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Disturbances of Natural Physical Fields by Technical Activities and their Implications for Marine Life: the case of the Baltic Sea

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Abstract

The Baltic Sea has already been intensively used by variety of activities such as shipping, fishing, tourism, extraction of sand and gravel and oil and gas exploitation; there have been also introduced various constructions, e.g. coastal infrastructure, energy transmission cables and gas transmission pipelines. Over the next decades, the use of the Baltic Sea will expand substantially, particularly due to constructions of new coastal and offshore wind farms, energy transfer network, intensification of shipping, construction of new ports and terminals and setting new oil extraction platforms. Some of these activities interfere with natural physical fields at sea (such as acoustic, magnetic, salinity etc.) as well as disturb different natural processes (such as natural coastal dynamics, sedimentation, migration patterns of mobile species etc).

In order to illustrate this problem, most important existing activities as well as the most recent large-scale constructions in the Baltic Sea are selected, and the disturbances of natural physical fields including some possible biological effects of such disturbances are analysed.

Keywords: Baltic Sea, technical constructions, physical fields, environmental disturbances

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1. **Introduction**

Main environmental pressures on the Baltic Sea stem from nutrient loads, inputs of harmful substances, fishing and shipping. Pressures caused by technical activities, until recently, have not been recognized as a serious environmental concern. However, in recent years this status is changing rapidly. Growing intensity of shipping, construction of new oil and gas terminals, construction of numerous marinas, high voltage direct current (HVDC) development, power network and particularly construction of huge *Nord Stream* gas pipe as well as plans for construction of numerous wind farms have raised environmental concerns related to technical activities and to the large scale constructions (Andrulewicz & Otremba 2008, Andrulewicz et al. 2010).

Most publications on anthropogenic pressures of the Baltic Sea focus on chemical pollution (caused by hazardous substances or by excessive nutrient loads). Far less is known about introduction of various forms of anthropogenic energy into marine environment, which is also a form of marine pollution (GESAMP 1991).

Thus, there is a need for an integrated system for assessing and predicting risks from pressures coming from the introduction of technical objects into the marine environment – often very complexed and impacting large marine areas.

It seems very reasonable to consider the impact of technical objects on the marine environment in two aspects, namely:

- the impact of defined technical object on the natural physical fields at sea (assessing scale of modification of natural physical fields)
- the effect of modification of physical fields on marine biota

These (combined) knowledge will allow to assess the impact of technical activities on the marine environment.

Environmental disturbances, caused by technical activities may have various negative effects (Fig.1). For example, mechanical pressure on bottom sediments may have direct effect in keeling of benthic fauna but may also result in siltation which will further affect benthic flora and fauna and may release nutrients and harmful compounds from sediments. Acoustic pressure may effect in immediate keeling of some organisms close to the strong acoustic source but also may create long distance disturbances for migrating species. Electric transmission power cables may disrupt natural magnetic field and therefore confuse migration patterns of some species. Introduction of hard substrate in sandy areas will result in creation of new habitat for some species (reef effect) which is not obviously positive or negative (however, at present mostly recognized as positive). Various other effects will be noted. These effects will obviously depend on type of technical activities and selected marine site.

The authors have proposed the idea of physical fields concept to assess biological effects of these disturbances, briefly described the most important fields and the most important disturbances resulting from technical activities in inshore and offshore areas (Otremba & Andrulewicz 2009).

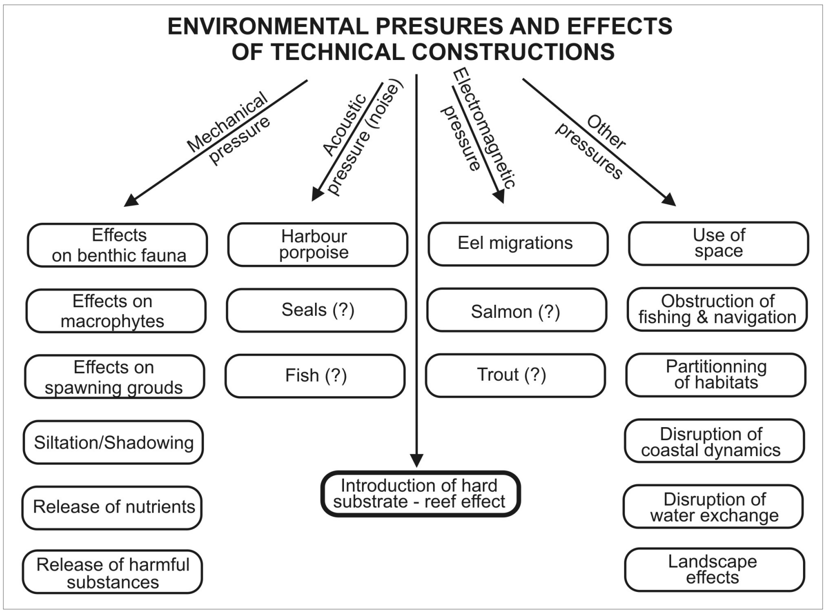


Fig. 1. Disturbances introduced by technical activities into the marine environment.

