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Physical fields during construction and operation of wind farms by example of Polish maritime areas

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ABSTRACT

The article discusses an important issue of technical pressure exerted on the marine environment during construction and operation of maritime wind farms (MFW) on waters of the Polish Exclusive Economic Zone. A motivation for analysing this issue is the need for attracting attention to the aspect of physical field modification as the factor which links large scale technical activity at sea with the existence and functioning of the marine ecosystem, including further consequences to its economic benefits. Based on current knowledge and authors' analyses, the scale of modifications (disturbances) of physical fields expected to take place during MFW construction and operation was assessed.

Keywords: marine environment, wind farms, physical field, large scale constructions, marine spatial planning

Introduction

Traditional use of maritime areas for sailing and fishing has been extended nowadays to cover new types of technical activity. Large scale constructions are appearing at sea, including: oil and gas rigs, gas and oil pipeline networks, electric energy transmission networks [2], road traffic routes (bridges, tunnels, artificial islands), communication lines (optical fibres) and installations for production of electric energy. In Polish maritime areas the electric energy is planned to be obtained via conversion of wind energy, while in other maritime areas devices making use of energy of waves and tides are also installed [29].

As far as the conversion of wind energy to electric energy is concerned, the most favourable areas for building sets of wind power plants are the shelf areas and shallow seas. More than ten wind farms work at the Baltic Sea area, of which most of electric power is delivered by "Rodsand II" (207 MW, Denmark, from 2010), "Nysted" (166 MW, Denmark, from 2003) and "Lillgrund" (110 MW, Sweden, from 2008). Sets of wind power plants (maritime wind farms - MFW) also produce electric energy in the maritime areas of Germany and Finland. Within the Polish Economic Zone, attention of investors involved in maritime wind farm industry is focused on the areas surrounding the Slupsk Bank, the Middle Bank, and the Pomeranian Bay (Fig. 1). The Slupsk Bank itself (down to the isobath of 20 m) and the stretch of coastal water are not taken into account in MFW installation projects, due to their status of protected areas [12].

Comparing the electric power produced so far by MFW's installed in the Baltic Sea with the power theoretically available from Polish maritime areas – estimated as equal to 6 to 9 GW – [35], leads to the conclusion that in the nearest decade Poland can become a largest producer of electric energy in the Baltic Sea region.

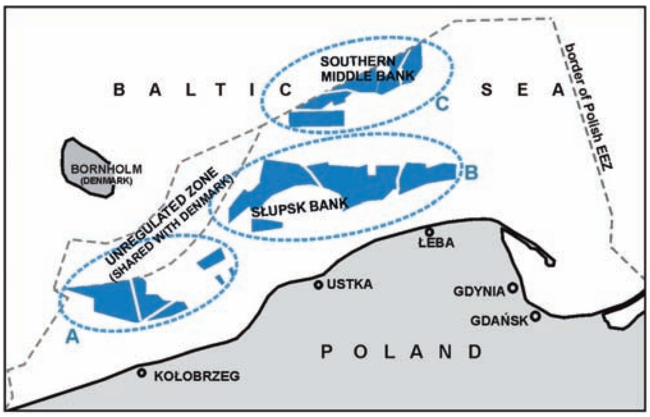


Fig. 1. Southern Baltic Sea areas proposed for installation of maritime wind farms: A - Bornholm Basin, B - Slupsk Bank, C - Middle Bank, based on the map published by the Ministry of Transport Construction and Maritime Economy

Like any form of technical activity, maritime wind farms contribute to permanent or temporal modification of quantities which characterise the maritime space. In Polish maritime areas, both construction and operation of MFW's can be locally accompanied by changes in distributions of natural physical fields and concentration of chemical compounds important for functioning of the marine ecosystem of the Southern Baltic Sea.

