary widely. In the majority of cases the cables are believed to be single phase, high current and unscreened/unarmoured. The magnitude of B and E fields produced is unknown but would likely be largest with directly heated cables."

The company Nexans has been involved in the development of direct electrical heating systems for Norwegian oil companies. Tab. 3 lists available project information.

Tab. 3 Information provided by the company Nexans on installation of direct electrical heating systems at pipelines in selected oil fields (NEXANS NORWAY AS 2005).

Project	**Åsgard**	**Huldra**	**Kristin**	**Norne**
Installation	2000	2002	2004	2005
Number of flowlines	6 x 10″	1 x 8″	6 x 10″	1 x 1,5″
Length of flowlines	6 – 9 km	16 km	6 – 8 km	9 km
Reason for use	Hydrate prevention	Hydrate and wax prevention	Hydrate prevention	Hydrate prevention

Fig. 9 Heating cable on flowline (from NEXANS NORWAY AS 2005)

2.2 Cable installation

Subsea cables are usually buried to minimise the risk of damage by, for example, anchors and fishing gear. For data cables on the continental shelf EMU LTD (2004) reports cables to be buried to a depth of 1200 m. DREW & HOPPER (1996) state that submarine cables around the British Islands in general are not buried in water depths > 1000 m. In German waters cables are also expected to be buried (compare http://www.bsh.de). Where cables cannot be burried, e. g. in areas of exposed bedrock, or it is not legally required to bury them, they are layed directly on the sea bed and covered fully or partially with concrete or other mechanical protection, or, in unconsolidated sediments, the cable is expected to self-bury (e.g. Basslink project Australia, NATIONAL GRID 2000). In rivers with heavy traffic, the best solution could be to lay the cable in a tube under the river (ABB 2006b).

The cable burial depth depends on factors like types of threats present, the type of habitat, the hardness of the sediment or the depth of water. In German waters cable burial depths are proposed to not remain below 1 m in the EEZ and not below 3 m in areas with heavy ship traffic (e.g. shipping channels). In exclusion zones like offshore wind farms cable burial depth is at least 0.6 m. In narrow channels of North Sea mud flats cables are buried 2 m below the seabed. A standard burial depth of six feet (~1.80 m) below the seabed was mentioned in connection with the installation of a submarine electric transmission cable system extending from Norwalk Harbour Substation in Norwalk, Connecticut to Northport Substation in Northport, New York, USA (NORTHEAST UTILITIES SERVICE COMPANY 2002). For KERITE COMPANY (2001), installing a 25 kV submarine cable off the southwest coast of Florida, USA, the target burial depth was 4 feet (~1.20 m). A self-contained, fluid-filled (SCFF) cable crossing the Long Island Sound (USA) for a distance of 12.7 km was laid and jetted approximately 3 m into the sea bottom (GRZAN ET AL. 1993). Other projects in the US and Canada favour laying depths of 3-6 feet (about 0.90 m - 1.80 m) below seabed (URS CORPORATION 2006, JACQUES WHITFORD LTD 2006a). Laying of a submarine fibre optical cable in Honkong between Tuen Mun and Chek Lap Kok required burial depths of 3.5 m below seabed, a depth regarded to be typical by the author for the described location (HUTCHISON GLOBAL CROSSING LTD 2000). DREW & HOPPER (1996) give a preferred burial depth of 0.6 to 0.9 m in many coastal areas of the U.K. FORGE TRACK LTD, a company from the U.K., gives burial depths of 0.6 and 1.5 m to apply across the whole of the Continental Shelf. EMU LTD (2004) specifies typical burial depths dependent on seabed types (Tab. 4).

Tab. 4 Typical subsea cable burial depths (after EMU LTD 2004).

Seabed type	**Typical burial depths [m]**
Exposed bed rock	0.0
Chalk	0.0 – 0.6
Stiff clay	0.4 – 0.8
Clay	0.6 – 1.2
Gravel	0.4 – 1.0
Coarse sand	0.4 – 1.0
Silty sand	0.6 – 1.2
Sand waves	0.0 – 3.0
Intertidal mud flats	0.6 – 3.0
Beach sand	1.0 – 2.0

Cable laying ships often bury the cable as it is laid. In other cases the subsea cable is first placed on top of the seabed and buried later. Cable laying methods include ploughing, trenching, jetting and directional drilling. Also mechanical excavators, such as small tracked backhoes, are employed for cable burial in the upper intertidal zone (JACQUES WHITFORD LTD 2006a). It seems that the different methods are more and more combined or turned into one another, in particular ploughing, jetting and trenching. Jetting or plough-jetting is usually describe as a method of fluidizing the sediment by injecting water with high pressure below the sediment surface. When the water pressure is removed, the sediment would resettle over the cables.

Companies engaged in subsea cable installation have developed laying vessels and sophisticated cable laying machinery to optimise cable installation under various laying conditions. Fig. 10 - Fig. 11 give an impression of installation equipment like cable laying ships, remotely operated vehicles and ploughs.

Duration of the cable installation process is not only a cost factor, it also is an important aspect for generated environmental impacts. EMU LTD (2004) regard a progress rate of 1 km/h a typical rate in soft seabed materials, although the authors acknowledge it to be very variable. In the project description for the Australian Basslink Crossing laying was expected to progress at a rate of about 10 km per day (BASSLINK PTY LTD 2002). NORTHEAST UTILITIES SERVICE COMPANY (2002) estimated a laying progress of 3 to 5 km/d for a project off the Connecticut (USA) coast. The average speed of the laying vessel C/S Skagerrak laying a 250 kV HVDC mass-impregnated submarine cable between Denmark and Norway was 1 - 1.5 knots. Laying took place in water depths up to about 550 m and the cable was placed on top of the seabed (HAUGE ET AL. 1988).

Fig. 10 Nexans´ Capjet system trenches cables and umbilicals by fluidising the seabed materials. The vehicle docks on the cable or pipeline, follows these objects and can start and stop trenching operations at any point along the route. Simultaneous back-fill with the fluidised materials is achieved during the trenching operation. It can be employed in shallow waters as well in water depths up to 2000 m (NEXANS 2005).

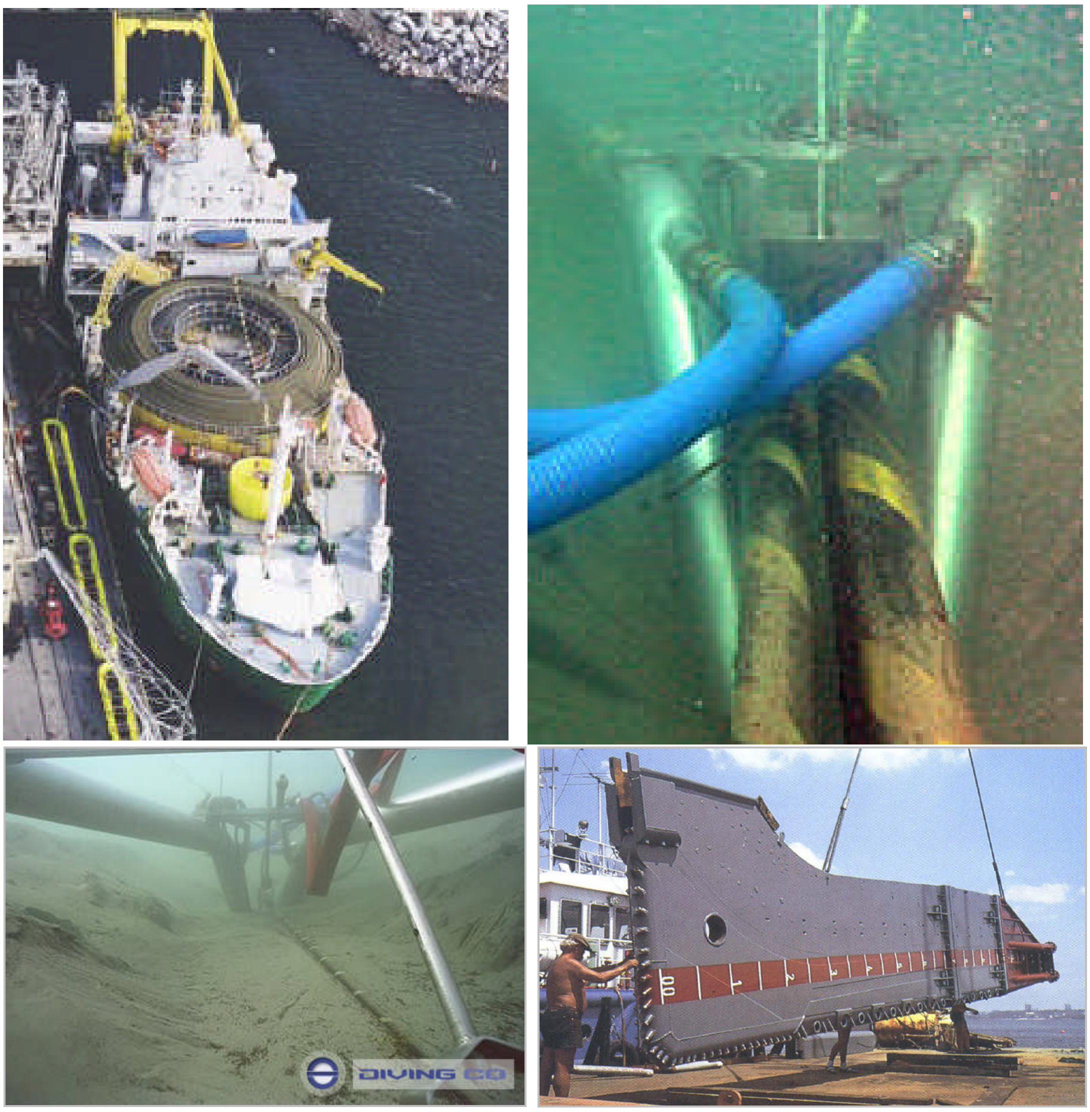


Fig. 11 From top left clockwise: 1) Laying vessel C/S Bourbon Skagerrak, owned by Bourbon Offshore Norway AS and operated by Nexans Norway for cable and umbilical laying (Nexans 2005); 2) Basslink cable burial (www.divingco.com.au); 3) Plough blade (Moll 2006); 4) Cable burial (www.divingco.com.au).

Fig. 12 Left: Jetting plough with 5 m blade extended (Lawrence 2002), right: close view of jetting plough blade (Moll 2006)

2.3 Cable protection

Where hard seabed occurs or when there is a high risk of cable damage the cable may require some form of protection. Protection may be applied in form of a rock-mattress cover, cast iron shells, cable anchoring, ducting or rock dumping. Other protection measures are the use of special backfill materials for cable burial or to cover cables with reinforced concrete slabs or steel plates. Examples for cable protection placed on top of the seabed are shown in Fig. 13.

Fig. 13 Left: Basslink cast iron shell cable protection (www.divingco.com.au), Right: Flexitex concrete mattresses for cable protection (http://www.marinetrench.com/alternative.html).

3 Environmental impacts associated with subsea cables

Environmental impacts associated with the different types of subsea cables are often specific for a certain phase in cable life as there are installation, operation and decommissioning. Anticipated environmental impacts associated with subsea cables are underwater noise, heat dissipation, electromagnetic fields, contamination, and disturbance. In the following chapters these impacts are 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. According to STEHMEIER (2006) monopolar transmission systems with electrodes are no longer EU standard and therefore environmental effects related to the use of electrodes are not addressed in this report.

3.1 Noise

3.1.1 Introduction

Discussion of impacts of anthropogenic sound emissions on marine fauna is a complex issue. It requires at least a basic knowledge of technical background on underwater sound. For that reason a short introduction in regard to noise expression scales is given in this chapter followed by a review of information available on anthropogenic sound emissions related to submarine cables and their potential impact on marine life.

3.1.2 The DeciBel scale

There are various units of noise measurement, however, commonly the decibel (dB) scale is used to express noise. Explanation of this scale was, for example, by NEDWELL ET AL. (2003): “The deciBel relates the measurement of noise to a reference unit; it expresses the ratio between the measurement and the reference unit logarithmically. The term “level” is applied to any unit expressed using the deciBel scale. For a sound of peak pressure P_m Pa the Sound Pressure Level (SPL) in deciBels will be given by SPL = $20 \log_{10}(P_m/P_{ref})$, where P_{ref} is the reference pressure, which for underwater applications is usually taken as 1 microPascal (µPa). For instance, a blast wave of 1 bar (105 Pa) would have a sound pressure level, referred to 1 µPa, of SPL = $20 \log_{10}(10^5/10^{-6})$ = 220 dB re 1 µPa.” As shown in the example, the reference unit is appended if quoting sound levels.

Another characteristic of sound is its frequency, which is the rate of oscillation of the sound pressure wave progressing through a medium such as water or air, measured in Hertz (Hz). In a draft OSPAR background document on the impacts of anthropogenic underwater sound in the marine environment presented by Germany **(WIE zitieren????)** the frequency range categorisation after HILDEBRAND (2005) was followed. According to that categorisation low frequency sound < 1 kHz, mid-frequency sound of 1 – 20 kHz, and high-frequency sound of < 20 kHz can be distinguished.

If evaluating the impact of noise on fauna it has to be considered how noise is perceived by different species. The hearing sensitivity of a species is shown in its audiogram, in which the lowest level of sound, or threshold, that the species can hear is shown as a function of frequency. Audiograms of different species are shown in Fig. 14.

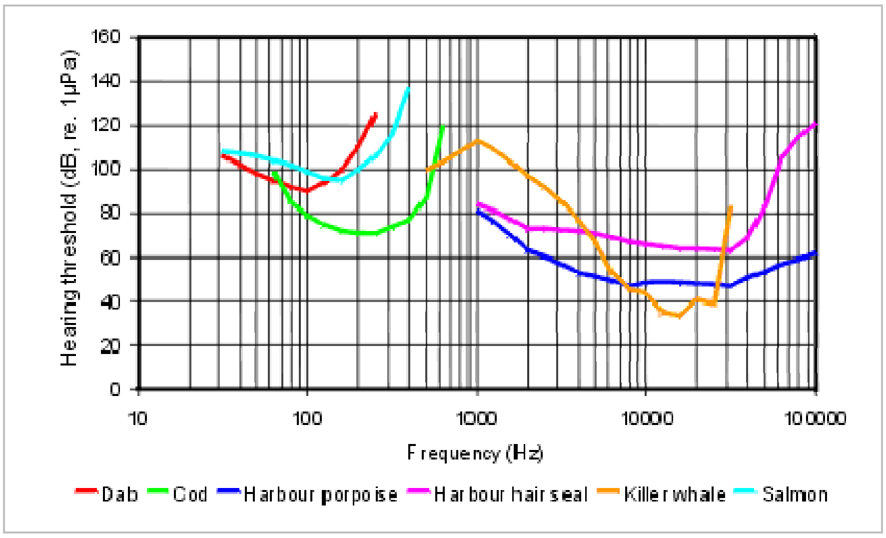


Fig. 14 Audiograms of various species (from NEDWELL ET AL. 2001).

NEDWELL ET AL. (1998) addressed that problem by developing the dB_{ht} (Species) scale (the suffix 'ht' stands for hearing threshold). The idea behind this concept is to estimate dB_{ht}(Species) levels by passing the sound through a frequency dependent filter that mimics the hearing ability of the species, and measuring the level of sound after the filter. A set of coefficients is used to define the behaviour of the filter so that it corresponds to the way that the acuity of hearing of the candidate species varies with frequency. At this scale a sound of 0 dB_{ht} is at the hearing threshold of the respective species (NEDWELL ET AL. 2001).

3.1.3 Anthropogenic noise emission related to submarine cables

Potential noise impacts associated with subsea cables occur during the construction phase and as episodic noise during the operational phase in connection with maintenance or repair. If HVAC cables are used permanent vibration noise emission from the cable also has to be taken into account. The construction activities considered include removal of the existing support structures and cables, installation of new support structures and cables, and trenching and backfilling. Noise impact may arise from operation of vessels or machinery. Sound emission from onshore converter stations is not considered in the scope of this study. For information on this subject see for example SIEMENS (2006).

3.1.3.1 General assessments, modelling of potential noise impacts and noise measurements

Impact assessment studies for various cable projects have usually addressed underwater noise as a potential environmental issue. In conclusion, however, noise emission related to subsea cable installation or cable operation was not regarded a serious problem in such reports. This conclusion was in most cases based on the prediction that anticipated noise levels related to the project would not exceed already existing ambient noise in the area, although measurements of background noise as well as results from modelling of potential noise impacts related to the project were often not presented. For example, URS CORPORATION (2006) assessed noise and vibration impacts from installation of the proposed TransBay cable system from San Francisco to Pittburgh (USA) to be less than significant. Submarine cable-laying activities for the Hong Kong Offshore Wind Farm were expected to generate no significant noise impacts (HK OFFSHORE WIND LIMITED 2006). CAPE WIND ASSOCIATES, LLC (2004) concluded the jet plough embedment process for laying submarine power cables for the Cape Wind Nantucket Sound project (USA) with a cable barge produces no sound beyond typical vessel traffic in Nantucket Sound.

A detailed presentation of a **noise impact study** conducted in the scope **of the Vancouver Island transmission reinforcement project** was presented by JASCO RESEARCH LTD (2006). It was considered that construction activities associated with installation of the new 230 kV HVAC system between the Lower Mainland and Vancouver Island will generate underwater noise in Trincomali Channel and the Strait of Georgia that may harass nearby marine wildlife. Both a measurement study to quantify existing noise levels as well as a separate modelling study to predict noise levels caused by construction activities associated with cable installations was performed to determine the relative importance of construction noise in the work areas. The primary source of underwater noise during the removal and installation operations was expected to be the cable laying ship. Shallow water workboats were also expected to generate a limited amount of noise during the shore pull operations. Small, diver operated dredging equipment in shallow water was not considered to radiate significant amounts of underwater noise. Since source levels for cable ships were not available the authors used measurements of 1/3-octave band source levels for a dynamic positioning rock dumping vessel for modelling (Fig. 15). Acoustic source levels for cable laying and cable removal were assumed to be the same, since the operation of ship's thrusters was regarded to be similar during both operations. To model shore pull operations in shallow water, 1/3-octave band acoustic source levels for a 9-metre workboat were used as a representative analogue.

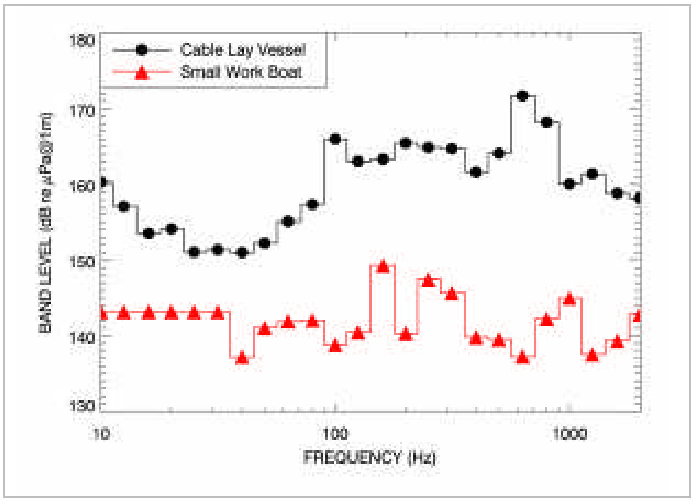
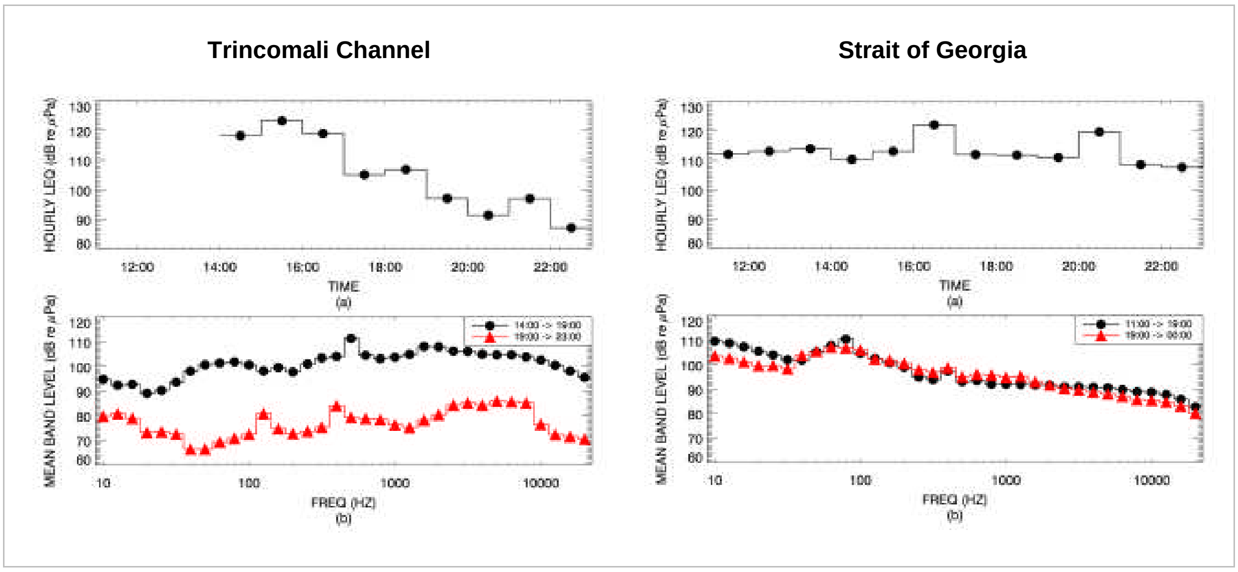


Fig. 15 Nominal 1/3-octave band source levels for a dynamic positioning cable lay vessel and for a small workboat that were used for the acoustic modelling. The nominal broadband acoustic source level for the cable ship was 177 dB re µPa @ 1m, the nominal broadband acoustic source level for the small workboat was 156.9 dB re µPa @ 1m (JASCO RESEARCH LTD 2006).

Recordings of underwater ambient noise were performed near planned cable installation sites using a bottom mounted autonomous recorder system. Baseline background noise levels were measured in both Trincomali Channel and the Strait of Georgia on two separate dates. Results of the measurements are shown in Fig. 16, those of modelling in Fig. 17 – Fig. 20.



Trincomali Channel

Strait of Georgia

Fig. 16 **Results of measurements of baseline noise levels for the Vancouver Island transmission reinforcement project** (JASCO RESEARCH LTD 2006), left: location with the majority of noise sources identified as being pleasure boats and fishing boats, Trincomali Channel, right: location with the primary noise sources identified as being commercial shipping (e.g., bulk carriers, container ships, and barge tugs) and ferries, Strait of Georgia.