2. Disturbances of natural physical fields

Physical fields are classified as scalar or vector type. Scalar fields include spatial distribution of concentrations of chemical substances, salinity, temperature, specific density, dissolved oxygen. Vector fields include the distribution of electrical and magnetic fields (the electromagnetic field in contrast to the land areas plays marginal role), the propagation of acoustic waves, marine currents and the distribution of light radiation.

New installations as well as related technical activities will modify natural physical fields in marine space. Changes of natural parameters of various physical fields can disturb or even damage marine life.

2.1. Disturbances of acoustic field

The seas are filled with natural sounds of varied natural origin that they are created by wind and surface waves, gas bubbles, precipitation, thunder storms, movements of ice-floes, volcanic and seismic activity, marine organisms, etc. (Klusek 1986, Popper & Hastings 2009a, JRS/ICES 2010, Wagstaff & Newcomb 1987) (Fig. 2, left).

Contrary to air, sea water is a very favorable medium for acoustic wave propagation; therefore, some acoustic wave frequencies are transmitted for distances of thousands of miles (Orłowski 2008, JRS/ICES 2010). The spectrum of acoustic waves is subjected to transformation along the propagation distance from the source. This transformation depends on properties of water (temperature, salinity, density, and chemical composition of the water).

Various human activities produce noise in coastal and off-shore marine areas including ship traffic (Fig. 2, right), seismic surveys, drilling, military activities, underwater explosions, gravel extraction, wind farm constructions and operations, and others.

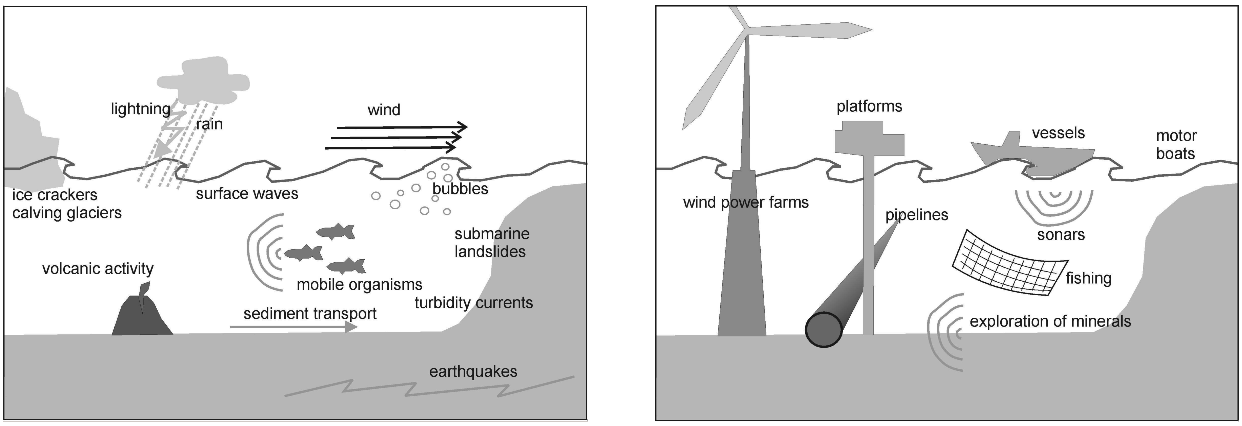


Fig. 2. Illustrative overview of possible natural (left) and anthropogenic (right) sources of acoustic field in the sea.

It is well known that some animal species can communicate by acoustic waves (JRS/ICES 2010, Popper & Hastings 2009b, SAMBAH 2009). Hearing ranges of animals are specific to species and differ from human hearing range. Some animals can emit and receive sounds at very low frequencies (infrasounds) (Frings & Frings 1967), while other can do so at high frequencies (ultrasounds) (Potter & Delory 1998, Engelmann et al. 2000). Animals can detect a sound when the source frequency corresponds to the animal's range of hearing frequencies and if the noise is louder than the animal's hearing threshold (Carlstensen et al. 2006, Zweifel 2009). Some sounds are temporary or permanent migration barriers for fish and mammals (Popper & Hastings 2009a). This knowledge is already being employed to construct pingers that deter mammals from fishing gears.