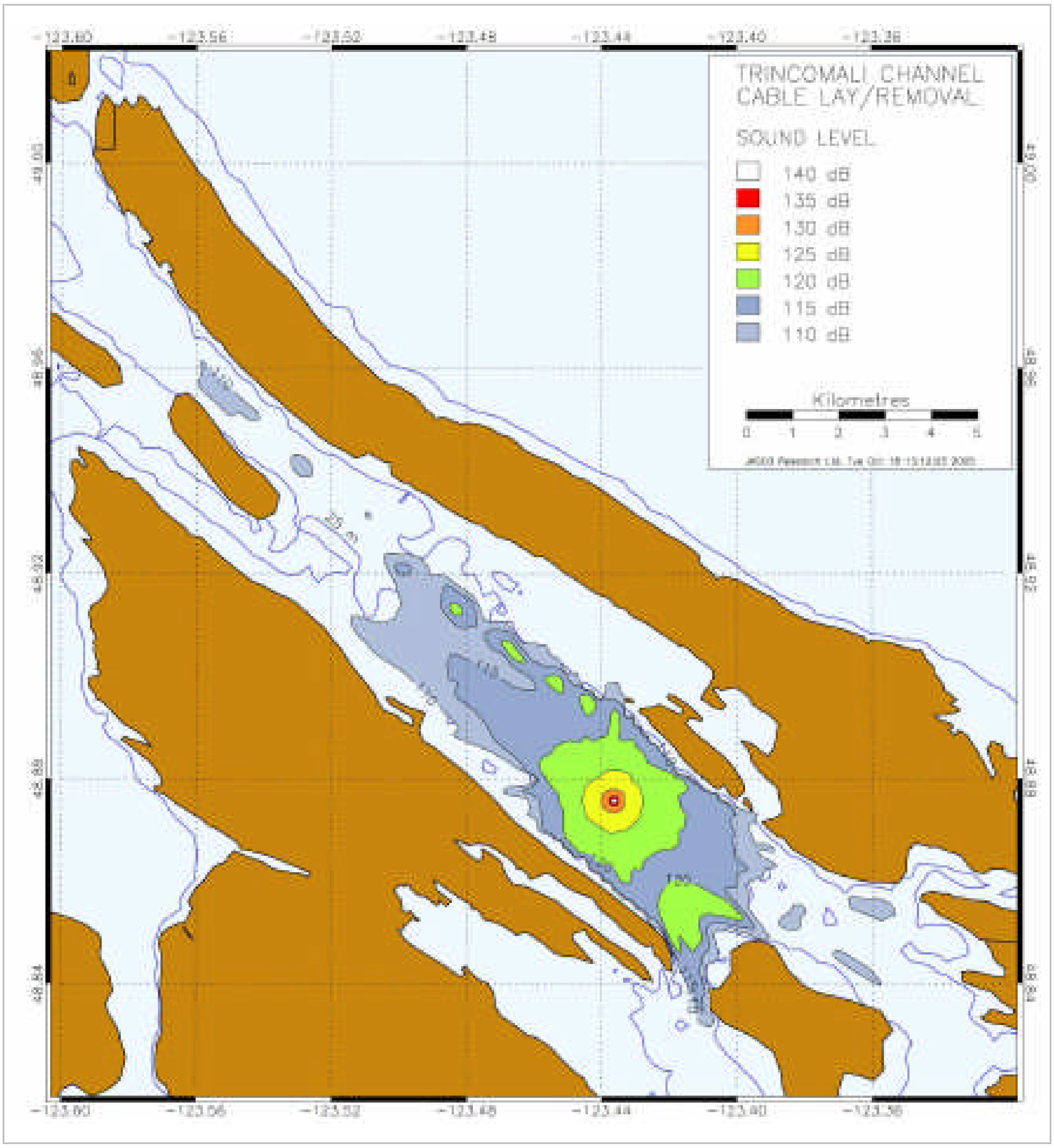


Fig. 17 **Modelling results Vancouver Island transmission reinforcement project**: underwater noise level contours for a cable ship performing cable lay/cable removal in Trincomali Channel (acoustic source is located in mid-channel). Noise levels are shown for a receiver at 50 metres depth (or at the sea-bottom where the water is shallower). Noise levels are unweighted, broadband sound pressure levels given in decibels referenced to 1 µPa (JASCO Research Ltd).

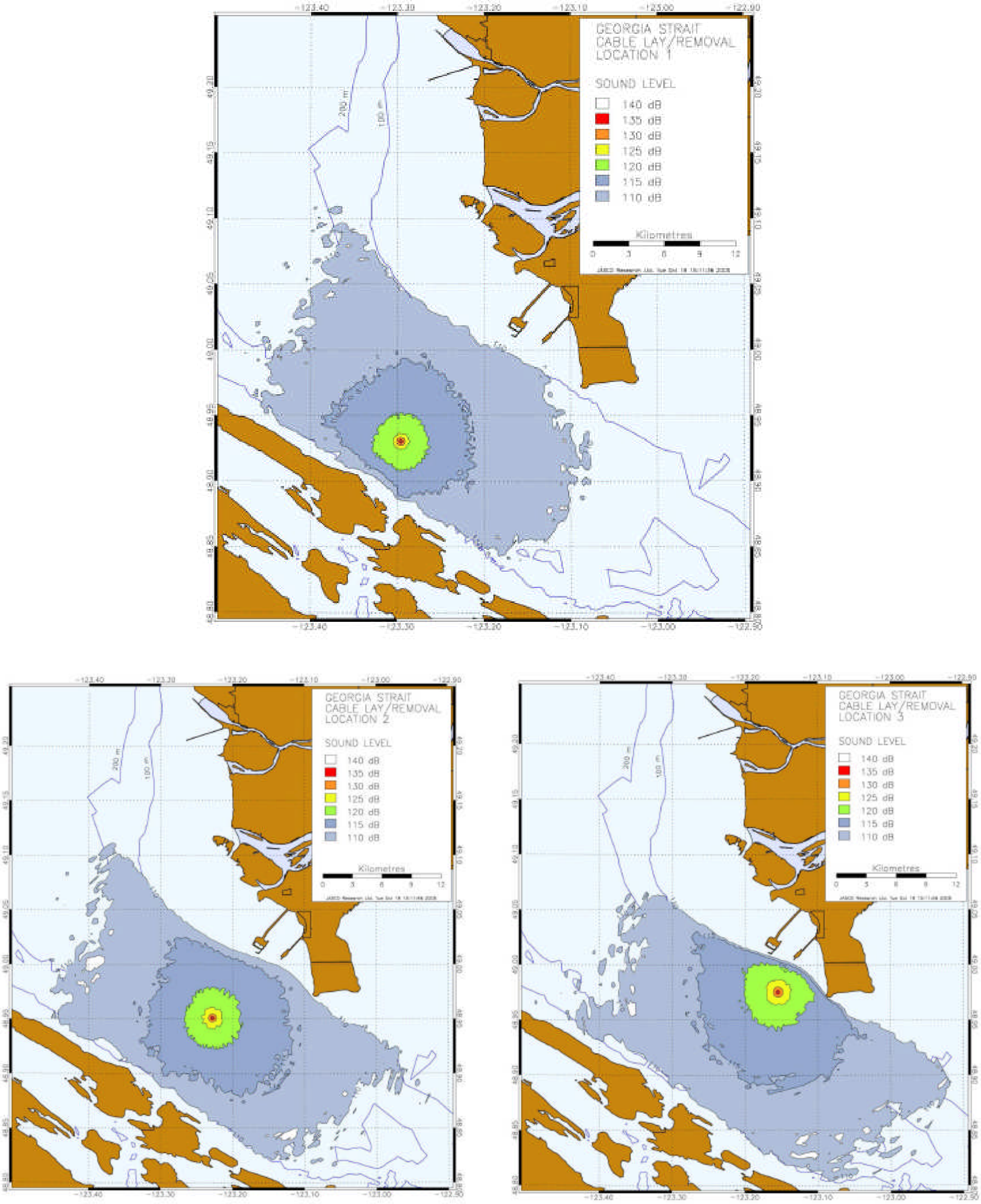


Fig. 18 **Modelling results Vancouver Island transmission reinforcement project**: underwater noise level contours for a cable ship performing cable lay/cable removal in the Strait of Georgia at 3 different locations. Location 1: acoustic source is located approximately 5.4 km from Taylor Bay terminal, 2: acoustic source is located in mid-channel, 3: acoustic source is located approximately 5.6 km from English Bluff terminal along the planned cable route. - Noise levels are shown for a receiver at 50 metres depth (or at the sea-bottom where the water is shallower). Noise levels are unweighted, broadband sound pressure levels given in decibels referenced to 1 μPa (JASCO RESEARCH LTD 2006).

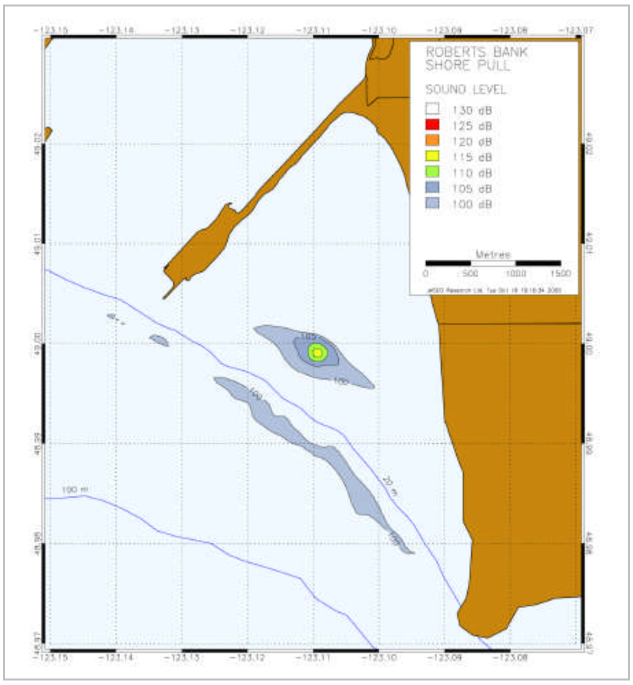


Fig. 19 **Modelling results Vancouver Island transmission reinforcement project**: underwater noise level contours for a small workboat performing cable pull on Roberts Bank; acoustic source is located at the 3 meter isobath approximately 1.3 km from English Bluff terminal. Noise levels are shown for a receiver at 50 metres depth (or at the sea-bottom where the water is shallower). Noise levels are unweighted, broadband sound pressure levels given in decibels referenced to 1 µPa (JASCO Research Ltd).

Conclusion from the study was that underwater noise generated by the construction vessels used for cable laying will be similar to that of other ships and boats (e.g., pleasure boats, fishing vessels, tugs and container ships) already operating in these areas. Average 95% ranges from the cable ship to the 130 dB, 120 dB and 110 dB noise level contours were 0.38 km, 3.03 km and 13.95 km, respectively. Noise propagation from a single workboat as it could be used for shore pull operation was estimated to be less than 110 metres from the workboat for all noise level contours >110 dB (95% range). No potentially significant noise impacts could be identified according to JASCO RESEARCH LTD (2006). However, drawing this conclusion the assumption that ambient noise levels in the area had no effect on the resident fauna has to be accepted.

Noise measurements were also conducted **during construction of the North Hoyle offshore wind farm** off the British coast. For example, NEDWELL ET AL. (2003) reported source levels of 178 dB re 1 µPa @ 1 m created by trenching of cables into the seabed and 152 to 192 dB re 1 µPa @ 1 m created by operation of vessels and machinery (based on measurements of large vessels in deep water and small vessels in shallow water). Fig. 20 shows results of trenching noise recorded at a range of 160 m from the trenching in very shallow water with the hydrophone at 2 m depth. The sound pressure level of this recording was 123 dB re 1 µPa. The noise was described as highly variable, and to apparently depend on the physical properties of the particular area of seabed that was being cut at the time.

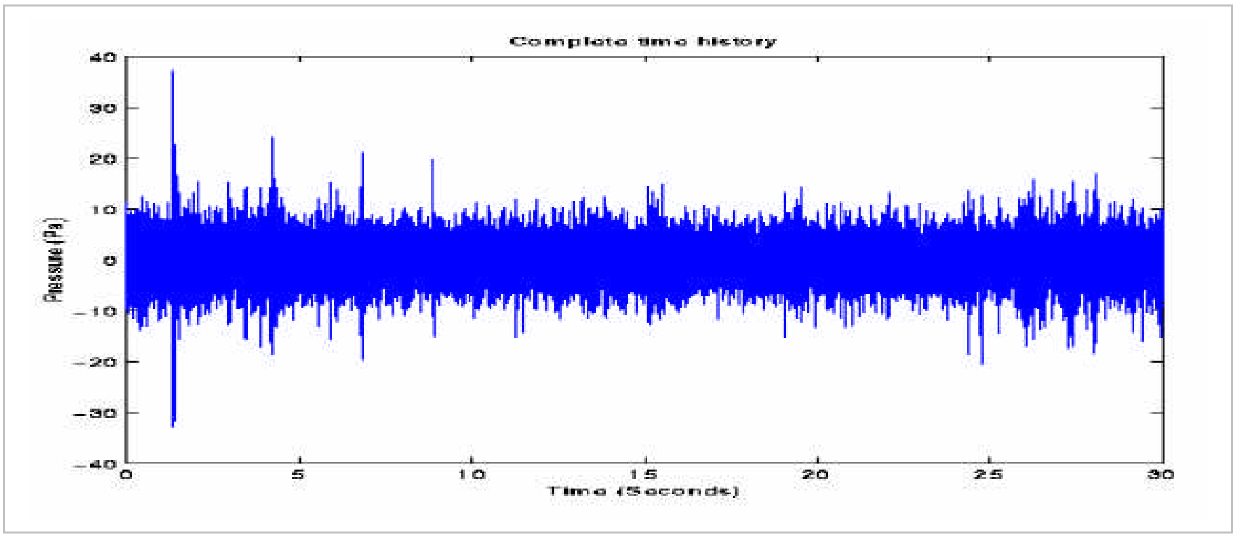


Fig. 20 A typical time history of cable trenching noise, recorded at a range of 160 m with the hydrophone at 2 m depth at North Hoyle offshore wind farm during construction (from NEDWELL ET AL. 2003).

The power spectral density of the measurements presented in Fig. 20 is shown in Fig. 21. The spectrum is characterized by the authors as “ …broadband, with some energy at 50 kHz and above, although in general it is only some 10–15 dB above the level of background noise. It is assumed that the peak in the spectrum at 40 kHz is due to the use of baseline sonar for positioning. Because of the variability of the noise it is difficult to establish the unweighted Source Level of the noise, but if a Transmission Loss of 22 log (R) is assumed, a Source Level of 178 dB re 1 µPa @1 m results.” (NEDWELL ET AL. 2003)

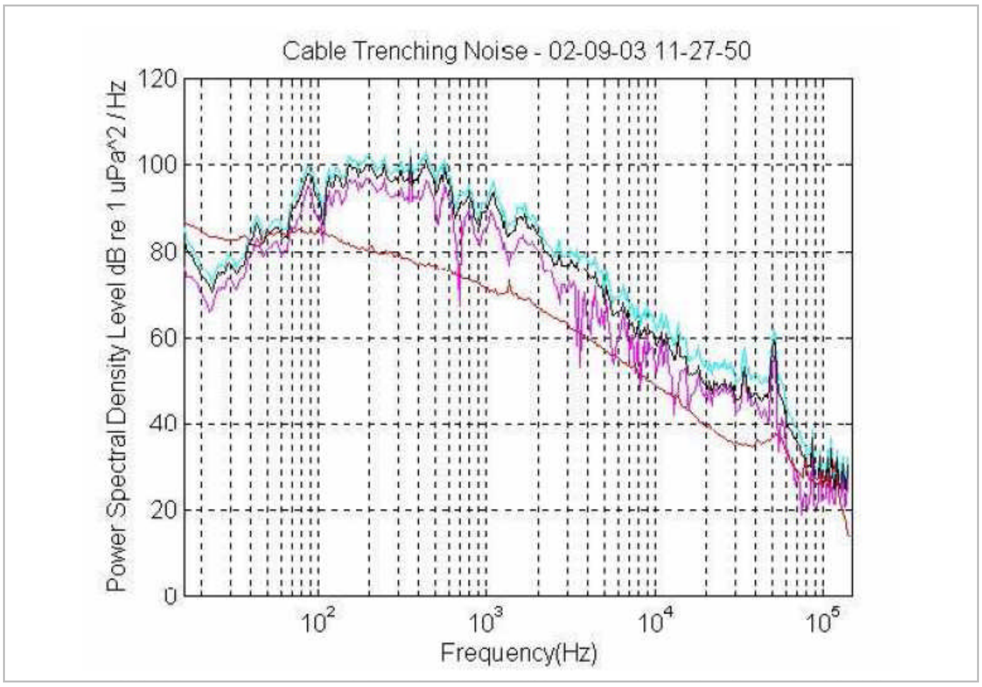


Fig. 21 The power spectral density of the cable trenching noise shown in Fig. 20; the brown line indicates the mean background noise level (from NEDWELL ET AL. 2003).

NEDWELL ET AL. (2003) also undertook measurements of ambient noise at different localities in British coastal waters. It was found that there was little variability in the level of noise at frequencies of about 2 kHz to 100 kHz and that this band corresponded to wind and wave-generated noise. At frequencies below 1 kHz the authors observed significant variability in levels and postulated the noise to be due to shipping movements.

3.1.3.2 Impact of noise on fauna

Depending on the hearing ability of a species both the perception and the effect of anthropogenic sound emissions varies. It seems a general rule that fish are low frequency hearers whereas marine mammals hear at high frequency. Also the view is taken that most marine species have high thresholds of perception of sound, this means they are relatively insensitive to sound (NEDWELL ET AL. 2003). Nevertheless, sufficiently high levels of sound on the dB_{ht} (species) scale are likely to cause avoidance reaction or damage in the hearing abilities of species. Often it is distinguished between acute and chronic effects, with acute effects including immediate auditory damage and chronic effects being, for example, behavioural effects. Other authors differentiate between primary effects (= immediate or delayed fatal injury), secondary effects (= injury or deafness, which may have long-term implications for survival) and tertiary effects (= behavioural effects, avoidance of the area).

A classification of avoidance reaction in fish related to sound was proposed by NEDWELL ET AL. (2003) (based on measurements of fish avoidance of noise reported in NEDWELL ET AL. 1998) (Tab. 5).

Tab. 5 Classification of avoidance reaction in fish proposed by NEDWELL ET AL. (2003).

Sound level	**Avoidance reaction in fish**
75 dBht (species)	mild
90 dBht (species)	significant
100 dBht (species)	strong

Compared to seismic surveys, drilling, pile hammering or military activities noise generation related to subsea cable projects may not be considered to have the greatest potential for harming marine fauna. For that reason only a few examples from the literature where this problem was discussed are to be found.

NEDWELL ET AL. (2003) investigated possible reactions of local fauna to noise created during **cable laying at North Hoyle**. Results of this analysis are illustrated in Fig. 22 (dB_{ht} levels of the noise as a function of range). According to what is seen in the graph marine mammals would perceive higher levels of noise during cable laying than the three fish species. Among the mammals bottlenose dolphin (*Tursiops truncates*) and harbour porpoise (*Phocoena phocoena*) perceive highest levels of noise. The salmon (*Salmo salar*) was the species least sensitive to sound. The authors admit that due to the high variability of the noise, no reliable estimates of source level or transmission loss could be made. However, they point out that, with one exception, all of the measurements were below 70 dB_{ht}, and hence below the level at which a behavioural reaction would be expected. For comparison, the authors state a perceived level of 53 dB_{ht} (perception of background noise level by harbour porpoise at North Hoyle) to correspond to the level of background noise that humans would perceive in a noisy office environment (NEDWELL ET AL. 2003).

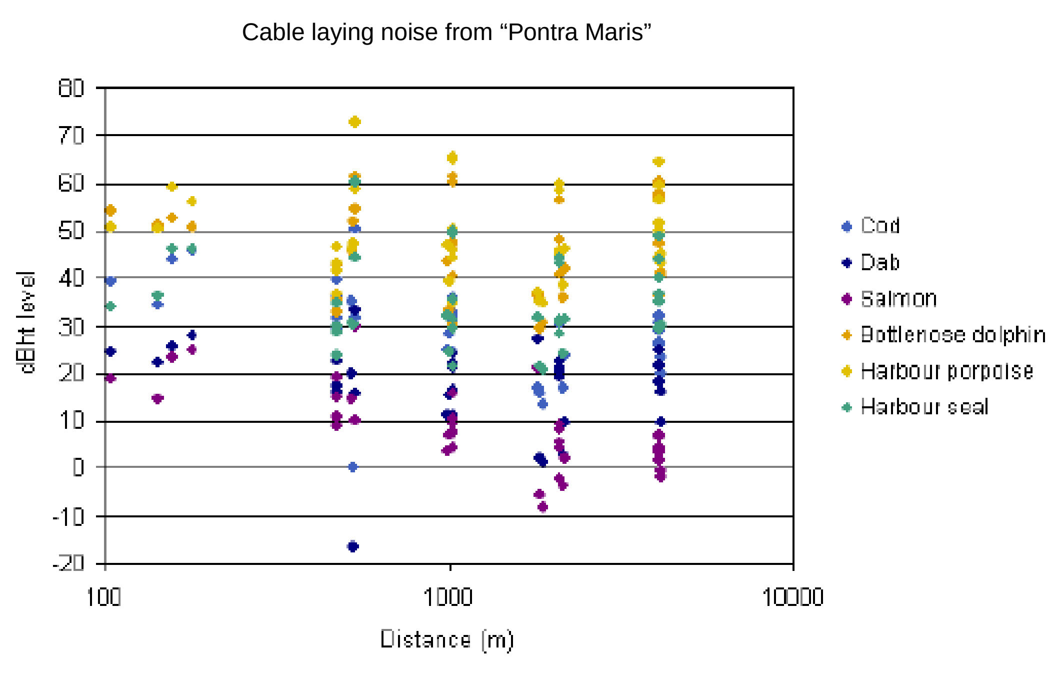


Fig. 22 dB_{ht} values for six species as a function of range, for cable trenching at North Hoyle (from NEDWELL ET AL. 2003).

For the **Basslink cable project** temporary and localised noise and acoustic impacts on Australian salmon and marine mammals during construction were discussed (BASSLINK PTY LTD 2002). It was concluded that active avoidance of noise sources would be an expected response when the comfort level for hearing is exceeded but that no adverse effects are to be expected. It was not clear from the source what conclusion were based on in detail.

Sakhalin II Phase 2 Project, an integrated oil and gas project in Russia´s Far East, also investigated noise impacts from the construction phase of pipelines and cables (SAKHALIN ENERGY INVESTMENT COMPANY 2005). Focus was laid on the possible impacts on grey whales migrating through the project area and using it as feeding grounds. It was anticipated that noise from pipeline/cable installation could block spring northward migration to feeding areas and result in disruption of feeding. If feeding was disrupted for a sufficiently long period of time, the condition of many individuals could have been adversely affected, leading to population-level impacts. Such impact was assessed being of major significance. Proposed mitigation measures were scheduling activities, daily aerial surveys, suspension of activities, ramp up and additional precautions in low visibility. Application of proposed mitigation measures was expected to minimise the anticipated impacts to a moderate level. The number of whales finally observed avoiding the area in which noise levels were greater than 120 dB was never higher than five and the actual noise thresholds that defined action criteria were not reached during installation. Project reports accessible for the general public at the time of writing this literature review did not provide any more information about the setup of field studies and their results in detail.

One chapter of the environmental and social impact assessment process of the same project (Sakhalin II phase 2 project) deals with dredging and disposal in Aniva Bay (SAKHALIN ENERGY INVESTMENT COMPANY 2005). Among other things noise levels during dredging are discussed. Since dredging activities may occur in connection with cable installation or removal a short summary of the results of this study is given. It was found that recorded noise levels for large cutter suction dredgers were higher than those associated with grab dredgers. Broadband noise data for the large cutter suction dredger *JFJ de Nul* are given as 183 dB/1 Pa at 1m. The authors compare this result with data from measurement of two other suction dredgers, the *Aquarius* and the *Beaver Mackenzie*, published by NEDWELL & HOWELL (2004). Their octave band spectra peaked between 80 and 200 Hz, with the *Aquarius* having the higher of the two spectra peaking at approximately 177 dB re 1 µPa. In the 20-1000 Hz band, the *Beaver Mackenzie* and the *Aquarius* were measured to have a 133 dB re 1 µPa level at 0.19 km and a 140 dB re 1 µPa level at 0.2 km respectively. SAKHALIN ENERGY INVESTMENT COMPANY (2005) assumes that acute damage to fish caused by sound does not occur below about 160 dB/1 Pa. The same authors further state this noise level to be highly unlikely to be generated during grab dredging, even when dredging through partially consolidated rock. Noise levels as high, or higher, than 160 dB/1 Pa could not precluded to be generated in close proximity to the cutter suction dredger. The authors conclude potential acute damage to fish would only be likely to occur up to 100 m of the cutter head and probably at a distance significantly less than this. The impact of generated sound pressure levels in association with the Sakhalin II project on resident fauna is certainly difficult to assess on the basis of unweighted sound pressure levels alone and might be not reliable.

In the draft environmental impact statement for the **North Pacific Acoustic Laboratory** (NPAL) prepared by the OFFICE OF NAVAL RESEARCH (2000) potential increases in ambient noise due to the placement of a small low-frequency sound source including the installation and / or removal of a power cable were investigated. Analysis of the potential effects on marine mammals was accomplished with results of the California and Hawaii ATOC Marine Mammal Research Programs (MMRPs) and a comprehensive program of underwater acoustical modelling (these sources were not available to the authors of this literature review). The biological environment potentially affected by the project included marine mammals, sea turtles, and fish. In conclusion of the study, no overt or obvious short-term changes in behaviour, abundance, distribution, or vocalizations in the marine mammal species studied (fin whale, sperm whale, dwarf and pygmy sperm whales, Blainville's beaked whale, Cuvier's beaked whale, short-finned pilot whale, fasle killer whale, melon-headed whale, Risso's dolphin, rough-toothed dolphin, bottlenose dolphin, striped dolphin, spotted dolphin, spinner dolphin) was observed. Only humpback whales near Kauai had a minimal chance for disturbance of a biologically important behaviour (percentage of 0.01 of the population at 120-180 dB, transmission duration of one day; no temporary threshold shift effects). For all sea turtle species of the area the potential for short-term behavioural disturbance or displacement was considered unlikely. No significant response was observed in rockfish at received levels up to 153 dB. Sharks were expected to be initially attracted to low frequency, pulsed sounds emitted by the NPAL source transmissions, but it was anticipated that their attractiveness would decline over a period of time, given that the transmission characteristics would be relatively constant at a duty cycle of 2- 8 percent. Thus, it was considered unlikely that NPAL sound transmissions would cause any measurable behavioural disruption to the indigenous fish species..

A factor not addressed in other studies but in the Vancouver Island transmission reinforcement project (JASCO RESEARCH LTD 2006) is **vibration of cables**. The new 230 kV submarine cables were expected to produce 120 Hz tonal vibration noise in the water, since Coulomb forces between the conductors would cause the high voltage AC lines to vibrate at twice the frequency of the current. The authors could not predict precise noise levels that would be generated by the new 230 kV cables since their electro-acoustic transfer characteristics were unknown. However, on the basis of reasonable assumptions, the acoustic source level of the new submarine cables was assumed not to be higher than that of the existing cables. Low level tonal noise from the existing 138 kV transmission lines was measured in Trincomali Channel during a very quiet period of recording: the sound pressure level at a distance of approximately 100 m from one of the cables was just under 80 dB re µPa

(Fig. 23). Thus, assuming cylindrical spreading of sound (which is the appropriate spreading law for a line source) the source level of the existing submarine cables was approximately 100 dB re µPa@1m (JASCO RESEARCH LTD 2006). Hence, anticipated sound pressure levels arising from the vibration of cables during operation are significantly lower than sound pressure levels that may occur during cable installation.

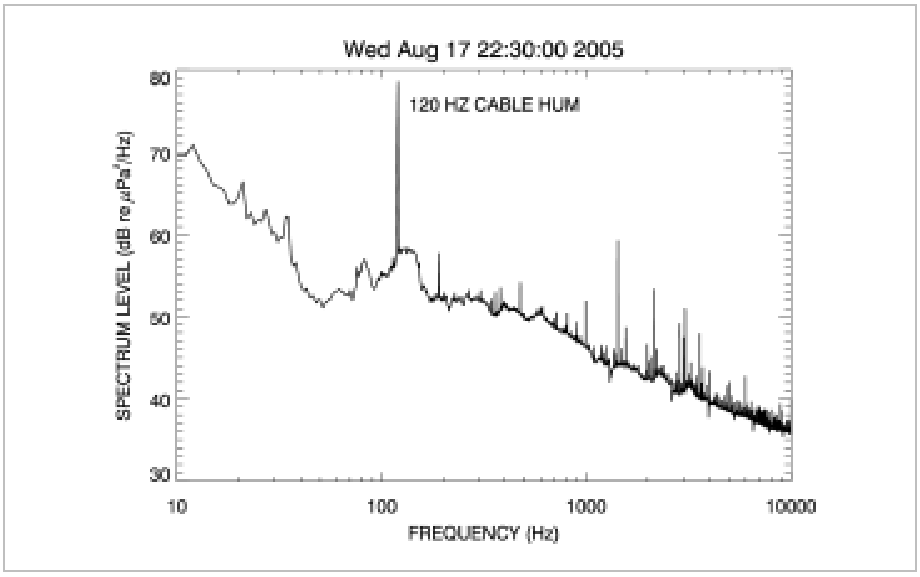


Fig. 23 Results of field measurement at a 138 kV submarine cables in Trincomali Channel (Vancouver Island Transmission Reinforcement Project). Spectrum of 120 Hz tonal noise versus frequency recorded ~100 metres from the proposed cable (JASCO RESEARCH LTD 2006).

3.1.4 Conclusions in regard to noise impacts

There are only few information on potential noise impacts due to the installation (or removal) and operation of subsea cables. That situation is probably due to the fact that noise is obviously not regarded a key environmental issue in association with subsea cables by most environmentalists. Indeed, 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 what sound pressure levels to expect. Only one publication of recordings of noise emission 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 risks.

As the characteristics of sound emissions associated with subsea cables are not very well known the same problem applies to the perception of sound by marine fauna. Specific knowledge such as audiograms only exists for a very limited number of species. Without such knowledge on hearing ability the assessment of noise effects is almost impossible and will remain rather hypothetical or based on conclusion of analogy.

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 though it has to be stressed that there are significant gaps in knowledge in regard to both the characteristics of sound emissions and sound perception by fauna.

More information on noise emission in connection with offshore windfarming, gas and oil exploitation, marine sand and gravel extraction, as well as the anticipated impacts on the biological environment (marine habitats, benthic organisms, fish, marine mammals and birds) are available from the results of literature reviews published by the German Federal Agency for Nature Conservation (BfN) (BFN 2006).

3.2 Heat dissipation

3.2.1 Introduction

Heat emission from cables has only recently become an important issue in discussions of environmental impacts related to submarine cables. For example, the topic became a standard to be discussed in the scope of Environmental Impact Assessment studies for offshore wind farms and offshore cables leading to a number of publications on seabed temperature modelling (e. g. BRAKELMANN 2005a, BRAKELMANN 2005b, BRAKELMANN & STAMMEN 2005, OFFSHORE WIND TECHNOLOGY GMBH 2004, WORZYK & BÖNGELER 2003). From the publications it can be concluded that important factors determining the degree of temperature rise are cable characteristics (type of cable), transmission rate, sediment characteristics (thermal conductivity, thermal resistance etc.), ambient conditions (currents, ambient temperature etc.). Potential risks related to seabed temperature rise due to the operation of power cables was also discussed at an international expert workshop on experiences on the assessment of ecological impacts of offshore wind farms held in Berlin in 2005 (see MEIßNER & SORDYL 2006a).

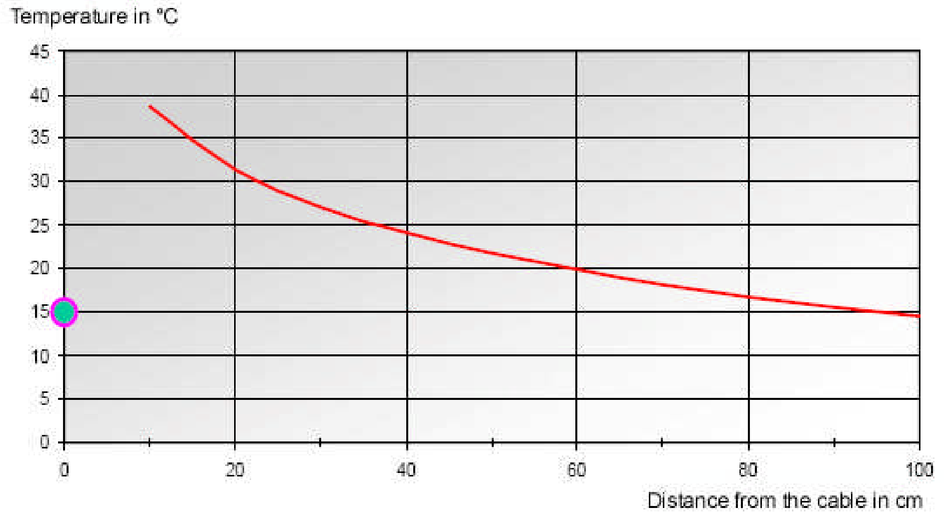
Discussing heat dissipation from offshore cables, focus can certainly be laid on high and medium voltage power transmission cables. Transmission capacity of power cables powering repeaters of telecommunication cables (see chapter 2.1.1) is comparably low and heat emission by them is supposedly negligible.

A recent update of information on ecological aspects of heat emission from power cables was by MEIßNER & SORDYL (2006b) and MEIßNER ET AL. (in press). Information available at that time was first of all results obtained from sediment temperature models for power cables of offshore wind farms. Also, results of field studies dealing with thermal pollution of coastal waters caused by heated effluents from power plants as well as studies on climate change were considered relevant. Results of the article shall only be briefly summarized here (for details see MEIßNER & SORDYL 2006b):

1. Based on theoretical models predicting sediment temperatures in the vicinity of power cables in German coastal waters and the EEZ, the guideline proposed by the German Federal Agency of Nature Conservation (BfN), that the temperature rise above the buried cable in 0.2 m sediment depth should not exceed 2 K, can usually be followed if a cable burial depth of 1 m is realized (e.g. see Fig. 24).
2. Models also predict that sediment temperature in greater depths closer to the cable will be much higher and temperature rise might even exceed 30 K directly at the cable.

3. As transmission losses are high for HVAC-cables compared to HVDC-cables (Deutsche WindGuard GmbH 2005), heat dissipation during cable operation can be expected to be more significant for AC-cables than for DC-cables at equal transmission rates.
4. Changes of physico-chemical conditions in sedimentary substrates (e. g. alteration of redox, O_2, sulfid profiles, changes of nutrient profiles), increase in bacterial activity, changes in distribution of faunal and floral elements (abundance of single species, population structure, faunal composition etc.) are conceivable effects of continued heat emission. As the absence of water movement (e.g. currents), high ambient temperatures, low thermal conductivity and high thermal resistance of the sediment promotes temperature increase in the seabed effects might be most severe in areas with stratified or small water bodies, in seabed sediments with high organic contents, or in tidal areas during low tide at high ambient temperature.

The authors pointed out that verification of these conclusions by field measurements and research is urgently required.



seabed temperature 14.7 °C (summer)
burial depth 1 m
thermal resistivity 0.7 Km/W
cable temperature (surface) 51.1 °C

Fig. 24 Example for modelling of seabed temperature in the vicinity of a medium voltage AC transmission cable in an offshore windpark with high production capacity (Poehler 2006).

3.2.2 Project-specific assessments on heat generation

The OFFSHORE WIND TECHNOLOGY GMBH (2004) investigated thermal dispersion around cables of a **wind farm in the German Bight, North Sea**, buried at 3 m depth. Preconditions considered for calculations of heat generation were a thermal resistance of the seabed of 0.5 $mK*W^{-1}$ (sand, Wadden Sea) and a thermal production of the cable of 23.8 $W*m^{-1}$. The authors predict a relative temperature increase of about 0.37 K at 0.30 cm sediment depth if full cable capacity is considered.

A study by WORZYK & BÖNGELER (2003) investigates sediment temperature rise in the vicinity of cables connecting turbines and transformer station at a proposed **wind farm site in the German EEZ**. Preconditions for their calculation model included a cable burial depth of 1 m, a sediment temperature of 6 °C, a turbine capacity of 4.5 MW, and turbines running at full capacity. Based on the results from that study, a sediment temperature of 11.6 °C is expected in 0.5 m sediment depth above a cable connecting five consecutive turbines with the transformer station. In case of emergency, the temperature could increase to up to 30 °C according to their calculations.

Heat generation during cable operation was briefly discussed for the **monopole HVDC Basslink subsea cable** crossing the Bass Strait in Australia (NATIONAL GRID 2000). The external surface temperature of the cable was calculated to reach surface temperatures of about 30 - 35 °C. The seabed surface temperature directly overlying the cable was expected to rise by a few degrees Celsius at a burial depth of 1.2 m. Unfortunately in documents currently available from the project website no further detailed information on heat generation can be found. Heat generation as an environmental issue in connection with the Basslink project is also discussed on the webpage of the Tasmanian Fishing Industry Council (TFIC) by A. May (MAY 2002). May is worried about heat generation by the return cable which from her point of view might produce significant heat over a greatly extended area of seabed because of its large resistance. The author also criticizes that no specific values for heat generation and associated impacts were provided in the various project reports.

The **high voltage subsea cable system** installed **in the Long Island Sound** from the mainland of New York to Long Island (USA) included a thermal backfill of the cable trench (GRZAN ET AL. 1993). The subsea cable system comprised of four self-contained, fluid-filled (SCFF) cables and two submarine type fiber optic cables. A 150 m cable separation and a 3 m embedment depth were selected. The cables were covered with 30 cm of thermal backfill, a 10 cm reinforced concrete slab and 12.7 mm steel plate. Purpose of the thermal backfill was to limit conductor temperature to 85 °C in normal continuous operation. The use of thermal backfill material instead of local sediment may indicate that high seabed temperatures were expected in the vicinity of the cable and specific measure had to be applied to guarantee undisturbed cable operation. Thermal backfill material was only specified for the terrestrial part of the cable route. A calculation of ambient temperatures in the seabed was not presented.

3.2.3 Field measurements of seabed temperature in the vicinity of power cables

Field measurements of seabed temperature near power cables were so far only published from Nysted offshore windfarm (Denmark, Baltic Sea). Measurements were conducted by the Institute of Applied Ecology Ltd (IfAÖ Ltd) and first published at the conference "Meeresumweltsymposium" in Hamburg, Germany in 2006 (contents of the oral presentations will be available as written articles in the conference proceedings, MEIßNER ET AL. in press). Seabed temperature was measured in the vicinity of the 33 kV and 132 kV power cables at defined distances from the cable. A sketch of the cable grid of Nysted offshore wind farm is shown in Fig. 25. The wind farm consists of 72 turbines, each with a capacity of 2.3 MW. The turbines are placed in eight north-south oriented rows, nine turbines are interconnected in each row. The most northerly turbine in each row is connected to the transformer platform located on the northern boundary of the wind farm area. From here the wind farm is linked to the shore by a 132 kV AC cable. The park-internal cable grid consists of 33 kV AC cable lines. All cables are buried into the seabed. The targeted cable burial depth of 1 m could not be realized consistently.

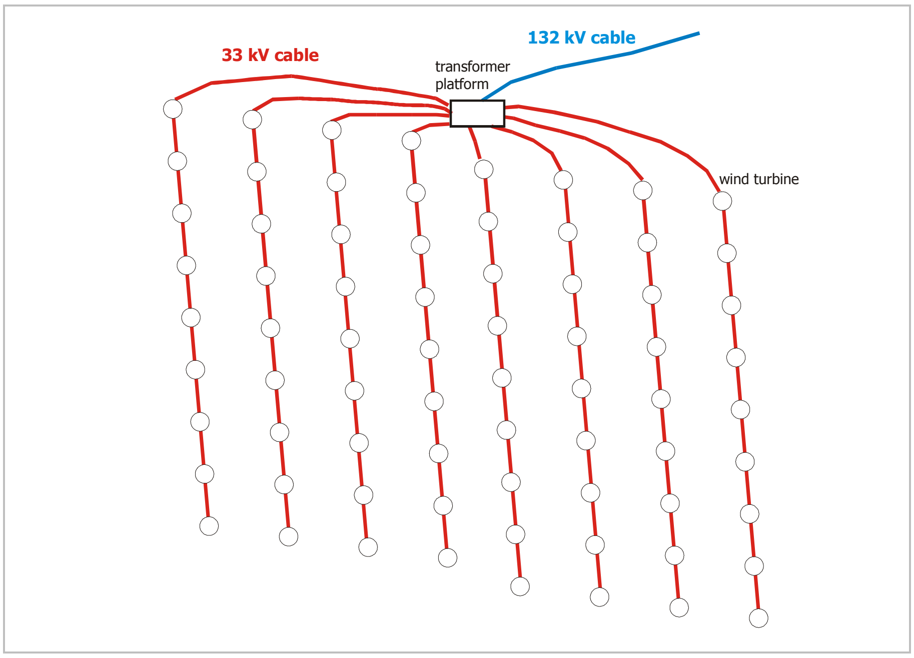


Fig. 25 Schematic drawing of cable layout at Nysted offshore wind farm (Baltic Sea, Denmark).

The two sites of measurement were both in close vicinity to the transformer platform (at a distance less than 30 m). Recording equipment included two sets of instruments, each comprising two titanium poles equipped with 16 PT100 thermosensors (T1 to T32) spaced at intervals of 10 cm (Fig. 26 left). The poles were deployed parallel to each other so that one pole was exactly perpendicular to the centre of the cable and the second pole 30 cm to the side (Fig. 26 right). T32 was the sensor closest to the cable.

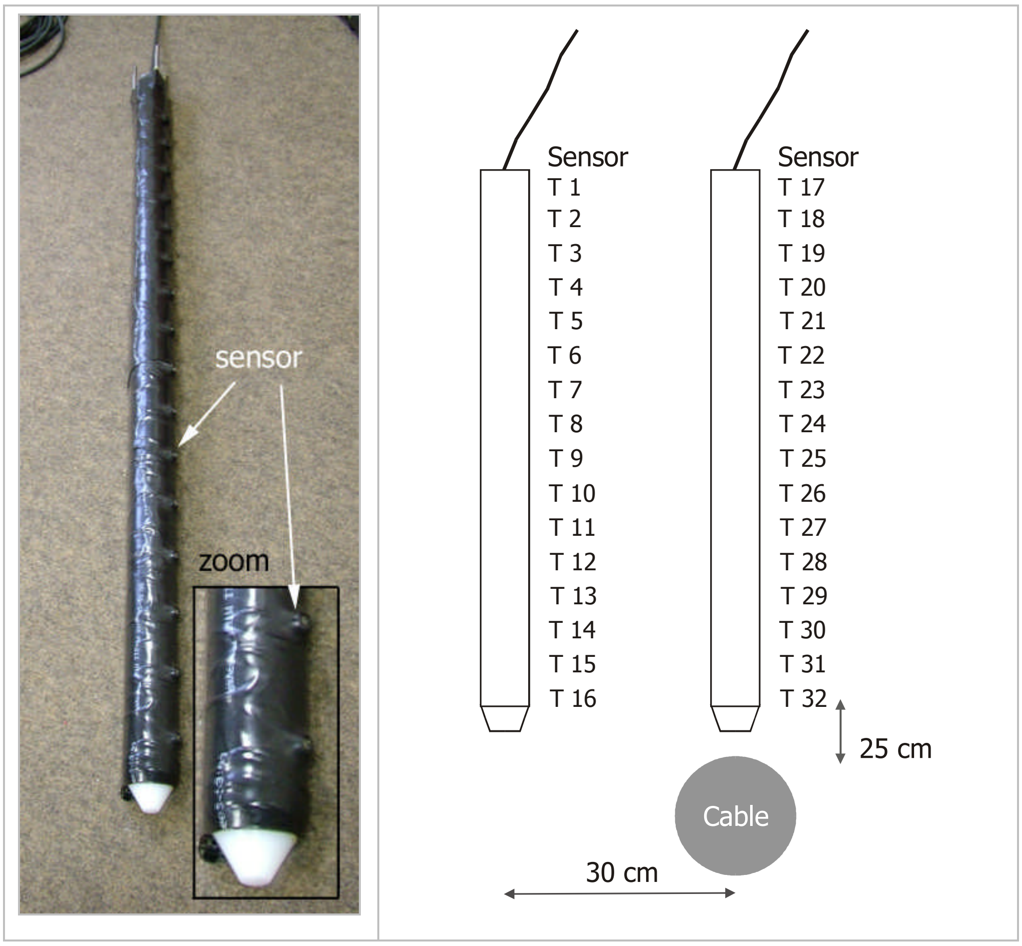


Fig. 26 Equipment for measurements at Nysted: titanium pole with 16 thermosensors spaced at intervals of 10 cm (left), schematic drawing of experimental setup in the field (right).

It was found that seabed temperature was generally higher at the 132 kV cable than at the 33 kV cable (Fig. 27). The highest temperature recorded closest to the cable (sensor T32) between March and September 2005 was 17.7 °C (132 kV cable, 16 July 2005).

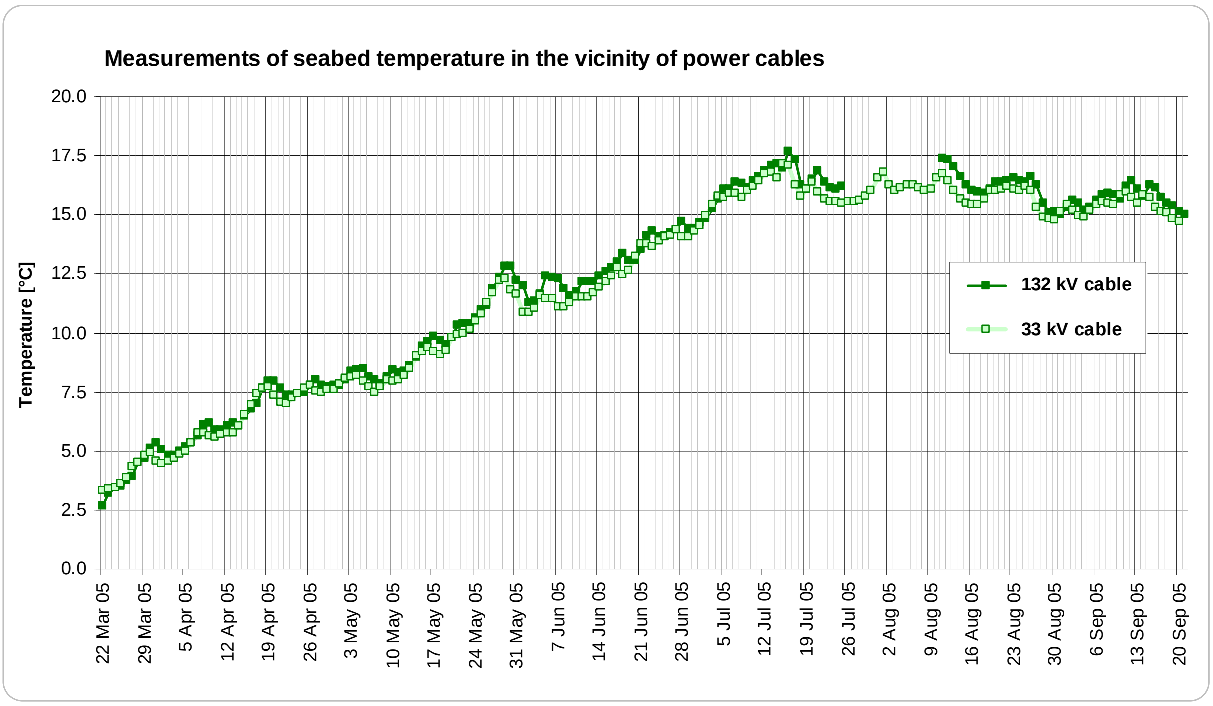


Fig. 27 Comparison of seabed temperatures recorded at Nysted offshore wind farm in 2005 in vicinity to the 132 kV cable and the 33 kV cable, shown are data collected by sensors closest to the power cable (T32); data loss in August 2005.