The noise can disturb or deter marine animals. Strong signals can frighten animals or even cause damage to them (Fig. 3) (JRS/ICES 2010, Popper & Hastings 2009b). Anthropogenic noise may also affect fish on spawning grounds and therefore affect their reproduction (Mosbech et al. 2000, Mitson 1995, Betke et al. 2004, Popper & Hastings 2009a). It may also be no effect, however at present we know nothing about long term exposure to elevated ambient noise level.

Marine mammals exhibit a similar range of responses to anthropogenic noise, depending on acoustic intensity and distance of noise (from injury/death to no effect). However, in case of cetaceans (eg. "Baltic" harbor porpoise) the consequences of noise pollution might be more serious than in fish (JRS/ICES 2010, Popper & Hastings 2009a, SAMBAH 2009).

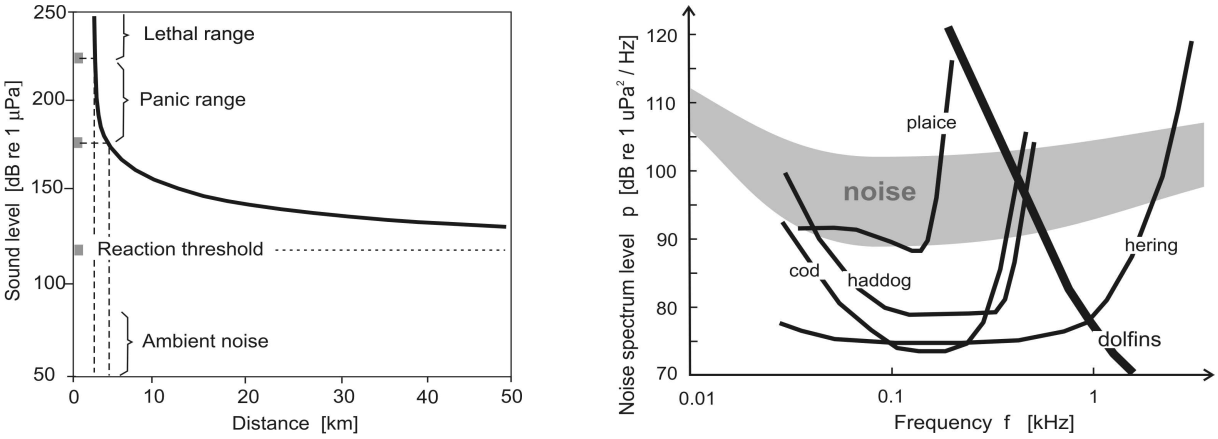


Fig. 3. Generalized responsiveness of cod to sound pressure levels from underwater blasts (modified from Mosbech et al., 2000) (left), and acoustic waves frequency spectra showing response threshold of some fish (right, fine lines) and marine mammals (thick line) to the noise created by pile (shadow stripe) at a distance of 100 m (modified from Mitson 1995 and Betke et al. 2004).

The most serious environmental impact of noise pollution may likely result from wind farms (Koschinski *et al.* 2003, Madsen et al. 2006, JRS/ICES 2010) (Fig. 3, right). Two types of noise are generated – high intensity construction (pile driving) and low intensity operational noise (rotors), both of which produce acoustic waves propagating over long distances (Orlowski 2008). During the pile driving phase, acoustic intensity signals may reach more than 200 dB re 1 μPa (BSH 2010) within the range of few nM which may damage fish (Popper & Hastings 2009b, Zweifel 2009) and mammals (Nowacek *et al*. 2007) (Fig. 3). For this reason, Germany has adopted some limits for sound pressure level, i.e. maximum 160 dB re 1 μPa (BSH 2010) for pile driving operations (Popper & Hastings 2009a). Therefore, during pile driving operations, introduction of some mitigation measures (e.g. bubble curtains) may be necessary.

Acoustic field disturbances is expected to increase rapidly in the Baltic Sea because of introducing new technical constructions such as: construction of numerous wind farms (Fig. 4), operations related to laying of the world longest *Nord Stream* (Fig. 5) gas transmission line, building of new marinas, development of ports and marine transport facilities and the use of sonars. Occasionally, high intensity noise will appear from the use of air guns during oil and gas exploration and from removal of conventional munition as well as during installations of wind farms. Dynamic growth of aggressive forms of tourism producing noise (e.g. high speed power boats, motor scooters) is rapidly raising in coastal areas (HELCOM 2010).