From September 2005 till March 2006 seabed temperatures at the 132 kV cable could be compared with seabed temperatures at a control site (unaffected by heat emission): seabed temperatures at the cable were higher at any time during this period (Fig. 28). The maximum difference between sensor T32 and the control site was 2.5 K (26.10.2006, measured in adequate depth below seabed), the mean difference was less than 1 K (0.8 K). All temperatures recorded by IfAÖ Ltd in Nysted offshore windfarm at the 26th Oct 2006 are listed in Tab. 6.

A second result of the seabed temperature recording was that temperatures varied significantly close to the cable whereas seabed temperatures at the control site changed more smoothly. Seabed temperature was positively correlated with power production and water temperature (Fig. 28).

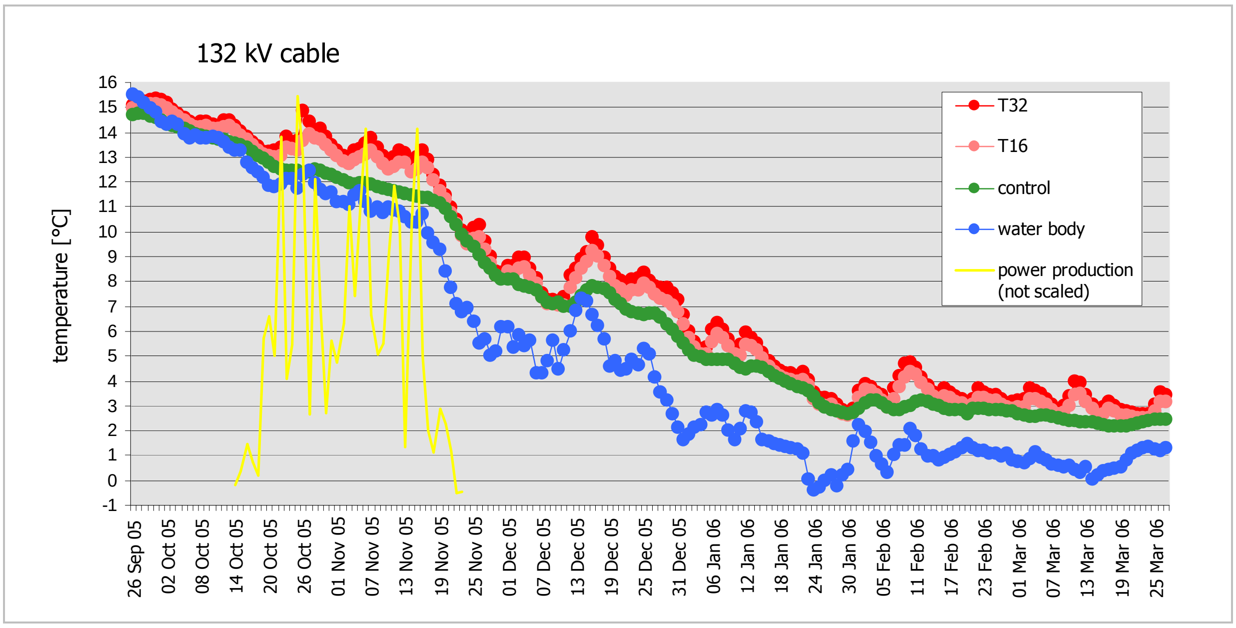


Fig. 28 Measurements of seabed temperature from Sep 2005 until Mar 2006 at the 132 kV cable at Nysted offshore wind farm: shown are data recorded by sensors T32 and T16 (see Fig. 26), seabed temperature at a location unaffected by heat emission, and temperatures measured in the water body. In addition, power production of the wind farm is illustrated for a short period of time (not scaled).

Tab. 6 Temperatures recorded at the 26th Oct 2006 (date of maximum difference of seabed temperature between the affected site in vicinity of the 132 kV cable and the control site) at Nysted offshore windfarm by IfAÖ Ltd.

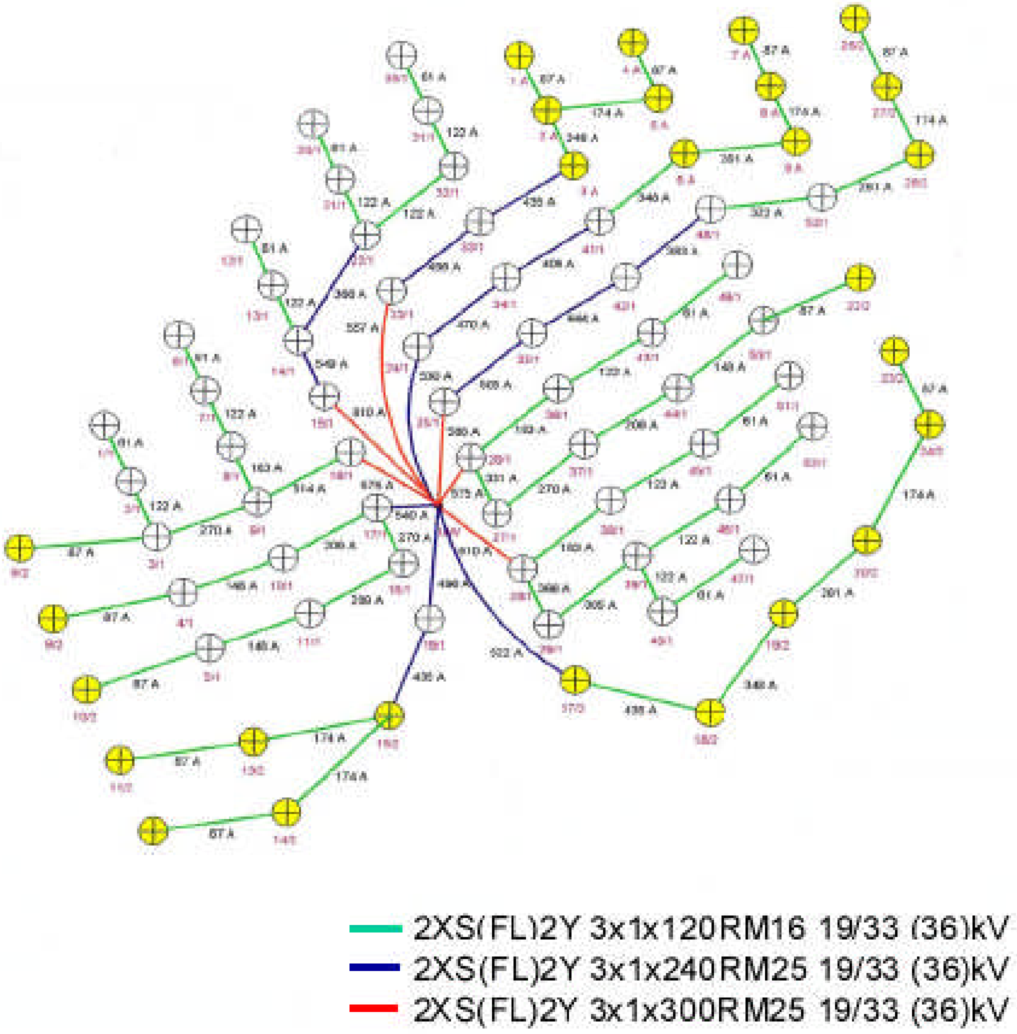
	depth below seabed	132 kV cable		reference	Δ T max
		perpendiclear above the cable	**30 cm to the side**		
seabed	**50 cm**	14.8	13.6	12.3	2.5
	40 cm	14.6	13.2	12.3	2.3
	30 cm	14.4	12.9	12.2	2.2
	20 cm	13.5	12.6	12.1	1.4
	10 cm	12.5	12.4	12.2	0.3
	0 cm	12.1	12.2	12.3	-0.2
water body		12.1	12.2	12.4	

Since temperature rise in the seabed also depends on ambient conditions (e. g. sediment characteristics) it also has to be mentioned that sediment at the measurement sites was relatively coarse. Grain size analysis revealed d50 values (grain size median) of 310 – 390 µm (medium sand). Compared to fine sand or mud, coarser sediment types rather favour heat abduction into the water body than keeping it back in the seabed (Tab. 7).

Tab. 7 Thermal resistance of different types of marine sediment (after different authors).

Sediment type	**Thermal resistivity [K*m/W]**
Gravel	0.3 – 0.5
Sand	0.4 – 0.7
Sand (Wadden Sea)	0.5
Fine sand	0.7
Clay	0. 6 – 1.1
Till and lag sediments	0.3 – 0.4
Mud	0.5 – 0.7

For evaluation of the results it should also be referred again to the comparatively low production capacity of Nysted offshore wind farm (166 MW). However, grid layout and cable parameters also play an important role for increase of seabed temperature in vicinity to the power cables. For example, with increasing transmission capacity the potential heat emission increases too. Also, conductor diameter is decisive: the thicker the conductor the lower the conductor temperature at a constant transmission rate and hence, heat emission of the cable. Since the conductor diameter also strongly influences the costs of the cable, conductor diameters are aimed to be kept as small as possible within the limits of technical requirements. As a result, cable parameters may differ within the wind farm grid (Fig. 29).



2XS(FL)2YRAA 3x1x120RM16 19/33kV
Imax = 377A (21,5MVA)*
Ikc = 17,5kA 1s, 31,7kA 0,3s
D= 104mm
G= 16,1t/km

2XS(FL)2YRAA 3x1x240RM25 19/33kV
Imax = 549A (31,4MVA)*
Ikc = 34,7kA 1s, 63,3kA 0,3s
D= 118mm
G= 21,6t/km

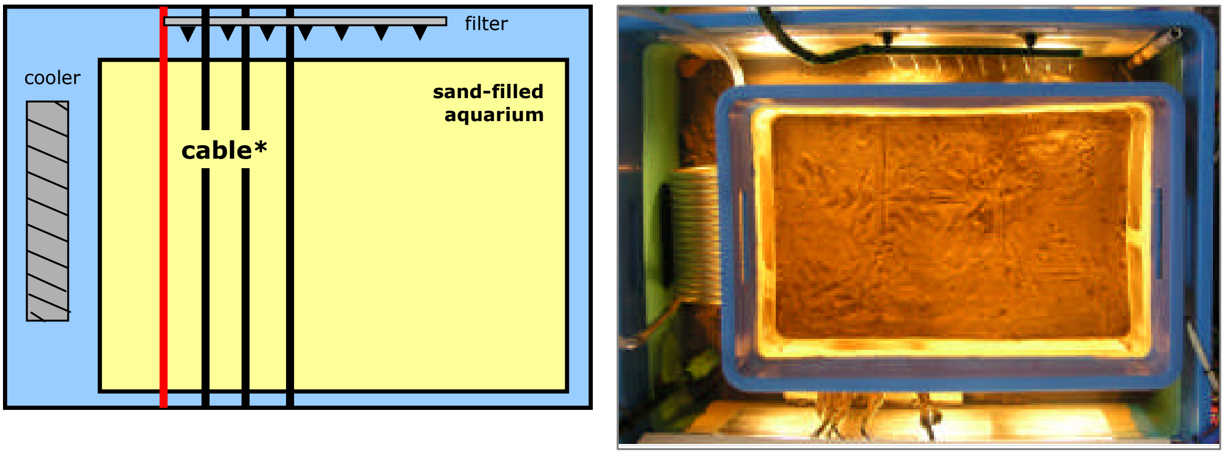
2XS(FL)2YRAA 3x1x300RM25 19/33kV
Imax = 610A (34,9MVA)*
Ikc = 43,4kA 1s, 79,2kA 0,3s
D= 123mm
G= 23,8t/km

Fig. 29 Potential grid layout for a wind farm with high production capacity, with information on cable specifications (POEHLER 2006)

3.2.4 Laboratory studies

In a laboratory study the **effects of heat emission** into the sediment **on the distribution of two benthic species** occurring in coastal waters of the Southern Baltic Sea, the mud shrimp *Corophium volutator* and the polychaete worm *Marenzelleria viridis,* was investigated (Fig. 30) (BORRMANN 2006). Both species build tubes into the sediment. The tubes of *C. volutator* do not penetrate as deep into the sediment as those of *M. viridis*. The mud shrimp also spents more time outside the tube on the sediment surface whereas *M. viridis* spents most of the time inside the tube. Individuals were kept in aquaria with sediment from their natural habitats and seawater which was constantly cooled. After an adaptation period of several days a horizontal temperature gradient was generated in the sediment (Fig. 31). A comparison between the distribution of individuals / tubes at the start of the experiment (no temperature gradient) and after 7 d of exposure to heated sediment was made.

Fig. 30 Benthic species investigated by BORRMANN (2006): mud shrimp *Corophium volutator* and spionid *Marenzelleria viridis*.



*cable employed to heat sediment; red cable to the left with highest temperature, next three cable to the right with stepwise lowered temperatures

Fig. 31 Experimental setup for laboratory studies conducted by BORRMANN (2006) to investigate effects of heat emission into the sediment on the distribution of the mud shrimp *Corophium volutator* and the polychaete worm *Marenzelleria viridis*: schematic drawing (left) and view from above (right).

Results are shown in Fig. 32. BORRMANN (2006) concluded that distribution of the mud shrimp *C. volutator* was not correlated with the temperature gradient in the sediment. For the polychaete *M. viridis* the tendency to avoid areas with highest temperatures in the sediment was postulated. After 7 d of exposure most individuals and tubes were found in the right part of the aquarium where temperatures were lowest. Twenty hours after the start of the experiment first significant “movements” of the worms away from the heated area were observed. Whether these results can be directly applied to field conditions has to be examined.

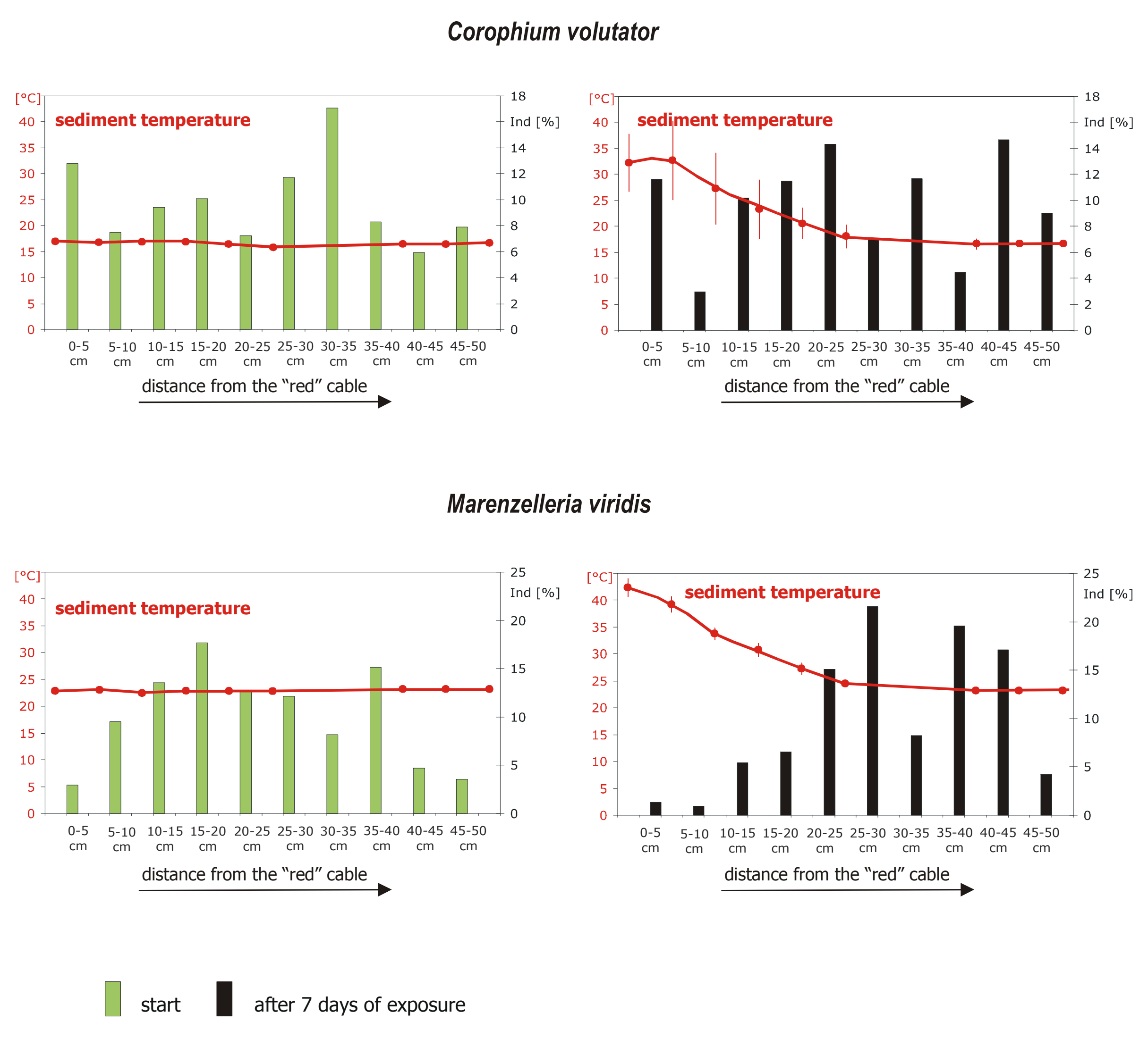


Fig. 32 Results of laboratory studies investigating effects of heat emission into the sediment on the distribution of the mud shrimp *Corophium volutator* and the polychaete worm *Marenzelleria viridis*.

Another laboratory study investigated **effects of inverse temperature gradients on the biogeochemical circular flow in natural sediments** (PROKOP 2006). The assumption was that the artificial temperature gradient would influence natural processes in marine sediments. The experimental setup is illustrated in Fig. 34. Incubation time for sediment cores of different sediment types (sand with 2 – 7 % organic dry weight) was between 9 and 14 days. Parameters investigated were O_2, redox parameters, NH_4^+, phosphate, sulphide, DOC and microbial activity (FDA, α/β glycosidase).

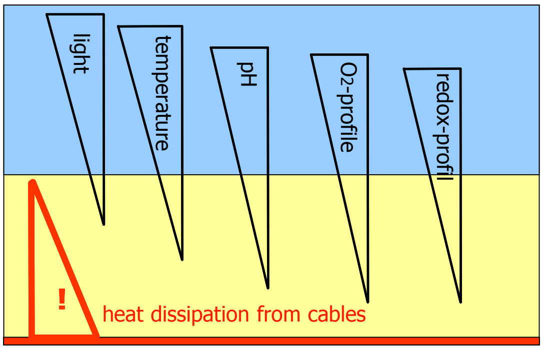


Fig. 33 Inverse temperature gradient in the seabed caused by heat emission from high voltage power cables.

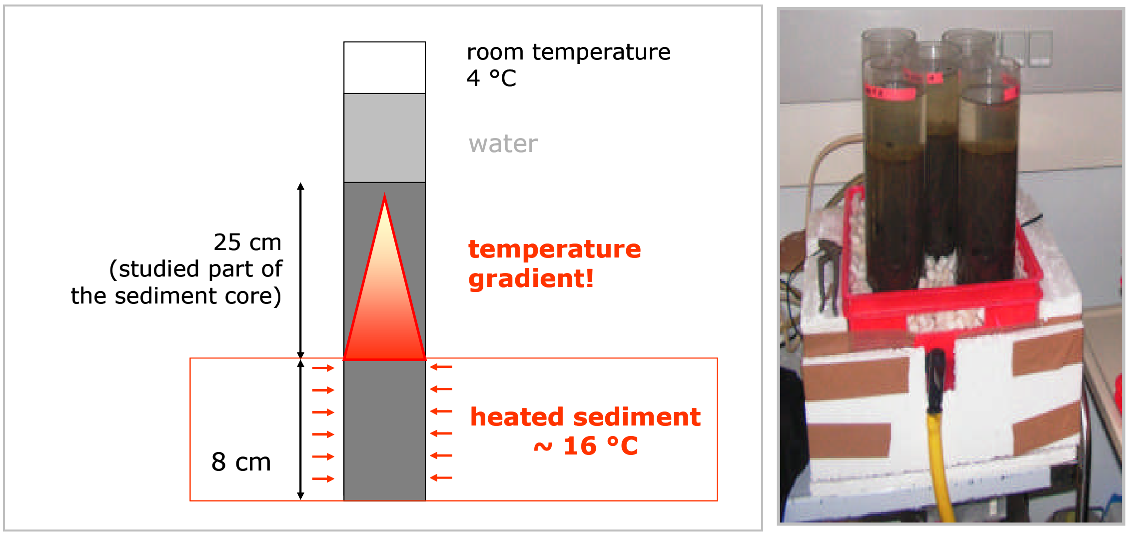


Fig. 34 Experimental setup for laboratory studies conducted by PROKOP (2006) to investigate the effects of an inverse temperature gradient on the biogeochemical circular flow in natural sediments; schematic drawing (left) and setup in the lab (right) (after PROKOP 2006).

Analysis of the results had not been finished at the time of writing, but first preliminary results of the study can be cited already (after PROKOP 2006):

1. increase in microbial activity at minor temperature increase of 0.5 K
2. increase in ammonium concentration in deeper sediment layers (Fig. 36), sulphide concentration decreases
3. O_2 and redox profiles were unchanged during incubation times examined

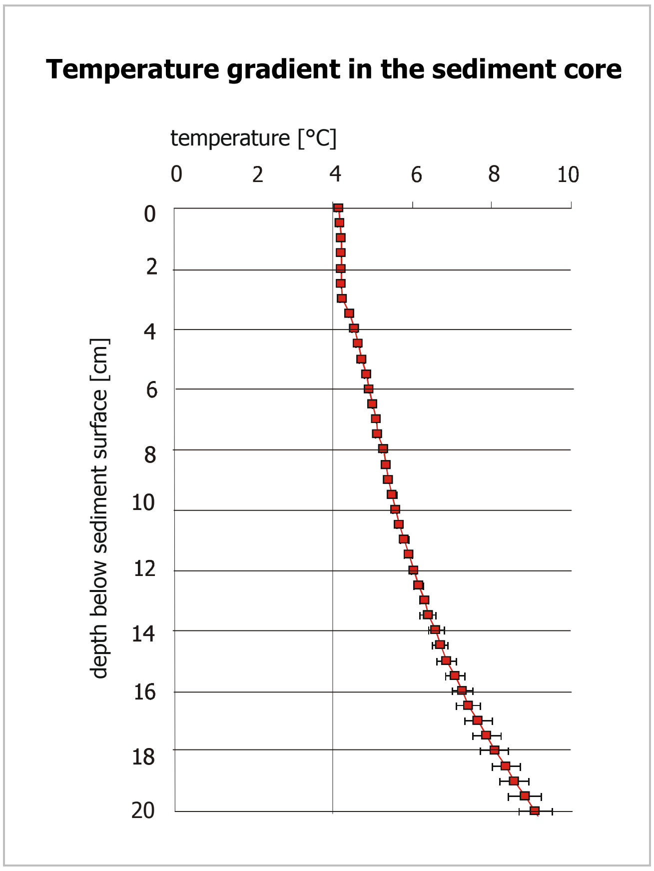


Fig. 35 Temperature gradient in sediment cores studied by PROKOP (2006).