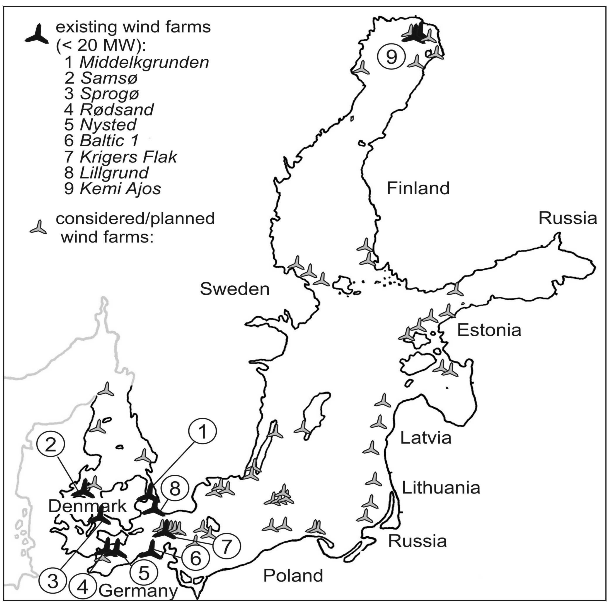


Fig. 4. Existing and planned wind farms in the Baltic Sea.

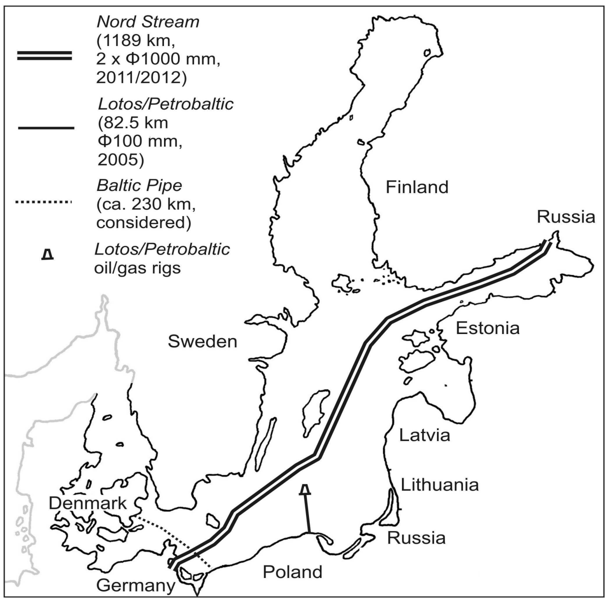
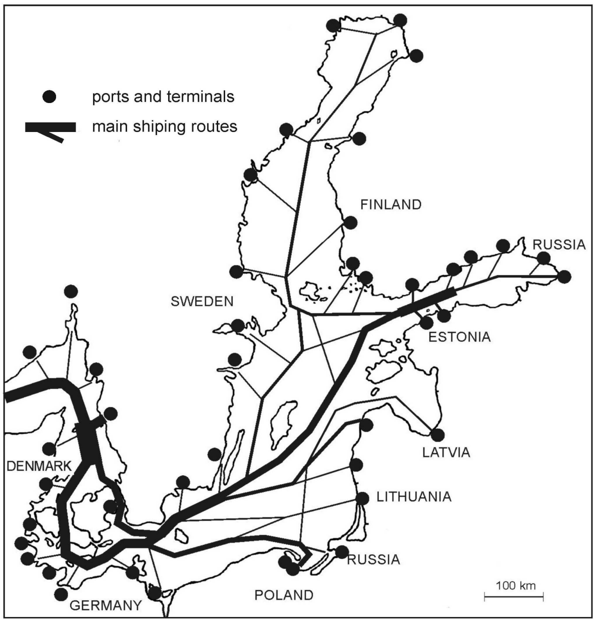


Fig. 5. Gas transfer pipelines in the Baltic Sea

HELCOM has produced a map of distribution of underwater noise in the Baltic Sea in 2003-2007 stemming from navigation intensity (HELCOM 2010) (Fig. 6), however, until now no holistic environmental assessment has been undertaken to asses possible acoustic pollution effects of these developments.



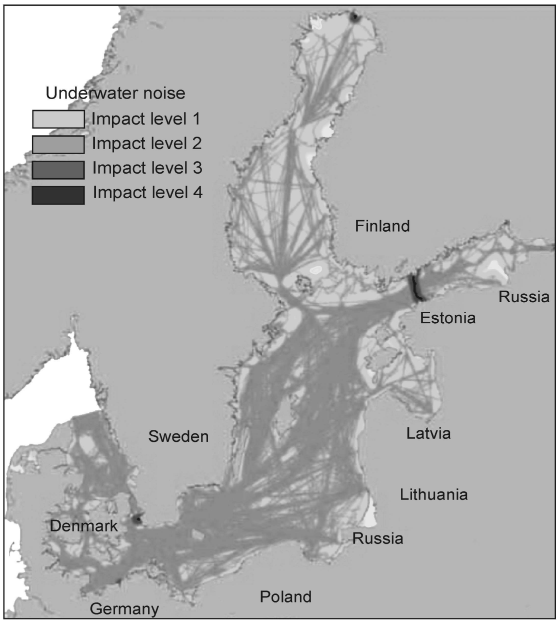
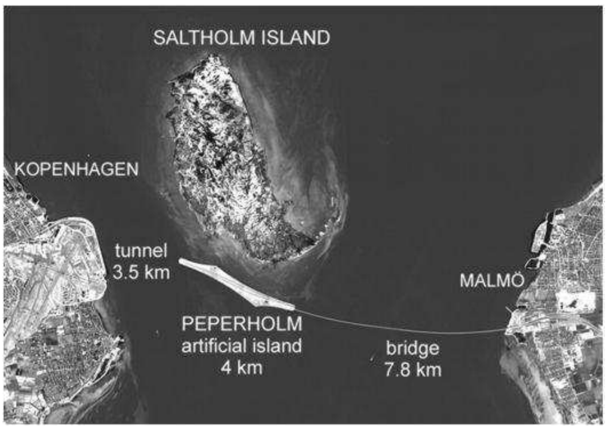


Fig. 6. Shipping routes (left) vs. underwater noise (right) in the Baltic Sea (modified from HELCOM 2010).

Recognizing problem of acoustic pollution, the Europen Commision Marine Strategy Framework Directive requests that underwater noise shall be reduced to the level that does not produce adverse affect to marine environment (EC MSFD 2008) and requests to introduce underwater noise (EC MSFD 2010).

2.2. Disturbances of marine current fields (natural water exchange processes)

Vitally important for the Baltic ecosystem is exchange of water with the North Sea. Disturbances of marine current in the narrow Danish Straits may have a significant impact on the whole Baltic Sea. Hard constructions placed in this area may reduce water exchange between the North Sea and the Baltic Sea. Therefore this issue was taken into serious consideration during construction of the communication link between Denmark and Sweden (Oeresund Link) (Fig 7, left). The potential blocking effect of the bridge piles was compensated for by deepening and widening Oeresund Sound (DHI 2010). Serious environmental problems appeared after construction of St. Petersburg Dam (Fig 7, right) due to limiting of water exchange of the inner part with the open part of the Neva Bay (Golubkov 2009).



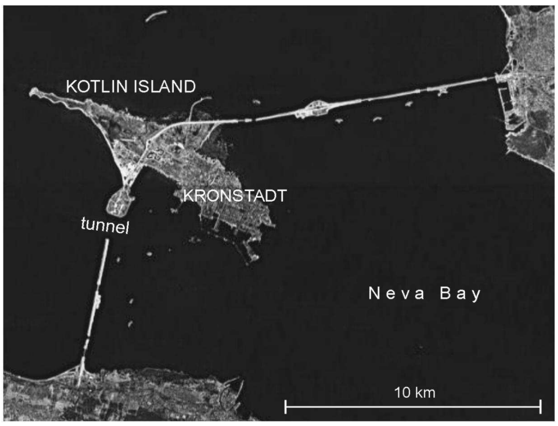


Fig. 7. "Oresund Link" connecting Denmark (left) and satellite image of the St. Petersburg flood barrier (right).

The construction of numerous wind farms in the Baltic Sea in the areas sensitive for water exchange should be avoided. In case disturbances affecting water exchange with the North Sea are predicted, the corresponding wind farms should be either relocated or abandoned.

Another serious issue is disturbance of coastal currents by coastal infrastructures (example Fig. 8, left) and by various technical measures undertaken against coastal erosion undertaken mainly in the southern Baltic Sea countries (example, Fig. 8, right). Construction of concrete walls as well as beach nourishment, etc. leads to disruption of natural coastal dynamics. In many cases, disruption of natural coastal dynamics leads to doubtful effects of coastal protection.

Fig. 8. Examples of coastal “hard” constructions: Władysławowo fishing port (left) (www photo) and concrete wall in the Puck Bay (right).

2.3. Disturbances of magnetic field

The earth magnetic field varies with geographical position. At the equator the magnetic induction of this field is approximately 25 μT, while at the poles reaches approximately 60 μT (Poleo et al. 2001). In the Baltic Sea, magnetic induction has varied within a narrow range of 50.1-50.2 μT during last few years (GOH 2010).