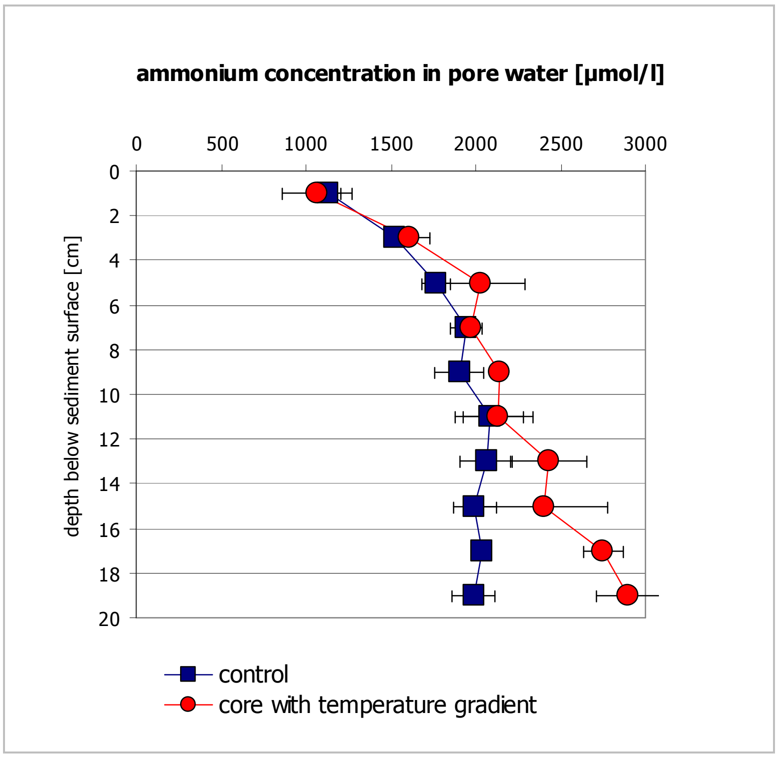


Fig. 36 Ammonium concentration in pore water of sediment cores with applied temperature gradient (PROKOP 2006).

Increase in microbial activity due to heat generation by power cables was also considered in a statement by the German Federal Office for Radiation Protection (BfS). Reviewing scientific articles on bacterial activity and natural aerobic / anaerobic processes in marine sediments the authors came to the conclusion that a temperature increase caused by heat dissipation into the seabed facilitates degradation of organic matter (BFS 2005).

3.2.5 Conclusions in regard to heat dissipation impacts

In regard to effects of heat dissipation apparent gaps in knowledge exist. A large number of publications about technical aspects of transmission losses is opposed to an almost negligible number of publications on ecological consequences of the heat release into the bottom of the sea. Calculations of seabed temperature in the vicinity of cables agree in their predictions of significant temperature rise in the vicinity of cables. Whether these predictions hold true under field conditions still has to be examined. The only field measurements published so far from Nysted offshore wind farm in Denmark (MEIßNER ET AL. in press) draw a different picture. The transferability of these results to other locations is however questionable. And even if the seabed temperature rise might not be as significant as predicted according to the different calculation models seabed temperature will be permanently higher compared to natural conditions (as long as the power cable is in operation) and highly variable. The effects of such artificially altered temperature condition on the bottom fauna are difficult to assess. Since the problem more or less has arisen with power transmission via subsea cables in the recent past the problem never really was in the focus of scientific studies. The amplitude of direct temperature effects on fauna, how organisms react to seabed temperature rise (avoidance reactions of any kind including emigration, attraction including immigration, changes in physiology, reproduction etc.), whether living conditions for the bottom fauna are altered on both short-term and long-term and so on, all these are questions to be asked and which cannot be answered at current.

Main purpose of the 2 K-guideline proposed by the German Federal Agency of Nature Conservation (BfN) for German waters was to avoid major direct temperature effects on benthic fauna. Standards set by this guideline can be met by appropriate burial depth. What is not covered by this guideline is alteration of biogeochemical circular flows in sediments. Processes set off in deeper sediment layers due to heat dissipation are likely to finally affect the entire seabed above the cable due to pore water contact. The solution of the problem by increasing burial depths is not guaranteed. Alteration of sediment chemistry is likely to exert secondary impacts on benthic fauna and flora. The here presented preliminary studies have indicated that effects on the marine environment, including fauna, have to be expected.

The investigation of effects of heat dissipation is urgently required. Impacts are most likely to be detected in shallow water areas, the Wadden Sea (especially during warm periods in summer) and areas with high organic content. Field measurements of seabed temperature in the vicinity of power cables as well as further laboratory and field studies are necessary to allow a well-founded assessment.

3.3 Electromagnetic Fields

3.3.1 Introduction

Another concern arising from subsea power cables is the occurrence of electromagnetic fields. First a short introduction to the technical background on electromagnetic fields is given followed by a review of information available on field strength related to submarine cables and their potential impact on marine life.

3.3.2 Technical background

Electric fields are produced by voltage and increase in strength as voltage increases. Hence, high voltage transmission potentially produces stronger electric fields than medium or low voltage transmission. **Magnetic fields** are generated by flow of current and increase in strength as current increases. Since the voltage on a power line remains more or less constant with time, changes to the power or load will result in changes to the current, and hence the magnetic field. Another aspect to be considered is the **induced electric field** generated by a magnetic field around a submarine cable.

Parameters of electromagnetic fields generated during power transmission strongly depend on the setup of the power transmission system. As already mentioned before (chapter 2.1.2), for DC transmission it is distinguished between monopolar and bipolar systems. Since monopolar system no longer meet environmental standards of most Western countries (in particular because of the electrolysis products and the occurrence of strong magnetic fields) they are the solution least favourable. For bipolar transmission different options are available. The first is to install two separate cables and operate them with opposite polarity. A second option is to use a bipolar two-conductor cable where a single cable includes both conductors for forward and return current. A bipolar two-cable system is more powerful than a bipolar two-conductor cable. DEUTSCHE WINDGUARD GMBH (2005) quotes a maximum tension of ± 400 kV for a two-conductor cable compared to ± 600 kV for a system with two separate cables. Maximum transmission capacity is 800 MW and up to 1 GW (in future development up to 2.5 MW), respectively. The system with higher capacities can potentially generate stronger electromagnetic fields.

The occurrence of electric fields can be controlled by application of shields (steel plates, sheaths within the cable insulating the conductor etc.), those of magnetic fields by cancellation (following certain conductor / cable placement patterns). For example, when using two separate single-conductor cables, they should be buried in the seabed parallel to and at the shortest distance possible from each other, so that the (electro)magnetic fields would neutralise each other. In a two-conductor cable this standard is fully met. In addition, here the two conductors lie within a common shield. With perfect shielding a cable does not directly generate an electric field outside the cable, however, as already mentioned an electric field is also induced by the presence of the magnetic field in the surrounding to the cable (KRAMER 2000, CMACS 2003).

For three-phase AC transmission same options as for DC transmission exist: either a three-conductor cable solution or three single conductor cables can be considered (DEUTSCHE WINDGUARD GMBH 2005). In a three-conductor cable each conductor is insulated separately, with the metal shield and outer insulation covering all three conductors in one. The electromagnetic field of the three conductors is almost neutralised at the surface of the cable, since the sum of the voltages and currents of the three phases is zero at any one time. Using three single conductor cables again they have to be installed as close as possible and parallel to each other to achieve sufficient field compensation.

While electric fields are readily attenuated by materials that conduct electricity (e.g., buildings, trees), magnetic fields pass through most materials (ACRES 2006). CMACS (2003) investigated the influence of the conductivity of cable sheathes and armour on the generation of electromagnetic fields and found that as the conductivity of the sheath and armour increased the resultant electromagnetic field strength outside the cable decreased. This indicates that using thicker sheaths or materials with higher conductivity values for the sheathing and armouring of submarine power cables can help to reduce the electromagnetic fields generated. Armouring material used for cables is, for example, steel wire or, alternatively, steel tape. The relative permeability μ_r of steel wire is about 300 whereas that of a steel tape is about 3000 (CMACS 2003). Hence steel tape would be the better option in regard to reduction of electromagnetic fields outside the cable.

For a subsea cables it was also investigated how cable burial affects field strength (CMACS 2003). It was found that magnetic fields were unaffected by burial as long as the sediment had non-magnetic properties. As the magnetic fields are unaffected by burial the induced electric fields will be unaffected to. However, as sea water has a higher conductivity than the sediment the induced electric fields will be higher in the sea water than in the surface sediment (Fig. 37). The authors suggest that although the burial of a cable will not effectively mitigate against magnetic fields and induced electric fields (if it is buried to the suggested 1 m depth) it is likely to reduce exposure of electromagnetically sensitive species to the strongest electromagnetic fields that exist at the ‘skin’ of the cable owing to the physical barrier of the substratum.

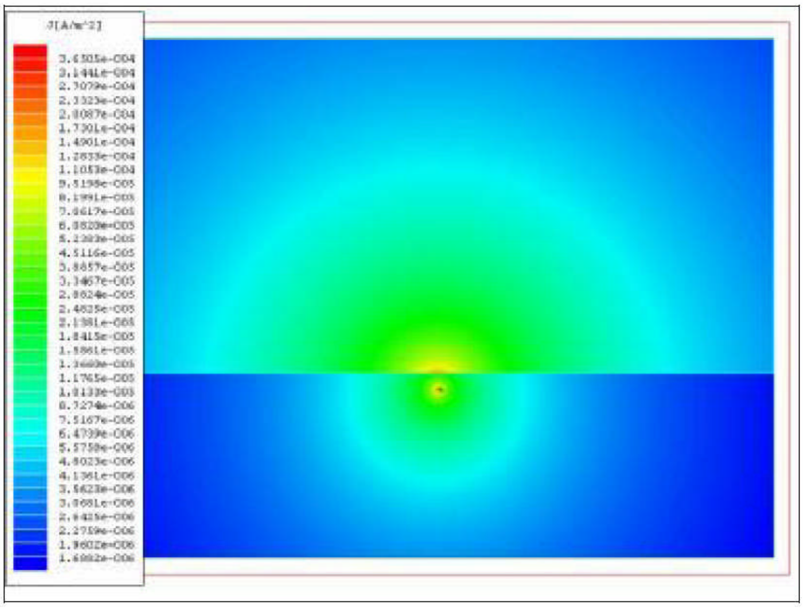


Fig. 37 Magnitude of current density outside a buried cable (from CMACS 2003).

The strength of both electric and magnetic fields rapidly declines as a function of distance from the cable. Magnetic fields are measured in microtesla (µT), another unit often used is milligauss (1 milligauss = 0.1 microteslas). Electric fields are measured in kV per meter (kV*m^{-1}). The geomagnetic field of the earth is approximately 50 µT. An electric field of about 25 µV*m^{-1} is regarded a natural ambient level in the North Sea (KOOPS 2000).

3.3.3 Strength of electric and magnetic fields in the environment of power cables

Information on strength of electric and magnetic fields in the vicinity of cables are available from either calculations or measurements. A few examples shall be given here.

According to KOOPS (2000) a **monopolar DC** transmission line carrying 1500 A produces a magnetic flux density of approximately 300 µT on the seabed above the cable, falling off to 50 µT at a distance of 5 m above the seabed, and 13 µT at 20 m above the seabed. Electric fields range from approximately 1 V*m^{-1} at a distance 10 cm from the cathode, to 0.07 V*m^{-1} at a distance 1 m from the cathode, falling to levels in the range 1 – 50 µV*m^{-1} far from the sea electrodes.

A 10 cm diameter monopolar HVDC cable carrying 500 A will induce a magnetic field of 2000 µT at the surface of the cable, 20 µT at a distance of 5 m, and 5 µT at a distance of 20 m (ACRES 2006). For two monopolar HVDC cables in British Columbia the same author calculated magnetic fields of up to 5000 µT produced at the surface of these cables, decreasing to about 50 µT (approximately equal to the Earth's geomagnetic field) at a distance of about 5 m. The maximum transmission values of these cables, operating at approximately 1200 A, are 312 MW at 260 kV and 370 MW at 280 kV, respectively (ACRES 2006).

According to calculations for Baltic Cable (monopolar DC transmission, 450 kV, 600 MW) weak electric fields (1 µV cm^{-1}) may occur at distances of up to 10 km from the electrodes. A direct current magnetic field occurs around the cable reaching up to 250 µT directly above the cable and decreasing to about 50 µT at a distance of 6 m. In addition, a magnetic alternating field may occur where sea cable and electrode cable run parallel. During high power transmission field strength is expected to reach 12 µT, at a distance of 5 m it should be as low as 1 µT (MATTHÄUS 1995). As reported by SÖKER ET AL. (2000) magnetic compasses show considerable deviations at the surface of the water directly above the Baltic Cable forcing ship traffic to be informed about the cable to avoid wrong navigation.

GRZAN ET AL. (1993) report about the installation of a 12.7 mm steel plate to limit above ground magnetic field to less than 2 mG milligauss (< 0.2 µT) for the underwater Long Island Sound cable (four 2,000 mm^2 SCFF cables, 345 kV).

The current state of knowledge regarding the electromagnetic fields emitted by **AC transmission lines** was summarised by CMACS (2003). Electric field strengths of magnitudes quoted as follows were calculated:

- sheathed three-phase 33 kV cable, conducting 50 A per phase at 50 Hz: 15 µV m^{-1} at a distance of 0 m, 4 µV m^{-1} at 5 m, and 1 µV m^{-1} at 20 m.
- sheathed three-phase 11 kV cable, conducting 60 A per phase at 50 Hz: 17.5 µV m^{-1} at a distance of 0 m, 12.5 µV m^{-1} at 5 m, and 6.2 µV m^{-1} at 20 m.

The same authors also investigated electromagnetic fields generated by a 132 kV XLPE three-phase submarine cable with both perfect and non-perfect shielding (AC, 350 A) through simulation by models. It was reported that no directly generated electric fields occur outside the cable in case the cable is perfectly shielded (conductor sheathes are grounded). However, magnetic fields generated by the cable will create induced electric fields outside the cable. The induced electric field is related to the current in the cable. Modelling predicted electric fields in seawater of around 91.25 µV m^{-1} above a cable buried to 1 m to be induced by magnetic fields. At 8 m distance in the seawater the electric field strength is approximately 10 µV*m^{-1}. The magnitude of the magnetic field in close proximity of the cable (i.e. within millimetres) is about 1.6 µT according to the simulations. A smaller current would proportionally produce a lower induced electric field, i.e. a cable current of 175 A will give rise to half the induced current density at 350 A and therefore half the induced electric field.

From simulations for the same cable with non-perfect shielding (poor grounding of sheathes) the occurrence of a directly generated electric field was predicted. The leakage electric field was stated to be smaller than the induced electric field. According to the authors again if the cable were operated at a lower voltage the electrical field results would need to be scaled. e.g. for a 33kV cable the scaling factor is 0.25 (CMACS 2003).

Calculation results were compared with data from field measurements of magnetic fields near both a 33 kV and an 11 kV cable. Near the 33 kV cable the magnetic field was measured as 50 nT. The field decreased with distance from the cable axis (Fig. 38). At 400 m from the cable the sensor picked up only noise (0.5 nT). The magnetic field from the 11 kV cable appeared to be more widely distributed than the 33 kV cable. The authors suggested that this may have been a consequence of the individually sheathed conductors.

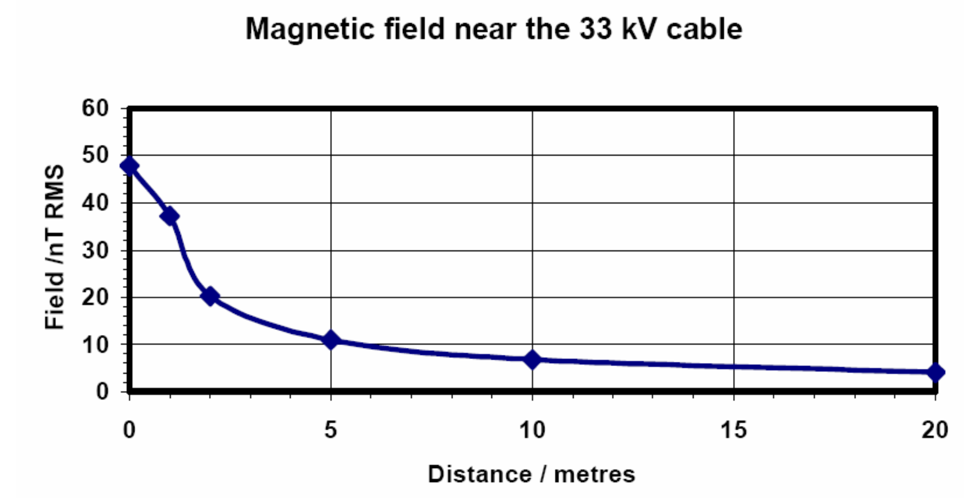


Fig. 38 Results of measurements with magnetic field sensors in the environment of a 33 kV cable (from CMACS 2003).

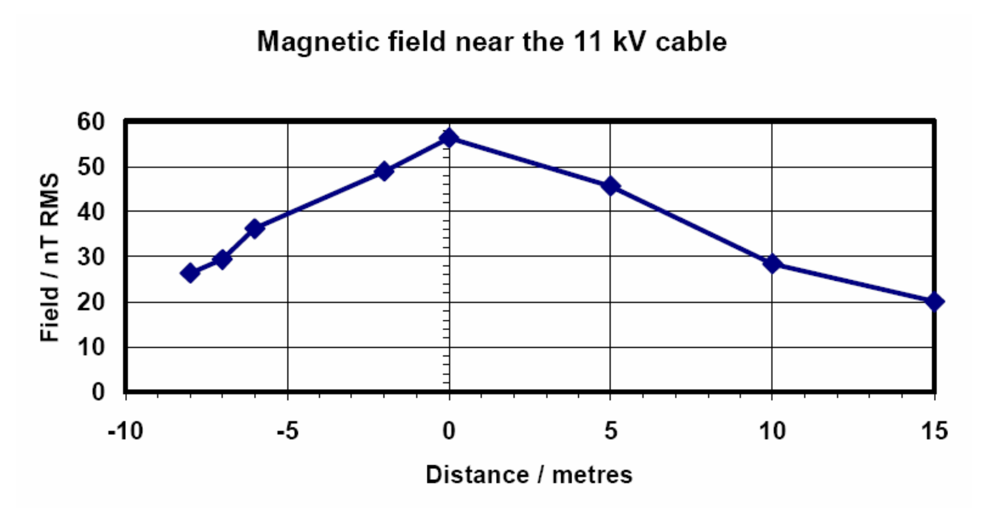


Fig. 39 Results of measurements with magnetic field sensors in the environment of an 11 kV cable (from CMACS 2003).

The electric field sensor used for the field measurements produced a maximum output (indicating an electric field in excess of 70 µV*m^{-1}) when placed in the cable environment (CMACS 2003). Measurements taken at a distance of approximately 1 km along the coast still recorded an electric field of greater than 70 µV*m^{-1}. The authors had not expected electric fields of such strength. They discussed the lack of steel armour in the 33kV cable to be a contributory factor. However, it would not sufficiently explain such large electric field detected at a distance of approximately 1 km from the cable. Time limitations did not allow further investigation of the detected field including the development of other sensors in the scope of the study (CMACS 2003).

Also, information on 33 kV XLEP cables carrying AC current was obtained by CMACS (2003). AEI Cables Limited, a company designing and manufacturing electrical cables, provided calculations of magnitudes of magnetic fields. According to that, for current flows of 641 A a magnetic field strength at 0 m and 2.5 m of 1.7 µT and 0.61 µT, respectively, was calculated.

For the Nysted offshore wind farm the magnetic field of three-core PEX-composite cable (AC) buried at a depth of 1 m was calculated to be about 5 µT at a distance of 1 m when the wind farm produces at full effect (600 A) (HVIDT 2004).

The Horns Rev wind farm was planned with an internal connection of 33 kV, 400 A cables and a shore connection using 3-core 150 kV, 600 A cable for which GILL & TAYLOR (2001) calculated electric field strengths at different distances from the cable (Fig. 40, Fig. 41). As seen in the diagrams electric fields directly above the cables were calculated to reach 1000 µV*m^{-1}. Ambient conditions of about 25 µV*m^{-1} would be reached at a distance of more than 30 m from the cables. These calculated data are in contrast to results for AC transmission cables published by other authors who give electric field strengths a fraction of what was calculated by GILL & TAYLOR (2001) (Tab. 8). The differences might be explained by the high currents considered for the Horns Rev cable. A discussion of the results was not presented in the report by GILL & TAYLOR (2001).

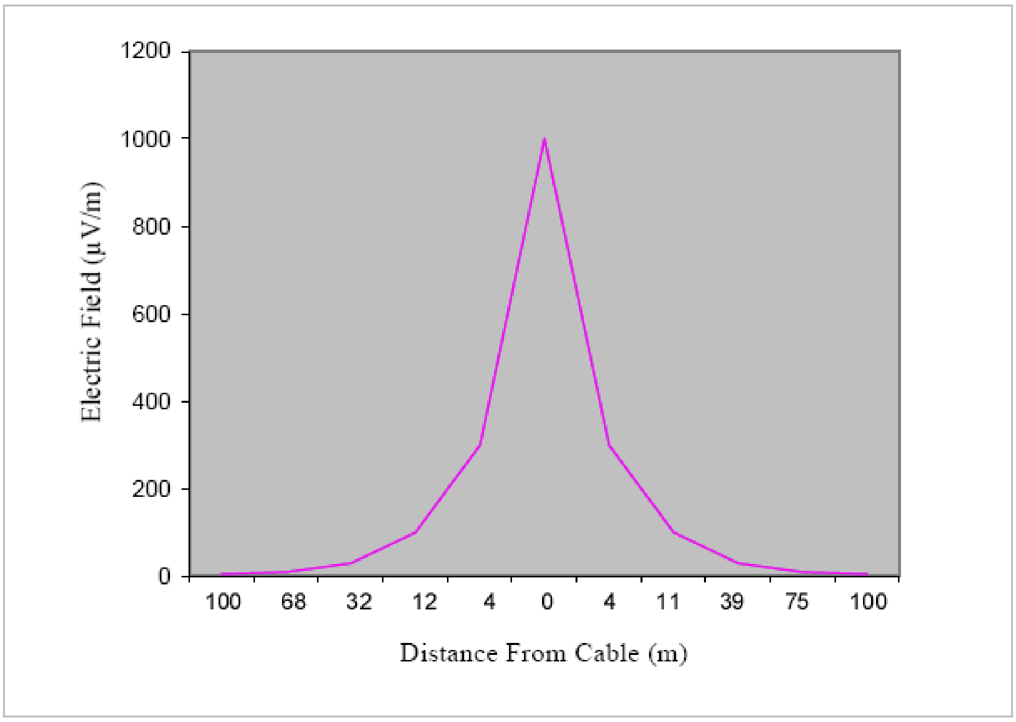


Fig. 40 Electric field intensity for a 33 kV cable (400 A current) deployed at Horns Rev offshore wind farm with a seabed resistance of 0.7 ohms (from GILL & TAYLOR 2001, slightly amended).