The magnetic field shows a cyclic variation between 0.01 and 0.10 μT every day (during magnetic storms variations can achieve the range up to 3 μT). In spite of these slight variations, the geomagnetic field should be considered to be very stable. Theoretically, the properties of the geomagnetic field could therefore be used by organisms as physical cues for the sensing of direction and position (Poleo et al. 2001). Diurnal fluctuations of the natural magnetic field in the southern Baltic area are smaller than one degree for both declination and inclination (GOH 2010). These fluctuations are modified locally by large ferromagnetic items on the seabed (steel wrecks, pipelines, etc.) and by electrical energy transfer cables, usually High Voltage Direct Current (HVDC) cables.

Anthropogenic disturbances of magnetic field are introduced to the marine environment whenever electric energy is transmitted from one point to another, and therefore generally is linked to operation of submarine cables (JRS/ICES 2010).

Disturbances of magnetic field in the Baltic Sea are expected from the network of HVDCs, and from the electricity transfer grids from marine farms (Fig. 9). There are currently dozen HVDC systems in permanent use in the Baltic Sea (Otremba & Andrulewicz 2008, Larsson 2010), and the *SwePol Link* which operates between Poland and Sweden is the longest at present (230 km) is the (Andrulewicz *et al*. 2003, SNBF 2009).

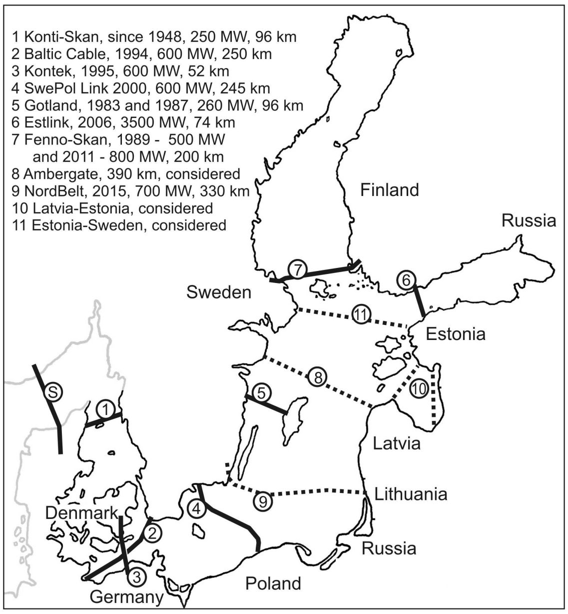


Fig. 9. Present and planned High Voltage Direct Current (HVDC) electric power cables in the Baltic Sea (after various sources)

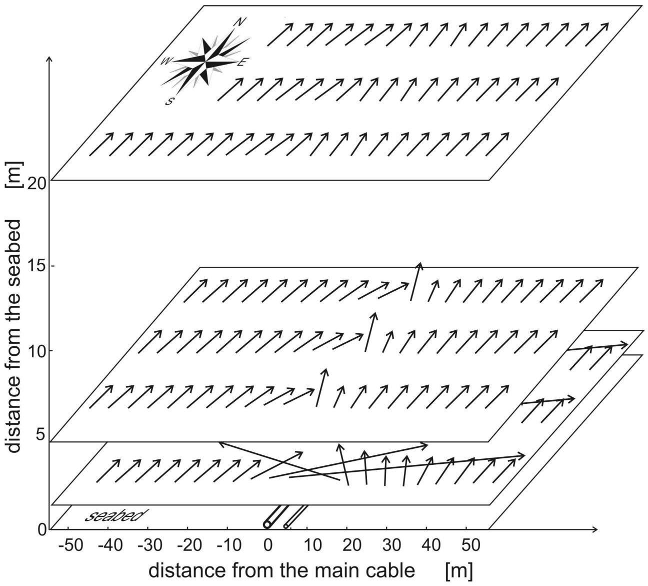


Fig. 10. Modification of magnetic field declination (an example) in the vicinity of *SwePol Link* HVDC

Magnetic field is induced by electric current in cables and linearly depends on value of intensity of electric current. In the vicinity of the HVDC systems, modifications of both value and direction of the induction vector are observed. An example of magnetic field modifications versus chosen distances from the seabed (1 m, 5 m, 20 m) is shown in the Fig. 10 (the distance between main and return cable is assumed to be about 5 m). If the distance between cables grows – magnetic field declination also grows. When cables are close to each other, the disturbances are minimal. Distribution of the modified magnetic field around the HVDC system depends also on orientation of cable to natural magnetic field.

A concern is raised that the magnetic field around HVDC cables may affect fish migration (Rochalska 2009, Souza 1984). Specifically some fish (e.g. eel and trout) may use the geomagnetic field for orientation (Kalmijn 1978, Karlsson 1984, Souza et al. 1988, Tesch & Wendt 1992, Wiltschko & Wiltschko 1995). Until now, little is known about the effects of local disturbances of magnetic field. Various research projects (SNBF 1997) have not produced definite results, particularly in relation to effects of HVDC on eel migration (Andrulewicz *et al.* 2003, SFI 1999).

Natural geomagnetic field will also be modified by energy transfer from offshore wind farms to land electrical network. Assuming that sector of wind farms will continue to grow, there will be set of many thousands of km of cables crossing the Baltic Sea. Environmental effect will depend on the applied solution (AC or DC cable nets). This issue will require information on the proposed technical solutions.

2.4. Disturbances of electric field

Electric fields in marine water masses can be temporarily generated due to spatial changes of salinity and temperature as well as by geophysical processes below the seabed. Also electric fields, caused by seawater movements through the geomagnetic field, have been measured between 5 and 50 μV/m (Enger 1992). Electric fields can also be generated by ship movement (Rannou & Coulomb 2006, Nakamura *et al.* 2006). However these fields are weak and possibly not significant to marine ecosystem. Electric fields (up to 1 mV/m) may also be locally created by some marine organisms (Moller 1995).

Artificial electric fields in the marine hydrosphere can be important when transferring electric current by electrode type solution (one cable) HVDC line. In this system water masses serve as a conductor between two electrodes situated on the sea bottom (Andrulewicz *et al.* 2003). In the vicinity of the electrodes (order of several centimeters), the strength of electric field may rich a few volts per meter (V/m). Fig. 11 presents distribution of the intensity of electric field in the vicinity of electrode which declines rapidly in a short distance.

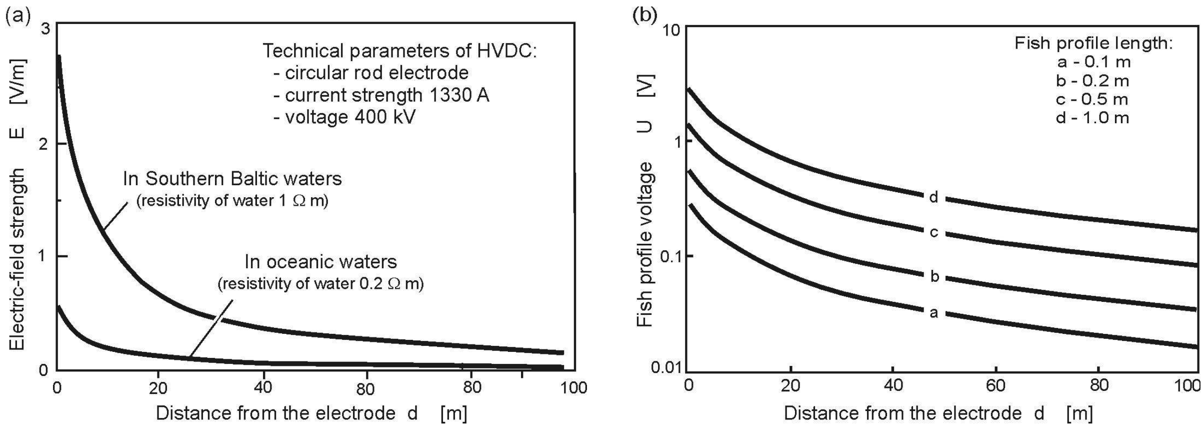


Fig. 11. Electric field in the vicinity of electrode: (a) drop of electric field vs. distance from the electrode, (b) examples of decline of fish-silhouette-voltage in the function of distance from the electrode for various fish sizes (elaborated by the authors).

"Electrode type solutions" of electric energy transfer (most of transfer systems in the Baltic) are dangerous for organisms close to the electrode. However, this is a local problem not causing large scale damages. Nevertheless, more "environmentally friendly" solutions are possible and shall be required. In the case of *SwePol Link* "electrode type solutions" was banned for the sake of local environmental safety. Solution with a return cable instead of electrode type was chosen and therefore some environmental disturbances were avoided (Andrulewicz *et al*. 2003).

2.5. Disturbances of optical field

Natural optical climate in the open waters of the Baltic Sea depends on the season and it significantly varies in productive and in winter season. It also varies among the Baltic sub-regions and it depends on a distance from the coast, particularly from the river mouths. Present optical climate in the Baltic Sea is seriously deteriorated by anthropogenically stimulated plankton growth in the production season.

Anthropogenic disturbances of optical field at sea may occur in the water column due to mobilization of sediments to water column during dredging and/or dumping activities as well as during construction and setting up various installations on the sea bottom. The release of sediment particles into water column as well as environmental effects of this release depend on local conditions (sediment type, water depth, technical gear applied etc).