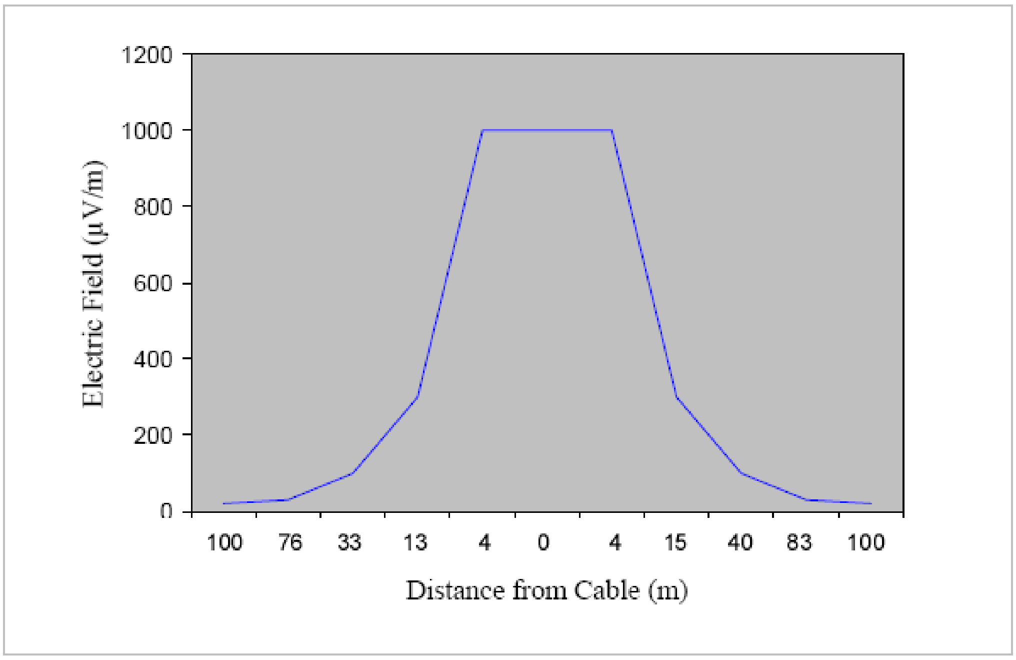


Fig. 41 Electric field intensity for the 150 kV cable (600 A current) deployed at Horns Rev offshore wind farm with a seabed resistance of 0.7 ohms (from GILL & TAYLOR 2001, slightly amended).

Tab. 8 Data on electromagnetic field strength for various cables obtained by both calculations and *measurements.

Cable type	**Capacity**	**Electric field strength**	**Magnetic field strength**	**Reference**
Monopolar DC	500 A		2000 µT at the surface of the cable 20 µT at 5 m distance 5 µT at 20 m distance	Acres (2006)
	1200 A (312 MW at 260 kV; 370 MW at 280 kV)		5000 µT at the surface of the cable 50 µT at 5 m distance	Acres (2006)
	max. 1335 A, 450 kV, 600 MW (Baltic cable)	100 µV*m^{-1} at 10 km distance from the cable	250 µT above the cable 50 µT at 6 m distance	Matthäus (1995)
	1500 A	10^{6} µV*m^{-1} at 10 cm from the cathode 7*10^{4} µV*m^{-1} at 1 m from the cathode 1-50 µV*m^{-1} far from the cathode	300 µT above the cable 50 µT at 5 m distance 13 µT at 200 m distance	Koops (2000)
AC (3-phase)	11 kV, 60 A, 50 Hz	17.5 µV m^{-1} at a distance of 0 m 12.5 µV m^{-1} at 5 m 6.2 µV m^{-1} at 20 m	*~57 µT above the cable *50 µT at 2 m distance *45 µT at 5 m distance *20 µT at 15 m distance	CMACS (2003)
	33 kV, 50 A, 50 Hz	15 µV m^{-1} at a distance of 0 m 4 µV m^{-1} at 5 m 1 µV m^{-1} at 20 m *>70 µV m^{-1} at >1 km distance	*50 µT above the cable *20 µT at 2 m distance *10 µT at 5 m distance	CMACS (2003)
	33 kV, 641 A		1.7 µT at 0 m 0.61 µT at 2.5 m	CMACS (2003)
	33 kV, 400 A	1000 µV m^{-1} at a distance of 0 m about 300 µV m^{-1} at a distance of 4 m 25 µV m-1 at >30 m		Gill & Taylor (2001)
	132 kV (with perfect shielding)	No directly generated electric field, but induced electric fields: 91.25 µV m^{-1} at 0 m distance, 10 µV m^{-1} at 8 m (sea water), 1-2 µV m^{-1} at 8 m (sediment)	*56 nT in the surrounding water 1.6 µT within mm around the cable	CMACS (2003)
	132 kV, 600 A (Nysted offshore wind farm)		5 µT at 1 m	Hvidt (2004)
	150 kV, 600 A	1000 µV m^{-1} at a distance of 0 m 1000 µV m^{-1} at a distance of 4 m 25 µV m^{-1} at >30 m		Gill & Taylor (2001)
Natural ambient conditions (marine)		**25 µV m^{-1}**	**50 µT**	**after different authors**

Other subsea power cables to potentially emit electromagnetic fields are **communication cables** with repeaters and **pipeline heating cables**. MARRA (1989) published information on a major communication cable. The induced electric field was quoted with 6.3 $\mu V*m^{-1}$. Since this is the only information found on communication cable no general assessment can be made. Voltages and currents in pipeline heating cables are understood to vary widely (GILL ET AL. 2005). In the majority of cases such cables are believed to be single phase, high current and unscreened/unarmoured. The magnitude of electric and magnetic fields produced is unknown but would likely be largest with directly heated cables (GILL ET AL. 2005). Further information are required to get an idea about generated electromagnetic fields.

3.3.4 Impacts on fauna

Not much information is available on impacts of electric or magnetic fields associated with subsea cables on benthic marine invertebrates. In terms of potential impacts and effects of electromagnetic fields on marine invertebrates available information does not allow conclusive assessments. The just recently published WHO fact sheet “Electromagnetic fields and public health” (WHO 2005) concludes that “…none of the studies performed to date to assess the impact of undersea cables on migratory fish (e.g. salmon and eels) and all the relatively immobile fauna inhabiting the sea floor (e.g. molluscs), have found any substantial behavioural or biological impact”. Key findings of a literature review by ACRES (2006) on potential electromagnetic field effects on aquatic fauna associated with submerged electrical cables were as follows:

- “No studies describing adverse effects on aquatic species or systems associated with anthropogenic EMF emissions in either field or experimental settings at the field strengths associated with submarine power cables were identified.
- No studies were found that described the potential effects of anthropogenic EMF associated with submerged power cables on fish populations or fish distribution. Similarly, no studies were identified that specifically described the potential effects of submerged AC cables on salmonid migration or behaviour.
- Although it is known that some elasmobranch species are capable of detecting and responding to electric fields within the range of levels induced by submerged power cables, no studies were found describing the effects of such exposure on elasmobranch behaviour under field conditions.
- Some aquatic species, such as the spiny lobster and loggerhead turtle, use the earth’s geomagnetic field as a means of navigation and positioning. The presence of

magnetite within many other migratory species, including salmonids, suggests that they also may use the earth's geomagnetic field for navigation. Experimental evidence to determine whether migrating salmon can detect and/or could be affected by anthropogenic magnetic fields of a magnitude comparable to the earth's geomagnetic field is inconclusive.

- Experiments involving cultured cells and animal models indicate that there is little to no evidence that extremely low frequency EMF causes damage to chromosomes or affects cell division or other cellular functions. No laboratory studies describing similar experiments on aquatic species or cultured cell lines from aquatic species were identified during this literature review." (ACRES 2006)

The author concludes that based on the limited number of studies undertaken to date it is not possible to form any conclusions regarding the possible impacts of EMF exposure on aquatic species and systems.

However, to give an impression on the subject of relevant studies some more detailed information is provided here. For example, survival rate and fitness in response to exposure to static magnetic fields of **benthic macroinvertebrates** common in the southern Baltic Sea was investigated by BOCHERT & ZETTLER (2004). The North Sea prawn *Crangon crangon*, the round crab *Rhithropanopeus harrisii*, the glacial relict isopod *Saduria entomon* and the blue mussel *Mytilus edulis* were exposed to static magnetic fields of 3.7 mT for several weeks under laboratory conditions. No significant differences between test and control groups were found.

Other studies just investigated whether species behaviour or orientation is related to electromagnetic fields. Results of studies on spiny lobster *Panulirus argus* from the West Atlantic Ocean revealed the possession of a magnetic compass sense (LOHMANN ET AL. 1995). Because inverting the vertical component of the earth's field had no effect on orientation under laboratory conditions, the results suggested that the lobster compass is based on field polarity and thus differs from the inclination compasses of birds and sea turtles. The authors suggested the magnetic compass of lobsters to function in homing behaviour, in guiding the autumn migration or in both.

Other crustaceans known to possess magnetic compass sense are *Talitrus saltator* (ARENDSE 1978, SCARPINI & QUOCHI 1992), *Orchestia cavimana* (ARENDSE & BARENDREGT 1981), *Talorchestia martensii* (PARDI ET AL. 1985) and *Idotea baltica* (UGOLINI & PEZZANI 1992). The nudibranch gastropod *Tritonia diomedea* inhabits subtidal waters of the northern Pacific Ocean. Laboratory experiments have demonstrated that the species can use the earth's magnetic field as an orientation cue (LOHMANN & WILLOWS 1987) while field studies have suggested that this sensory ability may help guide the specimens between offshore and inshore areas (WILLOWS 1999). Whether orientation of species using the earth´s magnetic field as an orientation cue is affected by artificially generated electromagnetic fields in the vicinity of power cables is unknown.

WANG ET AL. (2003) report evidence of increased electrical activity of particular neurons in response to alterations of a magnetic field around specimens. FOSTER & REPACHOLI (2005) recognise a variety of mechanisms by which electric and magnetic fields can interact with biological structures. These include electrically or magnetically induced forces and torques on biological structures, and excitation and electrical breakdown of cell membranes.

Among **fish**, electroreception has been recorded for a number of species (WALKER 2001). The majority of electroreceptive fish studied so far are either freshwater species, Elasmobranchii (sharks, skates and rays), or other chondrichthyans (e.g. sturgeons). Marine chondrichthyans are the most sensitive fish with receptor thresholds ranging from 0.005 µV cm^{-1} to 0.2 µV cm^{-1} in different species, hence electric fields generated by cables have successfully been used as a barrier for sharks to prevent attacks on humans (GILL & TAYLOR 2001, WALKER 2001). Also lampreys (Petromyzontiformes) show behavioural responses to fields of 1-10 µV cm-1 (POLÉO ET AL. 2001, WALKER 2001). Among teleost fish freshwater species have been studied whereas information on marine species is scarce.

Also species that lack electroreceptors may react to electric fields as is demonstrated by the effect of electrotaxis with a direct current in freshwater electrofishing. In general small fish require a higher field strength and repetition rate for effective electrotaxis than large fish (WALKER 2001), but exact measurements are rare and do not reveal a clear general pattern. Also eggs and larvae of many fish species react very sensitive to electric fields. According to FRICKE (2000) magnetic fields can potentially affect the orientation of marine fish during their migrations or even redirect the migration. Electric fields can have scaring effects on marine fish and probably also redirect the migration pattern (Fig. 42). In the German North and Baltic Seas possible impacts might be considered for herring-like fish (Clupeidae), sharks and rays (Elasmobranchs), flatfishes (Pleuronectidae), and other demersal migratory fishes (Teleostei).

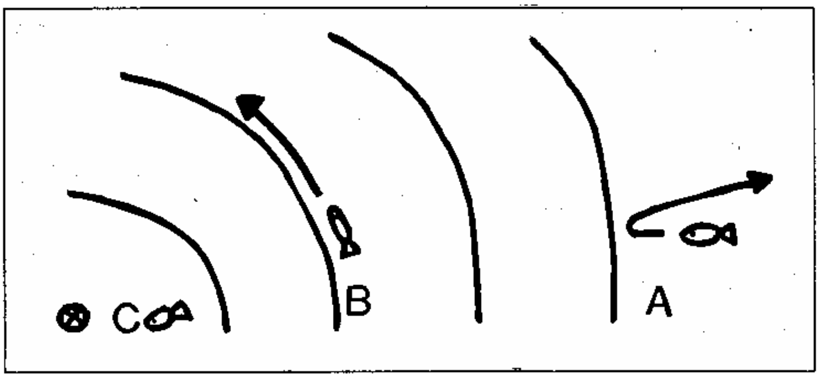


Fig. 42 Impacts of electric fields on fish: x = power source, A = scaring effect, B = redirection, C = torpidity (from FRICKE 2000).

Magnetic fields generated by cables might impair the orientation of fish and marine mammals and therefore negatively affect especially migratory behaviour. Although the biological process of magnetoreception is less well understood than that of electroreception there is sufficient evidence for the importance of magnetic information for orientation in a variety of animals. Marine fish use the earth's magnetic field and field anomalies for orientation especially when migrating (FRICKE 2000). Especially elasmobranch fish cean detect magnetic fields which are weak comparable to the earth's magnetic field (POLÉO ET AL. 2001) and react to fields of 25 - 100 µT (GILL ET AL. 2005). The influence of magnetic fields on orientation in teleost fish is still under discussion as some studies reported effects in salmonids and eels while other failed to do so (POLÉO ET AL. 2001). According to references in WARNEKE (2001), eels and several salmonid species react to experimental magnetic fields. FRICKE (2000) assumes magnetic orientation and thus a potential impact of artificial anomalies of the earth's magnetic field for allis shad (*Alosa alosa*), twait shad (*Alosa fallax*), Atlantic pomfret (*Brama brama*), herring (*Clupea harengus*), sardine (*Sardina pilchardus*) and Baltic sprat (*Sprattus sprattus*). While eels *Anguilla anguilla* under laboratory conditions show orientating reactions to relatively weak fields (4 % of the earth's magnetic field; TESCH 2000), much stronger disturbance reactions have been shown only for field strengths by far exceeding those of the earth's magnetic field (WESTERBERG 2000, POLÉO ET AL. 2001). Benthic fish are more exposed to magnetic fields around bottom cables and are thus expected to be stronger affected than pelagic species.

Investigations of potential effects on fish from electromagnetic fields from submersed cables have been carried out in relation to the demonstration project "Nysted Offshore Wind Farm at Rødsand" in autumn 2004 using pound nets on both sides of the cable trace (BIO/CONSULT AS 2004). The main results of this study were that the overall distribution of several indicator species did not changed beyond the level of natural variation since the establishment and activating of the cable and that eel *Anguilla anguilla* catches were similar on both sides of the cable, indicating no influence on eel migration (Fig. 44). The experimental setup was, however, not sufficient to reveal if the cable trace and the belonging electromagnetic fields has a barrier effect to moving or migrating fish (BIO/CONSULT AS 2004).

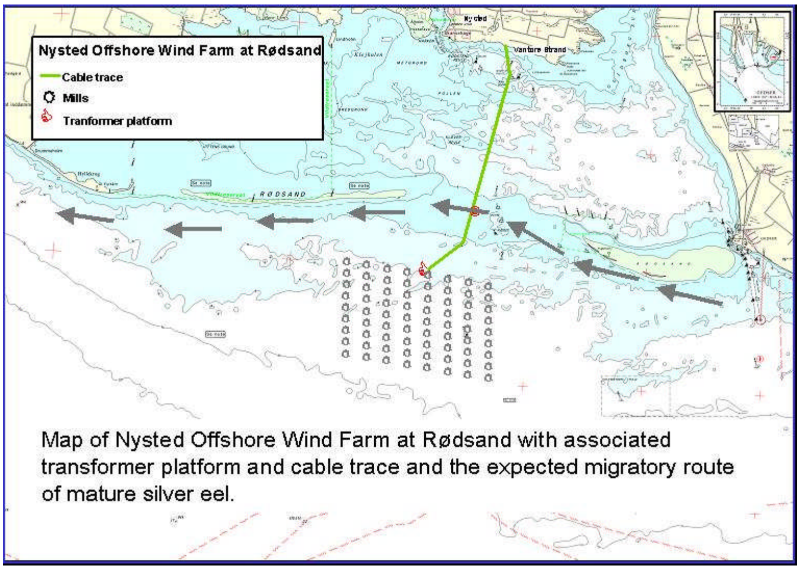


Fig. 43 Situation of the Nysted cable study area (from HVIDT 2004).

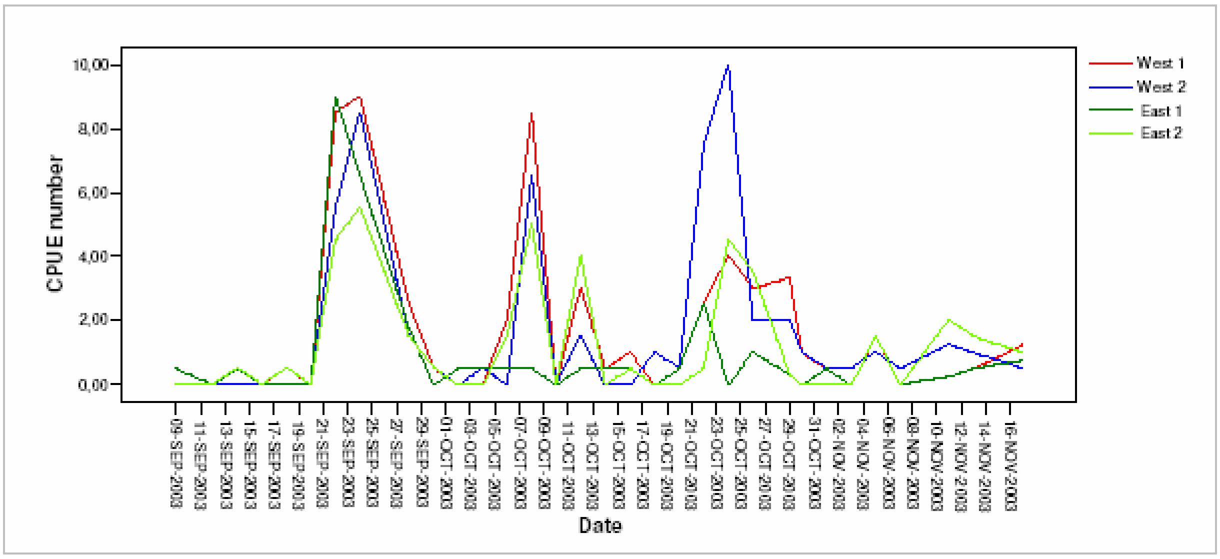


Fig. 44 Eel catches East and West of the Nysted cable in autumn 2003 (from BIO/CONSULT AS 2004).

For the Baltic Cable, a HVDC cable with a constant magnetic field of 5 µT at a distance of 60 m, WESTERBERG & BEGOUT-ANRAS (2000; in WALKER 2001) found that 57 % of 21 transmitter-tagged eels crossed the cable in spite of the magnetic anomaly within 3.6 hours after release. Only marginal changes of the swimming direction in the moment of crossing indicated an effect of the cable. Similarly, migration of elvers (young eel) was not notably affected by HVDC cables (references in POLÉO ET AL. 2001).

According to POLÉO ET AL. (2001), eels and salmonids show a bradycardial response (i. e. a reduction in heartbeat rate) at minimum field strengths of 7 mV*m^{-1} whereas lower threshold values reported in certain studies could not be reproduced later. Behavioural responses of marine teleost species could be observed at 0.5-7.5 V*m^{-1} (POLÉO ET AL. 2001) but it should be noted that observable changes in behaviour can be expected to occur at values well above the threshold of perception.

The behaviour of **elasmobranch fish** can be influenced by weak electric fields in different ways. GILL & TAYLOR (2001) tested the reaction of a benthic shark, the dogfish *Scyliorhinus canicula*, to simulated electric fields in a pilot laboratory study. The sharks avoided electric fields at 10 µV cm^{-1} which were the maximum expected to be emitted from 3-core undersea 150kV, 600A AC cables like those used in the Horns Rev wind farm but they also showed a high between-individual variance. Some very low threshold values for physiological responses of onl 0.006 mV/m were questioned by POLÉO ET AL. (2001). According to other studies eels and salmon responded to electric field strengths between 7 and 70 mV/m (POLÉO ET AL. 2001).

In **cetaceans** which probably use magnetic cues for navigation a disturbance of the local geomagnetic field has been suggested to cause strandings of whales in the USA and the UK (WARNEKE 2001 and references therein). Although such an effect could not be detected in stranding records from Australia and New Zealand there is sufficient circumstantial evidence to conclude that changes in magnetic fields may affect cetacean orientation (WARNEKE 2001). Circumstantial evidence further indicates that they would be capable of detecting variations in the geomagnetic field at the very least within a range of 30-60 nT and probably at much finer levels of discrimination (WARNEKE 2001).

3.3.5 Conclusions in regard to electromagnetic fields

Our current knowledge about effects of electromagnetic fields on the marine environment, in particular fauna, is not sufficient. Only a few preliminary conclusions can be reached.

Occurrence of magnetic fields associated with power transmission is best limited by field compensation to be achieved by an appropriate transmission system layout (preference of AC transmission systems or bipolar DC transmission system against monopolar systems). In case of monopolar transmission systems magnetic fields in close vicinity to the cable exceed natural ambient conditions significantly.

Directly generated electric fields are regarded to be controllable by adequate shielding. However, an induced electric field generated by the magnetic field occurs. In case of high current flows during power transmission the electric fields in proximity to the cable significantly exceed values typical under natural conditions.

Simulation studies revealed the potential for induced electric field mitigation by using highly specialised materials with high permeability or conductivity values for armouring of cables. Development of modern materials with such properties has to be encouraged. Though cable burial will not effectively mitigate against magnetic fields and induced electric fields it is likely to reduce exposure of electromagnetically sensitive species to the strongest electromagnetic fields that exist at the ‘skin’ of the cable owing to the physical barrier of the substratum and should therefore be realized.

There is an apparent lack of information on electromagnetic fields emitted from communication cables (with electric components) and pipeline heating cables.

In regard to effects on fauna it can be concluded that there is no doubt that electromagnetic fields are detected by a number of species and that many of these species respond to them. However, threshold values are only available for a few species and it would be premature to treat these values as general thresholds. The significance of the response reactions on both individual and population level is uncertain if not unknown. More field data would be needed to draw firm conclusions but data acquisition under field conditions is complicated.

3.4 Contamination

3.4.1 Introduction

Anthropogenic contamination of the marine environment including its fauna and flora is an intensively studied field. A review of the huge amount of available information would be very time-consuming and beyond the ambit of this literature review. Moreover, the final formulation of general conclusions is difficult if not impossible for a non-specialist. For that reason the following chapters concentrate on information directly related to cable projects. Regarding the impact 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 and from release of contaminants of the cable itself due to cable damage or degradation. Hence contamination can become an environmental issue during installation and removal as well as during service life.

3.4.2 Contamination related to seabed disturbance

The risk of contamination related to seabed disturbance is restricted to the potential release of contaminated sediments into the water column from cable burial, recovery of buried cables and repair work. Usually, sediment quality is assessed before a cable is laid and a cable route is designated which avoids so-called “toxic hot spots” (e.g. URS CORPORATION 2006). Typical potential contaminants the areas are screened for are arsenic, cadmium, copper, lead, mercury, nickel, selenium, silver, zinc and total polycyclic aromatic hydrocarbons (PAH). However, there might be circumstances in which areas with contaminated sediments can not 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.

The problem of release of contaminants to the water column was addressed in a **review of information from the U.K. on cable decommissioning** (EMU LTD. 2004). The authors concluded that the concentration of contaminants released to the water column resulting from grappling / cable removal, will be very low even in heavily polluted areas and rapidly diluted beyond the immediate area of release. Effects were therefore assessed as temporary and insignificant.

For the **Vancouver Island Transmission Project** a potential for release of metals or hydrocarbons contained in the sediments was identified for each the construction, operation and decommissioning phase. It was anticipated to be similar in magnitude and scope for all three phases (BCTC 2006). Risk assessment was determined with reference to Canadian Sediment Quality Guidelines (CSQGs) and screening limits developed under the auspices of the Water Quality Task Group of the Canadian Council of Ministers of the Environment (CCME). CSQGs are defined as numerical concentrations or narrative statements that are recommended as levels that should result in negligible risk to biota, their functions, or any interactions that are integral to sustaining the health of ecosystems and the designated resource uses they support. To date, over 60 freshwater and marine CSQGs have been developed and published for a number of contaminants of concern in sediments including metals, PCBs, PAHs, dioxins and furans, and organochlorine pesticides. For example, there is a 0.7 mg*kg^{-1} CCME interim sediment quality guideline for cadmium. The Disposal at Sea screening limit for cadmium has been set at 0.6 mg*kg^{-1} dry weight. This is considerably lower than the CCME probable effects level of 4.2 mg*kg^{-1}. For arsenic a CCME guideline of 7.2 mg*kg^{-1} and a probable effects level of 41.6 mg*kg^{-1} for marine sediment have been designated.

Results of the sediment analyses from the Vancouver Island Transmission Reinforcement Project indicated the presence of a few locations where sediment levels exceeded CCME or Ocean Disposal criteria (BCTC 2006). However, since contaminant levels were well below probable effect levels it was suggested that these levels pose a minimal threat to marine life when the sediment is dredged for removal and installation of the cables. To minimize potential risks hydro-jetting, a method regarded to cause least sediment disturbance, was going to be used in soft sediments for cable removal and installation. It was expected that approximately 70 % of the fluidized sediment would remain or settle back in the approximately 1 m wide and up to 1 m deep trench, and only the remaining 30 % would be suspended into the water column. Other proposed mitigation measures included the use of a plow method to bury the cables where the bottom substrate is harder and water-jetting is not feasible and 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.

For the **Transbay Cable Project**, with the main component being a 57-mile-long HVDC cable in San Francisco Bay, sediment quality data were compared to NOAA (National Oceanic & Atmospheric Administration) benchmarks termed Effects Range Low (ERL) and Effects Range Mean (ERM) (URS CORPORATION 2006). The ERM is the concentration below which toxic or adverse effects in organisms living in the sediment are rarely observed, and above which adverse effects are frequently observed. According to the authors, sediment concentrations greater than the ERM are generally interpreted as an indication of contamination. For example, ERLs for lead, mercury, cadmium, silver, and zinc are set at levels of 47, 0.15, 1.2, 1.0, and 159 mg/kg, respectively.

Sediment quality analysis along the proposed cable route of the Transbay Cable Project revealed the presence of locations with sediments with elevated PAH, nickel, arsenic, chromium, and copper concentrations. Arsenic, chromium, and copper, were detected at concentrations above the respective ERLs, but below the ERMs. A potential risk to significantly impact water quality due to disturbance of sediment in the respective areas of contamination was postulated. An exception was made for nickel. Highest nickel concentrations found were above NOAA ERL and ERM benchmarks. But nickel naturally occurs in rock formations of the area, and ambient concentrations of nickel in the local sediment are high. For that reason, nickel concentrations were considered to be consistent with background concentrations and unlikely to pose a risk (URS CORPORATION 2006). Mitigation measures concentrated on avoidance of known areas of contamination.

3.4.3 Contamination related to cable deterioration

Discussing contamination in relation to subsea cables the potential long-term risk of releasing heavy metals into the sediments caused by cable deterioration has to be included. Service life is limited since the cable coating weathers over time due to changing cable temperature during operation or wave action and current (BCTC 2006, SCHREIBER ET AL. 2004). Cable components posing a potential risk, as there are conductors and sheaths made of copper, lead and other metals, might become exposed and eventually leach into sediments in which they are buried. SCHREIBER ET AL. (2004) calculate an amount of about 12 kg lead*m^{-1} for cables with a 3.5 mm lead sheath. However, a study proving this effect of elevated contamination levels in the vicinity of cables could not be found. Nevertheless, the removal of cables from the marine environment after termination of service life is usually proposed (BCTC 2006, SCHREIBER ET AL. 2004).

3.4.4 Contamination effects on fauna

Contamination effects on fauna have been intensively studied under laboratory conditions. There are several web portals providing very detailed information on toxicity of chemicals for aquatic and terrestrial life. From such sources information could be sought what effects on species are to be expected due to contaminant exposure of defined dosages. A background in chemistry will be helpful for drawing some general conclusion. The basis for a project-related

risk assessment however is to be in the position to predict contaminant concentrations specimens will be exposed to in the course of a planned project.
Some examples for such web portals shall be given here: The DATEST Portal (http://projects.cba.muni.cz/datest/) functions as information source for ecotoxicological tests and bioindication methods. It features a public on-line database of methods used in Ecological Risk Assessment process. The ECOTOXicology database (ECOTOX, http://cfpub.epa.gov/ecotox) is a source for locating single chemical toxicity data for aquatic life. With the search tools integrated in this database it is possible to search for data on certain species, species groups or genera as well as for data on specific chemicals. Another example provided here is TOXNET (http://toxnet.nlm.nih.gov/), a database on toxicology, hazardous chemicals, environmental health, and toxic releases. The PAN Pesticides Database (http://www.pesticideinfo.org/Index.html) provides current toxicity and regulatory information for pesticides. The Aquatic Ecotoxicity section at current includes 223,853 aquatic toxicity results from U.S. EPA's AQUIRE database. These data can be searched by species, chemical or effect.

Results from field studies are in comparison less numerous. A publication discussing the topic with focus on a cable project could not be found. The few examples cited in the following paragraph intended to serve as reference for some common effects of exposure to contaminants on benthic organisms as there are impairment of body functions, reduction in growth and reproduction, lethality.
KLARI ET AL. (2004) investigated seasonal variation of total arsenic concentration in the edible part of mussels *Mytilus galloprovincialis* as well as in the tail muscle of the lobster *Nephrops norvegicus* in the coastal area of Rijeka Bay (North Adriatic Sea, Croatia). Facilities like an oil refinery and an oil thermoelectric power plant are located in the area. A linear relationship between arsenic concentration in specimens and shell length or body length, respectively, was found. USSENKOW (1997) studying contamination of harbour sediments in the eastern Gulf of Finland (Neva Bay), Baltic Sea found an inverse correlation of biomass of Chironomidae with contaminant concentration (oil products, Hg, Pb, and Cu) in the sediment of Kronstadt port. Contamination of sediments with oil-based drilling muds have been found to cause changes in faunal composition and to lead to both, low diversity and dominance of opportunistic species (GRAY ET AL. 1990, KINGSTON 1992, DAAN ET AL. 1994, OLSGARD & GRAY 1995, DAAN & MULDER 1996, GRANT & BRIGGS 2002). The sea urchin *Echinocardium cordatum,* the bivalve *Montacuta ferruginosa* and the amphipods *Harpinia antennaria* and *Ampelisca* spp. were identified sensitive species in respect to sediments contaminated by oil-based drilling muds (DAAN ET AL. 1994, DAAN & MULDER 1996, GÓMEZ GESTEIRA & DAUVIN

2000). Chronic exposure of adult sea scallops from Georges Bank, *Placopecten magellanicus*, to different types and concentrations of used operational drilling fluids and their major constituents under laboratory conditions caused high mortalities at concentrations as low as 1.0 mg/l (CRANFORD ET AL. 1999). Also effects on growth and reproductive success could be documented in this study.

3.4.5 Additional risks of contamination related to fluid-filled cables

A last point to be taken into consideration only applies to a certain cable type, the fluid filled cable. There is a potential risk that insulating fluid may enter the aquatic environment from cable leaks (due to mechanical damage) or complete severing of the cable (by ship anchors or other mechanical damage). The amount of fluid spilled will be related to the response and repair time, extent of damage and its location (SCHREIBER ET AL. 2004, JACQUES WHITFORD LTD 2006b).

SCHREIBER ET AL. (2004) consider flat-type cables to generally release the greatest amount of oil among different types of **oil-filled cables**. For the NorNed-cable the authors calculate an initial spill rate of approximately 50 $l*h^{-1}$ after spontaneous cable rupture. With sinking pressure within the cable the spill rate decreases. It is expected that cable rupture would be noticed within the first 100 h. During this time 1000 l oil could be spilled. A spill of 2000 l of oil is considered the worst case scenario. The overall risk of such event was assessed low. Effects on the marine environment were not discussed in this article. Typical consequences known from major oil spills are that birds and marine mammals get injured or killed by oil that pollutes their habitat. Also small organism (planktonic and benthic) would be affected. However, considering the maximum amount of oil potentially spilled from the cable (for the above mentioned example), severe effects on the marine environment are unlikely.

For the Vancouver Island Transmission Reinforcement Project (VITR) **linear alkylbenzene (LAB) fluids** are proposed to be used as the insulating agent in new cables at the core (JACQUES WHITFORD LIMITED 2006b). LAB is manufactured from benzenes and alkenes and is a mixture of compounds with varying carbon chain length (10 to 16 carbon atoms per chain) attached to a benzene ring. Decylbenzene and dodecylbenzene, the constituents of the proposed VITR cable fluid, possess similar properties and toxicological characteristics. The summary of technical information by JACQUES WHITFORD LIMITED (2006b) regarding possible source, pathway and fate of the cable insulating fluid to be used in the transmission line, should it be accidentally released to the environment, is as follows:

“Cable fluid is a used as a dielectric insulator in submarine electrical transmission cables. Pressure within the cable is maintained by pump stations on either end of the cable. In the event of a leak, pump stations will maintain sufficient flow through the cable to prevent an influx of seawater that would otherwise result in irreparable damage to the cable…. British Columbia Transmission Corporation has estimated a repair time of up to 14 days for either a leaking or severed cable. Assuming a typical flow rate of 10 $l*h^{-1}$, which would be a maximum value necessary to expel sea water, the maximum volume of fluid potentially released has been estimated as up to 3,400 litres for a leak and up to 40,000 litres for a completely severed cable. Flow rates would be high initially and decrease gradually over several days as the fluid temperature cools to ambient sea temperature. The 40,000 litres represents the entire contents of the fluid storage tanks at both cable terminals, an amount sufficient to service three cables in the unlikely event all three are severed at the same time. The more likely total volume, based on calculations of flow rates and repair times, is up to 12,000 litres (both ends of a severed cable). The pathway of cable fluid in the marine environment is migration to the surface to form a very thin slick, evaporation or transportation via adsorption to suspended particles and biodegradation in the water column. Accumulation in benthic sediments is possible if leaks occur in areas where the cable is buried near shore. Factors affecting migration of LAB to and on the water surface include sea conditions (rapid spread and evaporation in calm water, partial re-mixing into the water column in turbulent water), distance between the source of the leak and the water surface and flow rate. The fate of LAB on the water surface is primarily loss through evaporation, which will increase with increasing wind speed and surface temperature, although some remixing may occur at greater wind speeds. The rate of photodegradation is low (less than 1% in direct sunlight over 14 days). LAB biodegrades rapidly in marine waters (80 to 99% in 21 days), with complete mineralization by microorganisms under aerobic conditions (producing carbon dioxide and water). The rate of biodegradation is affected by temperature, sunlight, water flow patterns and types of microorganisms in the area. In anaerobic conditions (marine sediment) LAB biodegrades slowly, as it has a high affinity to soil, sediments and organic matter and is known to persist in aquatic sediments for 10 to 20 years.”

In regard to impacts on the marine environment JACQUES WHITFORD LIMITED (2006b) concluded that alkylbenzene has a low order of fish, mammalian and human toxicity. Environmental damage resulting from damage to a fluid-filled cable would likely to be small. Effects on sensitive shoreline ecosystems and aquatic birds might be possible, although unlikely, given the ability of the dynamic marine environment to disperse, evaporate and biodegrade the cable fluid. The authors proposed that further study of the toxic effects of alkylbenzenes on marine aquatic life should be generated, given the lack of aquatic toxicity data and aquatic toxicology and hazard evaluations for many relevant species.

3.4.6 Conclusions in regard to contamination

A risk of contamination associated with subsea cables arising from activities causing seabed disturbance can only be anticipated for heavily contaminated localities. Avoidance of (sediment disturbance in) such areas would be an appropriate mitigation measure. Information available on contaminant release due to disturbance of polluted sediments during cable installation (as well as removal and operation) reported about temporary and insignificant effects. Only few information however were available.

Introduction of contaminants into the environment from the cable itself can only occur if cables are not removed after termination of service and if fluid-filled cables are used. Pros and cons of the decision for removing the cable after termination of service life have to be weighed up. In some areas disturbance related to the cable removal might have more severe effects than effects exerted by potential release of contaminants from the gradually disintegrating cable. In regard to fluid-filled cables it has to be considered that they pose a permanent risk of release of contaminations into the environment. Thus their use seems debatable under aspects of environmental protection. However, there might be other advantages (e.g. certain technical properties) justifying the employment of fluid-filled cables.

The toxicity of different chemicals to aquatic organisms was extensively examined under laboratory conditions. A lot of such information is freely accessible via various web portals. It can be concluded that if fauna is exposed to contaminants in their natural environment an uptake of the substances in any form usually takes place. Common effects of exposure to contaminants on benthic organisms are e.g. impairment of body functions, reduction in growth and reproduction, lethality.

A potential risk of contamination due to the operation of subsea cables (including installation, repair-work, cable removal) certainly exists. A project-specific risk assessment is required.

3.5 Disturbance

3.5.1 Introduction

Among disturbance effects which might occur in association with subsea cables are direct effects on organisms such as physical disturbance, damage, displacement and removal as well as effects on the marine environment, in particular water quality effects, physical alteration to the seabed and habitat destruction. Most of these effects are restricted to the installation phase and cable recovery. Physical alteration to the seabed however may be long-term.

3.5.2 Physical disturbance, damage, displacement and removal of flora and fauna

Physical disturbance, damage, displacement and removal of flora and fauna occurs during trenching, cable burial and cable removal. EMU LTD (2004) summarized results of a comprehensive review of available information and concluded that mobile species are able to avoid disturbance and survive. Although a principal risk to sessile species could be postulated the long-term significance was only likely to occur in sensitive habitats which included slower growing vulnerable species. EMU LTD (2004) also tried to make generalisations in relation to the sensitivity of ecology likely to be found on different seabed types. In summary, faunal communities populating exposed bedrock, chalk, gravel, coarse sand, silty sand and intertidal mudflats were identified to be potentially prone to long-term (> 6 months) damage. Fauna supported by seabed types like stiff clay, sands of high mobility and clay was considered less at risk.

ANDRULEWICZ ET AL. (2003) published an article on environmental effects of the installation and functioning of the submarine *SwePol* Link HVDC transmission line in the Polish marine area of the Baltic Sea. One part of the study included investigations of the bottom macrofauna in regard to mechanical disturbances due to cable installation. Significant changes in zoobenthic species composition, abundance or biomass which could have been clearly related to cable installation had not been observed.

Disturbance of species is most obvious if biogenic habitat structures like mussel beds, sea grass beds, *Sabellaria* reefs or maerl beds are affected. ‘Maerl’ is a collective term for several species of calcified red seaweed. Maerl beds are mixed sediments built by a surface layer of slow-growing, unattached coralline algae creating a habitat for rich fauna. The high sensitivity of maerl beds is explained by the slow growth and poor recruitment of maerl species. Sabellarian reefs (*Sabellaria spinulosa*) are considered to be less prone to destruction by physical damage (e.g. due to shrimp fishery gear). Provided that the worms are not killed or removed from their tubes, the natural growth and capacity for repair is such that they can rebuilt destroyed parts of their dwellings within a few days (GRUET 1971 in VORBERG 2000).

Establishment of a subsea cable route in a shallow water area off the Florida coast (USA) was hampered by sea grass (KERITE COMPANY 2001). To solve the problem the planned routing was surveyed to zigzag around most of these areas; however, 2 100 feet of the route could not avoid the sea grass and sea grass rhizomes had to be cut. The same problem occurred at Nysted offshore windfarm (Denmark). Monitoring accompanying the cable laying revealed that shoot density of eelgrass and the biomass of rhizomes were reduced close to the trench as a combined effect of excavation and back filling and temporary burial below sediment deposited alongside the cable trench (BIRKLUND 2003).

3.5.3 Water quality effects (turbidity)

Water quality effects may affect benthic fauna and flora in a wider range if sediment is redistributed during cable burial or removal. Increased suspended sediment concentrations and changes of the oxygen level, for example, influence the submarine light absorption as well as environmental factors for benthic and pelagic organisms. The species´ mechanisms of filtration could be at least temporarily obstructed (SÖKER ET AL. 2000). Possible turbidity of the seawater can affect growth of the macrobenthos for a certain time. Coverage with soil may have a lethal effect on some macrobenthos species.

KÖNNECKER (1977) in an article on epibenthic assemblages as indicators of environmental conditions presumes that water turbidity and sediment precipitation exert a major control on epifaunal distribution patterns, especially so in case organisms are particularly prone to clogging of their incurrent canals. The author reports tunicates to be immune to sedimentation whilst hydroids and bryozoans seem to be able to cope. MAURER ET AL (1986) reported that epifaunal or deep-burrowing siphonate suspension feeders were unable to escape burial by more than 1 cm of sediment whereas infaunal non-siphonate feeders tolerated burial by 5 cm but less than 10 cm (in HISCOCK ET AL. 2002). As pointed out by BAKER (2003) the relative impact of sediment redistribution will be controlled by the amount of redistribution (the thickness of the layer of resettled sediment), its variance from the existing material (introduction of mud onto a sand sediment is expected to have a more substantial effect than mud settling on mud) and the sensitivity of the species or community. The area affected by plumes and smothering depends on the amount of excavated and dumped sediment, on the depth of the seabed and the dispersal in the water column; finer particulate remain in suspension longer than larger particulate and can potentially disperse over a wider area (HISCOCK ET AL. 2002). TNU (2005) report based on the results by GSX PL (2001) that suspended fine and medium sands require about 9 h for resettlement whereas silty sediments remain in suspension up to 4 days.

SÖKER ET AL. (2000) estimate that laying of the cable may disturb a two meter wide sector on the ground on both sides, and water will be troubled some meters around the site of construction. The same authors expect the effect on water to be diminished after some hours whereas effects on the sea floor will be observable for some weeks. At Nysted offshore windfarm, Denmark, a backhoe was used to excavate a 1.3 m wide, 1.3 m deep and 10.300 m long cable trench. Excavation work took one month (BIRKLUND 2003). The excavated sediment was placed alongside the trench and later used for the back filling. The total volume of seabed material excavated was approximately 17 000 m^3. The sediment spill was estimated to be 0.5 – 1 % of the amount excavated. Inspection of the trench after the back filling showed that the surface of the trench was below the surrounding seabed due to an inadequate filling of the trench. In addition, the lowered seabed acted as a trap and the trench was filled with detached macrophytes. Change in the overall composition of the surface sediment was not detected. However, at some stations close to the trench the silt/clay content of the sediment was higher after the earthwork and this increase was probably caused by a local sedimentation of fine sediment spilled during dredging and back filling. The structure of the benthic fauna had changed significantly at the impact stations close to the trench. Whereas the abundance of the benthic fauna was reduced by 10 % at the control stations abundance at the impacted stations decreased to 50 %. According to the author all effects were confined to a narrow zone close to the cable trench (BIRKLUND 2003). Fast recovery of the benthic community was expected at the stations close to the cable trench. Within the trench the accumulation of macroalgae was assumed to delay or prevent a re-colonisation of the sediment by the local fauna. However, in regard to the area affected the impact on the offshore environment was considered negligible.

For a windfarm development site in Great Britain, the Inner Dowsing offshore windfarm (Greater Wash Strategic Area), it has been predicted that 90 % of resuspended sediments from cable laying settled out 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.

The study of Cook Cove Cable 5 Submarine Cable Replacement Project reports a turbidity intensity of 21 NTU (Nephelometric Turbidity Unit; ≈ 21 $mg*l^{-1}$) in a distance of 15 m from jet trench (from EBA 2004 cited in BCTC 2006). Such intensities are regarded as a slight increase in waters with naturally low turbidity.

The environmental impact report for the proposed Trans Bay Cable Project (URS CORPORATION 2006) refers to experiences from other cable laying projects and concludes that by use of a hydro plow or equivalent technologies 10 to 20 % of the fluidized sediments would be dispersed.

Estimation of sediment deposition and suspended sediment concentration in connection with the Cape Wind Energy Project was undertaken by modelling (GALAGAN ET AL. 2003). Results are presented in Fig. 45 and Fig. 46. Effects are clearly a function of range. Sediment deposition is predicted to occur in a maximally 90-120 m wide corridor (depending on the sediment type). Water quality effects might occur at a distance of more than 0.9 km from the site. Results of the prediction are again summarized in Tab. 9 and Tab. 10. 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 are expected to last only a few minutes to less than one hour.