The most sensitive to light availability (shadowing), are benthic macrophytes particularly those living at their depth limit (in Baltic usually 5 to 15 m), e.g. reduction of bottom vegetation coverage (by 30 %) due to shadowing was observed during the construction of Oeresund Link (DHI 2010). Disruption of light availability will also affect primary productivity, however the consequences for primary productivity will not be as critical as those regarding bottom vegetation.

Disturbances of optical field occur locally during dredging and dumping of sediments. Dredging may have significant effect due to increased turbidity which may affect local macrophyte communities. Brief periods of light disturbances occur during beach nourishments (turbidity) and setting new coastal constructions in coastal areas. However, due to the limited scale of these activities no serious effects of optical disturbances have bee observed so far.

Some effects of light disturbances can be expected during wind farms constructions. Layering of cables may stir up silt from the sea bottom (release particles into seawater) and therefore affect optical field.

2.6. Disturbances of salinity field

Salinity is the best recognized property of seawater. The salinity field is very stable with the exception of estuaries and river mouths where fresh water mixes with seawater. Anthropogenic disruption of salinity field occurs when industrial fresh water is discharged to the sea or salt brine (hypersaline water) is released into marine environment.

Industrial fresh water discharge usually occurs when cooling water is discharged from power stations to the coastal marine area. This is usually a local case, limited in volume, and the cooling water is mixed quickly with surface sea waters by winds and waves (see next chapter).

Hypersaline water is discharged into the open part of Puck Bay in Poland (from construction of salt cavern near Gdynia) applying a forced dispersion of salt brine at the discharge location (Robakiewicz 2009). Environmental threat can be posed by the possible separation of the water column into two layers of different density. Density stratification usually leads to oxygen deficits in the bottom layer and may cause mortality of bottom organisms. The discharge remains under continual observation, until now no negative environmental effects are observed. In case of water stratification will appear, the salt-brine discharge will be discontinued.

2.7. Disturbances of temperature field

Water temperature regulates physiological processes of marine organisms and in fact regulates seasonal functioning of the whole marine ecosystem. Temperature field in the Baltic Sea fluctuates seasonally and locally from 0^{o} C to above 20^{o}C.

Anthropogenic disturbances in the natural temperature field of the marine environment occurs when heated water is discharged from cooling systems (usually from power stations). The best known case of discharge of cooling water is experimental atomic power station in Forsmark, Sweden where heated water discharge is used for aquaculture and various experimental purposes (Sandstroem 1999).

Temperature field can also be disturbed when cooled water is discharged from heating systems (e.g. from regasification of liquid natural gas - LNG). The scale of the phenomenon will depend on the quantity and temperature of the discharged water, and on selected discharge place. This discharge might create at least a temporary barrier for fish migration patterns. As yet, there are no cases of such discharges in the Baltic Sea, however, this will happen after construction LNG terminals and regasification of LNG in Świnoujście, Poland (www MOS).

3. Concluding remarks

Baltic Sea is already under technical pressures stemming from existing activities and technical constructions. Until recently, these pressures (besides shipping and fishing), have not been recognized as a serious environmental concern. However, recent developments indicate that we face significant changes in the use of the Baltic Sea space and services. There are planned numerous new constructions: oil and gas terminals, marinas, development HVDC power network and particularly construction of numerous wind farms. These developments will bring new pressures onto Baltic environment.

We are convinced that we are far from full understanding environmental effects of coming environmental disturbances. As it has been demonstrated, these disturbances are very diversified, and they relate various environmental properties and processes. These disturbances may affect marine organisms, particularly those from the higher level of the food chain: mammals, ichthyophauna, macrozoobenthos and macrophytobenthos.

To assess environmental effects and consequences of new technical activities, we propose to utilize concept of physical field disturbances. In our study we analyze modifications of exemplary/selected fields, namely: acoustic, marine currents, magnetic, electric, light, salinity and temperature as well as possible impacts of these modifications on marine environment. It is quite possible that in the future, the other types of natural field modifications shall be considered.

We assume that EIAs for a selected technical activity as well as for the defined technical installations shall be carried out in two stages:

a) description/assessment of disturbances of natural physical fields
b) description/assessment of biological effects of these disturbances

For the impact assessment, it is necessary to recognize that some technical activities have a large (pan-Baltic) scale (e.g. navigation, fishing, coastal infrastructures, wind farm constructions, electric power cables), therefore they should also be the cases for the Strategic Environmental Assessments (SEA). Some other activities, have a local nature (e.g. sediment disturbances, salt-brine discharges, cooling water discharge) and therefore Environmental Impact Assessment (EIA) as well as relevant case studies should be sufficient.

Physical-field-approach for the assessment of implications of new technical activities should be considered in the Maritime Spatial Planning process to avoid serious environmental and societal conflicts and to fulfill requirements of the EU Maritime Strategy Framework Directive.

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