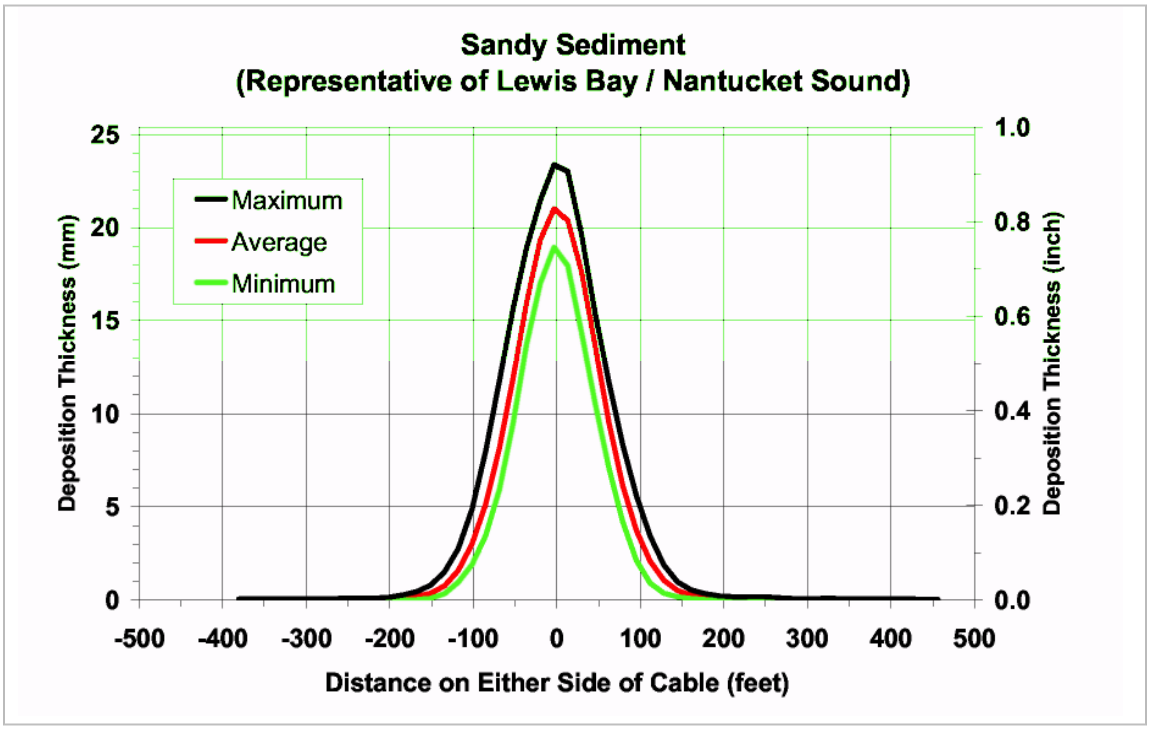


Fig. 45 Sediment deposition thickness as a function of distance in sandy sediment in Lewis Bay for the Cape Wind Energy Project (GALAGAN ET AL. 2003)

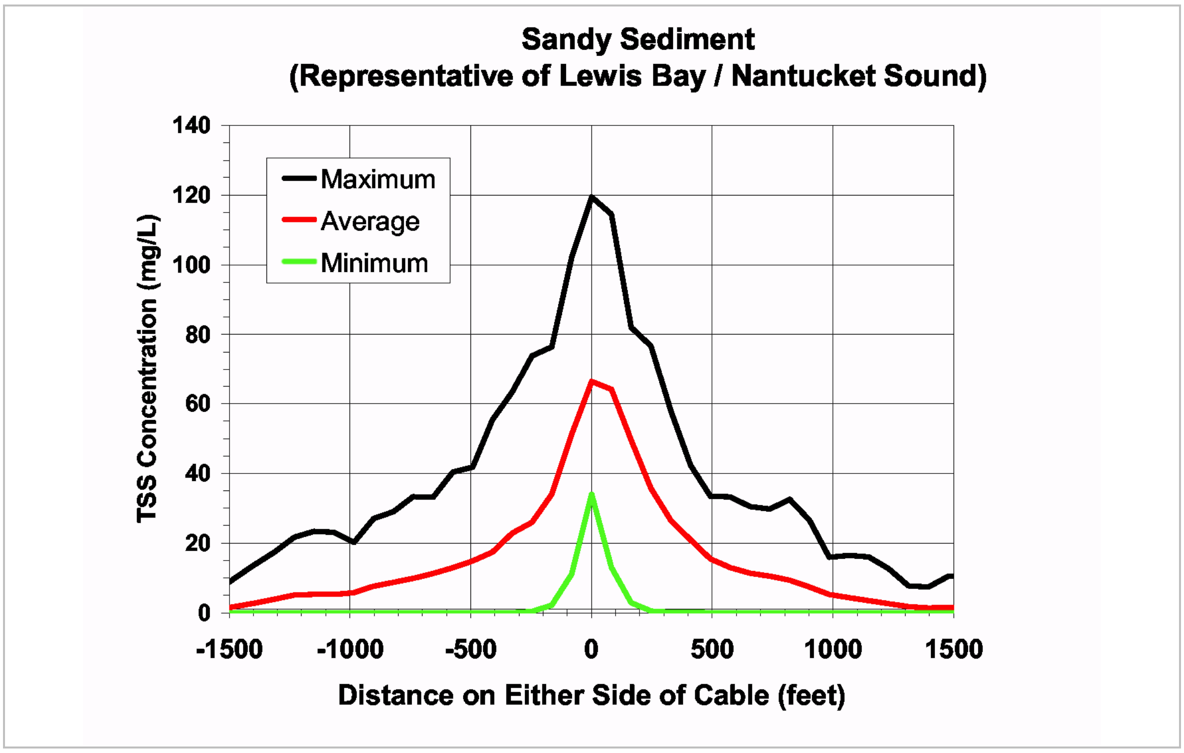


Fig. 46 Suspended sediment concentration as a function of distance from the cable route in sand-sized sediment in Lewis Bay for the Cape Wind Energy Project (GALAGAN ET AL. 2003).

Tab. 9 Intensity and extent of sedimentation caused by using a hydro plow at sandy conditions (after GALAGAN ET AL. 2003)

Area	**Sedimentation range**
cable trench	ca. 19 - 24 mm
15 m distance from hydro plow	ca. 11 - 17 mm
30 m distance from hydro plow	ca. 2 – 5 mm
45 m distance from hydro plow	up to ca. 1 mm
60 m distance from hydro plow	low

Tab. 10 Intensity and extent of turbidity disturbance caused by using a hydro plow at sandy conditions (from GALAGAN ET AL. 2003, amended by IfAÖ)

Area	**Minimum**	**Average**	**Maximum**
cable trench	ca. 35 mg/l	ca. 65 mg/l	ca. 120 mg/l
60 m distance from hydro plough	< 5 mg/l	ca. 35 mg/l	ca. 78 mg/l
150 m distance from hydro plough	none	ca. 15 mg/l	ca. 38 mg/l
300 m distance from hydro plough	none	ca. 10 mg/l	ca. 20 mg/l
450 m distance from hydro plough	none	none	ca. 10 mg/l

In the scope of the Vancouver Island Transmission Reinforcement Project an estimation of the volume of sediment disturbed at English Bluff has been made. Assuming that 1) each cable will be buried to, or removed from, a depth of 1.0 m, 2) the width of the disturbed area is 1.0 m for cable burial and 0.6 m for cable removal, 3) the total length of cable to be buried within

Canadian jurisdiction is 2,040 m, including all intertidal trenching; and 4) the total length of cable to be removed within Canadian jurisdiction is 2,730 m, a total volume of 1 103.4 m³ has been estimated to be suspended due to cable installation/removal (BCTC 2006). This estimate was based on the assumption that 70 % of the disturbed material settles back immediately or remains within the trench. The authors also provide information on settling velocities of unhindered discrete particles (theoretical and laboratory determined) reported by HITCHCOCK ET AL. (1999) (Tab. 11).

Tab. 11 Settling velocities of unhindered discrete particles (from BCTC 2006, according to HITCHCOCK ET AL. 1999), characteristics of the receiving environment (water depth, salinity, density, tidal current etc.) not taken into account.

Particle description	Size	Settling velocity [cm*s-1]
Sand	0.2 mm	2.1417
	0.1 mm	0.67
Silt	0.05 mm	0.1816
	0.02 mm	0.0298
	0.01 mm	0.00749
Clay	5 µm	0.00187
	1 µm	0.0000748

A factor influencing the extent of water quality effects is the use of appropriate cable installation techniques. The width of seabed that is directly disturbed during cable burial can vary between ploughing, trenching and jetting. For example, the actual width of seabed directly disturbed during cable burial in connection with the Basslink project, Australia, was estimated to range from approximately 0.5 m (ploughing) to about 1 m (jetting) (NATIONAL GRID 2000). NORTHEAST UTILITIES SERVICE COMPANY (2002) regard a hydraulic jet plow to create a relatively narrow trench.

Anthropogenic turbidity effects due to trenching and burying of cable have to be assessed against the background of **naturally induced turbidity** by tides, wave, currents etc. Under normal conditions suspended matter from open seawater of North Sea and Baltic Sea has values of < 3 mg/l and coastal waters of < 20 mg/l. River estuary and silty coastal waters like the Wadden Sea often contain high concentrations of suspended matter (Tab. 12, Tab. 13, Fig. 47, Fig. 48). Field measurement results conducted during extreme situations such as storms were not available. Results of a simulation of storm event in the North Sea are shown in Fig. 49. CHRISTIANSEN ET AL. (2006) mention for an area at Danish Wadden Sea concentrations of suspended matter for a storm situation of 100 - 300 mg/l compared with medium averages of < 50 mg/l.

Tab. 12 Concentrations of suspended solids (mg/l) at coastal waters of Mecklenburg-Vorpommern, 2000 (LUNG M-V 2004)

Locality	Station	N	Minimum	Average	Maximum
Lower Warnow river (near shipyard)	UW4	6	0.7 mg*l^{-1}	5.5 mg*l^{-1}	21.9 mg*l^{-1}
Greifswalder Bodden	GB19	6	2.2 mg*l^{-1}	4.8 mg*l^{-1}	11.1 mg*l^{-1}
Kleines Haff	KHM	11	4.4 mg*l^{-1}	21.1 mg*l^{-1}	61.8 mg*l^{-1}
Pommeranian Bay	OB IV	6	1.1 mg*l^{-1}	2.6 mg*l^{-1}	3.9 mg*l^{-1}

Tab. 13 List of total suspended matter (TSM) in European coastal waters (Ferraria et al. 2003)

Site	Period	Number of Sampling	TSM (mg/l) (average; max and min values)
Loire plume	May-1998	9	1.91; 0,86-2.3
Seine plume	May-1998	9	2.73; 1.2-4.31
Thames plume	May-1998	7	5.6; 0.77-20.9
Rhine plume	May-1998	10	3.5; 1.87-7.63
Humber plume	May-1998	8	2.53; 0.76-8.22
German Bight	May-1998	17	1.55; 0.6-6.7
Plymouth - English Channel	September-1998	51	1.05; 0.4-3.13
Texel North Sea	September-1998	33	8.9; 1.17-70.1
Wilhelmshaven - German Bight	September-1998	32	10.1; 1.2-38.9
Heringdorf - Baltic Sea	September-1998	51	3.2; 0.51-5.98

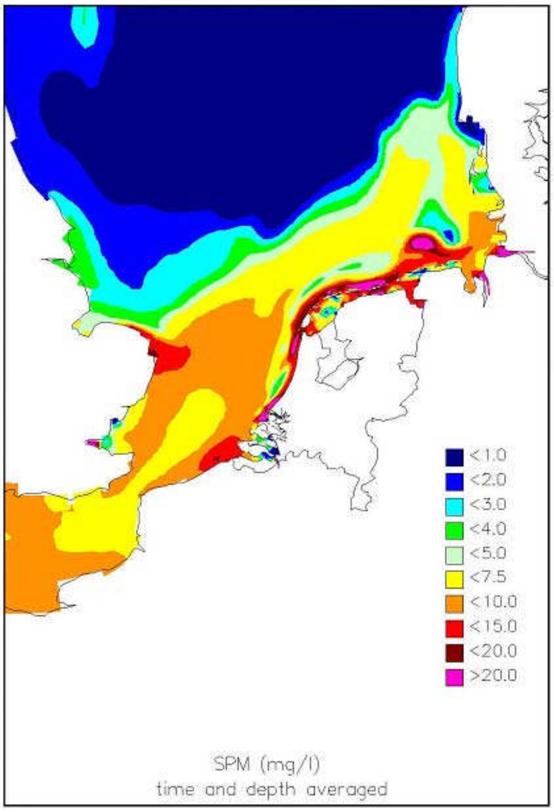


Fig. 47 Modelling of suspended particulate matter (SPM) in the North Sea with the 3D hydrodynamic model Delft3D-SED (http://www.wldelft.nl/rnd/intro/topic/transport-of-suspended/index.html).

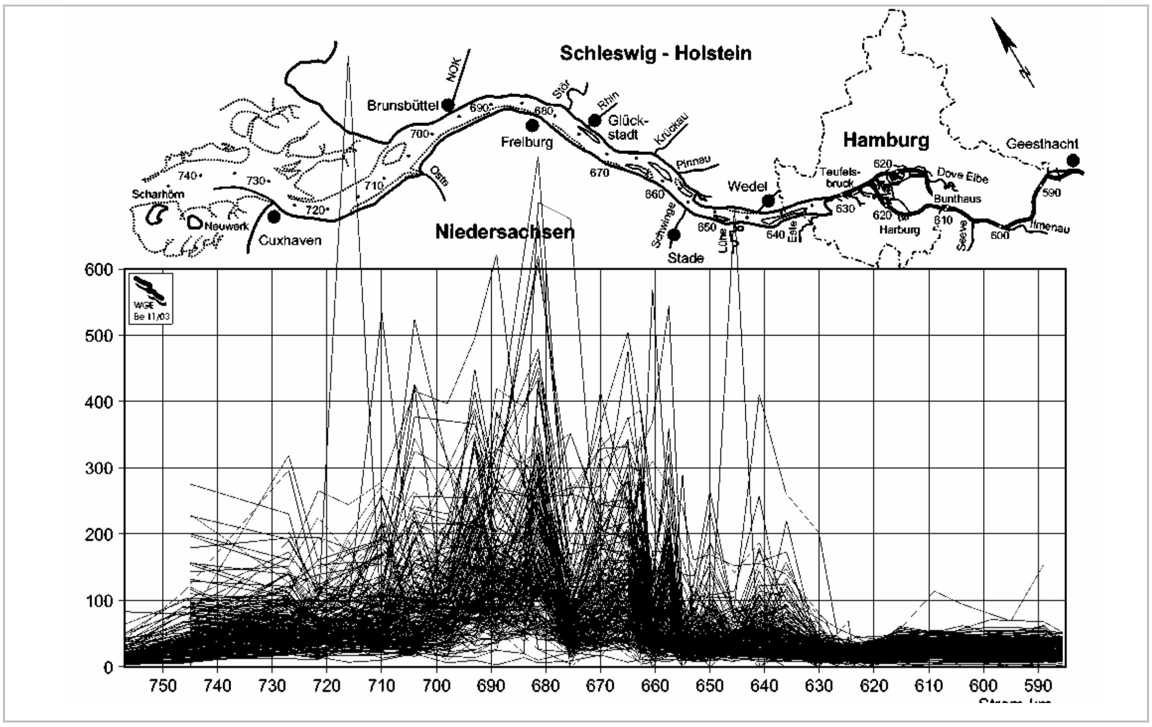


Fig. 48 Transect of suspended solids at tidal Elbe – 1979-2003 (BERGEMANN 2004).

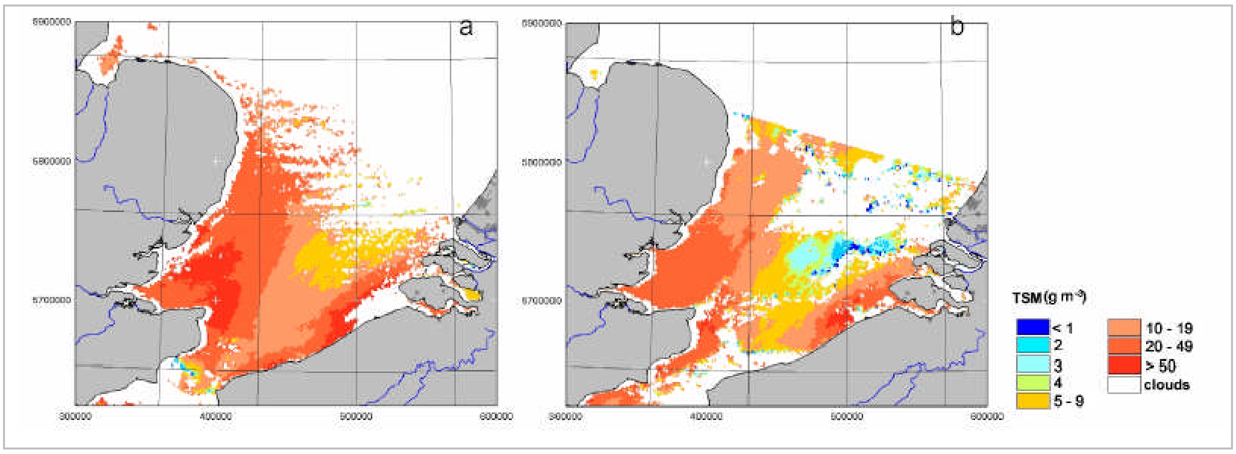


Fig. 49 Example for sediment settling after storm at southwestern North Sea (simulation); a: High sediment concentrations during storm (28 December 2001); b: The system is restoring three days after the storm (ELEVELD ET AL. 2004)

3.5.4 Physical alteration to the seabed

A last point to be discussed under ´disturbance effects` is physical alteration to the seabed. It was already mentioned that cable protection may be applied in form of rock-mattress covers, cast iron shells, cable anchoring, ducting or rock dumping. Other examples for protection measures are the use of special backfill materials for cable burial, reinforced concrete slabs or steel plates. All these protection measures lead to physical alteration of the seabed. The use of any backfill material rather than local sediment may attract non-local fauna. The introduction of artificial hard bottom into an environment dominated by sand will certainly support the settlement of non-local hard bottom fauna. Changes in the structure of the local sand communities in the immediate vicinity of such ´artificial reef` could be expected. Such processes were described as ‘reef effect’ and extensively discussed in literature (see e.g. WENNER ET AL. 1983, BUCKLEY & HUECKEL 1985, AMBROSE 1994, REIMERS & BRANDEN 1994, HISCOCK ET AL. 2002, BIRKLUND & PETERSEN 2004, JOSCHKO ET AL. 2004, BIOWIND 2005, LEONHARD & PEDERSEN 2005). The submarine cables themselves if not buried/covered along the seafloor will provide a solid substrate for a variety of species. The larvae of sessile encrusting organisms (encrusting corals, sponges, anemones) have been observed settling on and colonizing the cable surface (Fig. 50). Numerous other species would also be attracted to the area for camouflage and predation purposes. Studies specifically investigating such effects for subsea cables could not be found.

Fig. 50 Subsea power cable, in place for approximately 50 years, covered with sessile encrusting organisms at Vancouver Island (BCTC 2006).

3.5.5 Conclusions in regard to disturbance

Disturbance effects related to submarine cables are in general expected to be temporary and localized. It seems that technical standards and modern equipments today guarantee that suspended sediment concentrations which occur during cable burial or removal do not exceed those occurring under natural conditions. Areas along the cable route affected by coverage with protective structures will usually be restricted to a narrow strip along the cable. The potential for introduction of non-local fauna by the application of such protective cover (artificial hard bottom) into soft sediment areas exists. Effects on the local fauna related to that will in most cases be very localized although long-term.

In environmentally sensitive areas physical disturbance, damage, displacement and removal of flora and fauna might turn out to be a significant impact. Avoidance of such areas would be an appropriate mitigation measure.

4 Conclusions and Recommendations

Noise emission, heat dissipation, occurrence of electromagnetic fields, contamination and disturbance were identified potential environmental issues associated with submarine cables. Following preliminary assessments can be made after reviewing available information:

1) Based on current knowledge there are no clear indications that **noise** impacts commonly related to the installation (or removal) and operation of subsea cables (in particular cable trenching in soft sediments, maintenance work, cable vibration) pose a high risk for harming marine fauna though it has to be stressed that there are significant gaps in knowledge in regard to the characteristics of sound emissions as well as to sound perception by fauna. Further field measurements of sound emissions during cable laying activities and cable operation should be conducted. Knowledge on sound perception of marine fauna is insufficient. Reactions to anthropogenic sound emissions on individuum and population level are only vaguely known. Further information from laboratory and field studies are required.
2) **Heat dissipation** from power cables is the factor least assessable at current. Apparent gaps in knowledge exist. As transmission losses are higher for HVAC-cables compared to HVDC-cables. Heat dissipation during cable operation can be expected to be more significant for AC-cables than for DC-cables at equal transmission rates. Whereas the number of publications about technical aspects of transmission losses increased steadily in the last years almost nothing is known about ecological consequences of heat release into the bottom of the sea. Calculations of seabed temperature in the vicinity of cables agree in their predictions of significant temperature rise in the vicinity of cables. Whether these predictions hold true under field conditions still has to be examined. It has to be expected that seabed temperature will be permanently increased compared to natural conditions (as long as the power is transmitted) and highly variable. The effects of such artificially altered temperature condition on the bottom fauna and biogeochemical processes in the seabed are difficult to assess because of the lack of scientific studies addressing this problem. Based on first preliminary result from laboratory studies it can be assumed that impacts on faunal composition and alteration of biogeochemical processes occur.

   The 2 K-guideline proposed by the German Federal Agency of Nature Conservation (BfN) for German waters only reduces direct temperature effects on benthic fauna in the uppermost sediment layer (20 cm). Processes set off in deeper sediment layers due to heat dissipation are likely to finally affect the entire seabed above the cable due to pore water contact. Alteration of sediment chemistry is likely to exert secondary impacts on benthic fauna and flora. Impacts are most likely to be detected in shallow water areas, the Wadden Sea (especially during warm periods in summer) and areas with high organic content. Field measurements of seabed temperature in the vicinity of power cables as well as further laboratory and field studies are necessary to allow a well-founded assessment.

3) The occurrence of **electromagnetic fields** potentially presents a risk for significant impacts on the marine environment. Our current knowledge about effects of electromagnetic fields on the marine environment, in particular fauna, is not sufficient. Only a few preliminary conclusions could be reached.

   Monopolar transmission systems currently account for most severe alteration of field strength. Magnetic fields in close vicinity to this type of cable exceed natural ambient conditions significantly. In general, occurrence of magnetic fields associated with power transmission is best limited by field compensation to be achieved by an appropriate transmission system layout (preference of AC transmission systems or bipolar DC transmission system against monopolar systems). An induced electric field generated by the presence of the magnetic field occurs. In case of high current flows during power transmission the induced electric fields in proximity to the cable significantly exceed values typical under natural conditions. Simulation studies revealed the potential for induced electric field mitigation by using highly specialised materials with high permeability or conductivity values for armouring of cables. Independently from the cable type directly generated electric fields occur. They are regarded to be controllable by adequate shielding.

   Cable burial is likely to reduce exposure of electromagnetically sensitive species to the strongest electromagnetic fields that exist at the ‘skin’ of the cable owing to the physical barrier of the substratum and should therefore be realized.

   There is an apparent lack of information on electromagnetic fields emitted from communication cables (with electric components) and pipeline heating cables.

   In regard to effects on fauna it can be concluded that there is no doubt that electromagnetic fields are detected by a number of species and that many of these species respond to them. However, threshold values are only available for a few species and it would be premature to treat these values as general thresholds. The significance of the response reactions on both individual and population level is uncertain if not unknown. More field data would be needed to draw firm conclusions but data acquisition under field conditions is complicated.

4) **Contamination** might be of significance if seabed disturbance is caused in heavily contaminated areas although so far it was only reported about temporary and insignificant effects in this connection. Only few information however were available.

   In regard to fluid-filled cables it has to be considered that they pose a permanent risk of release of contaminations into the environment. That is of particular importance in environmentally sensitive areas.

   The toxicity of different chemicals to aquatic organisms was extensively examined under laboratory conditions. A lot of such information is freely accessible via various web portals. It can be concluded that if fauna is exposed to contaminants in their natural environment an uptake of the substances in any form usually takes place. Common effects of exposure to contaminants on benthic organisms are e.g. impairment of body functions, reduction in growth and reproduction, lethality.

   A potential risk of contamination due to the operation of subsea cables (including installation, repair-work, cable removal) certainly exists. There is no indication however that it is of high significance. Nonetheless, a project-specific risk assessment should be undertaken.

5) **Disturbance** effects related to submarine cables are in general expected to be temporary and localized. In environmentally sensitive areas physical disturbance, damage, displacement and removal of flora and fauna might turn out to be significant. Avoidance of such areas would be an appropriate mitigation measure.

Another aspect difficult to assess are **cumulative effects**. The subject might be most relevant if cables are aimed to be placed next to each other in designated corridors adjacent to other infrastructure such as pipelines. In current discussions such designated cable corridors are favoured by environmental agencies and nature protection organizations. Decisions are probably based on the prospect to limit disturbance during installation and repair work. However, since occurrence of electromagnetic fields and heat dissipation might pose the comparably bigger problem to the marine environment such recommendations should be critically examined.

New facts could be revealed by conducting research and by the application of effective monitoring programs to on-going developments:

- **Focus in research** should be laid on: 1) effects of heat dissipation on the marine environment, 2) impacts of electromagnetic fields on fauna, and 3) effects resulting from concentration of cables and other infrastructure in designated corridors.

- **Monitoring during cable installation and removal** could be concentrated on measurement of sound emission and on disturbance effects in general. In areas with elevated contaminant load the effects of contamination should be documented (recording of contamination levels in substrats and biota, specific effect monitoring). In environmentally sensitive areas additional aspects have to be addressed.
- For the **operational phase** a **monitoring** of seabed temperature in the vicinity of the cable and of generated electromagnetic fields should become a standard. Monitoring during cable operation also has to include investigation of the ecology of seabed (biogeochemical flow, composition and structure of benthic communities).

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