Polish maritime areas – Internal Waters (2004 km2), Territorial Sea (8682 km2), Polish Exclusive Economic Zone (22000 km2) – occupy the area of more than 33 thousand km2, which is approximately equal to 10% of the land area of the Republic of Poland (311888 km2). In these areas, regions which are favourable for installation of wind farms amount to about 1500 km2 [34; Żygowska, 2013]. From the oceanographic point of view, the Polish maritime areas represent various morphological forms, among which deep basins (Bornholm Basin, Gdansk Basin), sandbanks (Odra Bank, Slupsk Bank, Southern Middle Bank), bays (Pomeranian Bay, Gulf of Gdansk) and lagoons (Szczecin Lagoon, Vistula Lagoon) can be named. A distinctive morphological structure is the Slupsk Furrow, through which water exchange between the Western Baltic Sea on the one hand, and the Gotland Basin and the Gdansk Deep on the other hand takes place (Fig. 2).

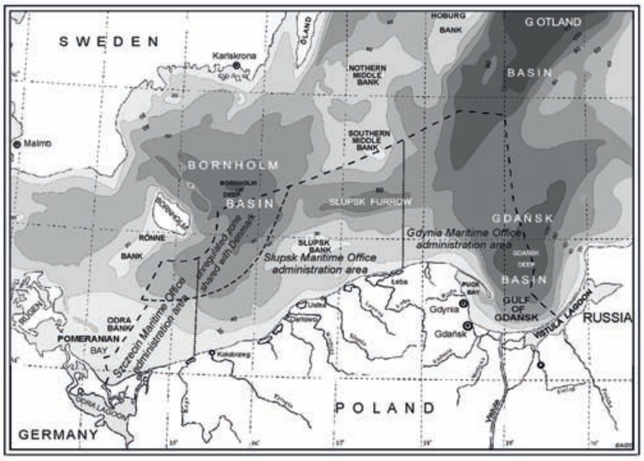


Fig. 2. Polish Maritime Areas – morphology and administrative division.

Like for the entire Baltic Sea, the topography of the seabed is closely related to glacier activity. In the southern part of the Baltic Sea, the post-glacial accumulation material, the thickness of which reaches several hundred metres, has been preserved on the rock basement of the Finnish-Scandinavian plate. This material is mainly composed of clay, sands, gravels, stones and boulders. Mineral-organic suspension carried by numerous rivers to the Baltic Sea and the sediments formed from dead organisms permanently accumulate on the seabed. Transported by sea waves and currents, the suspension moves towards deeper areas of the sea, where it is permanently accumulated in deep basins. In case of the Polish maritime areas, they include the Bornholm Basin, the Gdansk Basin and the southern verge of the Gotland Basin.

The Baltic Sea is a turbulent sea. Depending on the water region, the sea state exceeding 3°B occurs in 160 to 320 days per year (IMGW, 1987-2012). During storms, the height of the waves can reach as much as 6 m. The action of waves is perceived down to the depth of 12 m, while the mixing of waters caused by this action can reach as deep as 40 m. Surface water currents of the Baltic Sea depend on the wind situation. The speed of the currents does not exceed 10 cm/s in general, although it can reach 20 - 40 cm/s during and after storms (IMGW, 1994).

Due to subtly salty nature of the water, the flora and fauna of the Baltic Sea is poor in diversity of species, but, on the other hand, high fertility of the water makes it rich in biomass. At present, negative effects of excessively high fertility of waters are recorded. In the summer, intensive plankton blooms can be observed, which leads to remarkable decrease of surface water transparency. Once dead, these plankton blooms contribute to excessive consumption of oxygen in deep waters, where so-called stagnating zones are created.

To the present, no set of wind power plants has been built in the Polish maritime areas, therefore it is impossible to collect results of in situ research. However, the scale of the planned investment projects forces analysing the expected effects of wind farm installation. For the time being (July 2013), 65 applications for authorisation for wind farm installation were submitted by investors to the Ministry of Transport and Maritime Economy (formally these authorisations concern construction of artificial inlands) [PSEW, 2013]. The water regions intended to be used for MFW's were proposed by the Maritime Institute of Gdansk [MTBiGM, 2013].

Like the land space, the maritime space is penetrated by the energy of acoustic, electric, and magnetic fields. Technical activity introduces energies to the ecosystem which in some cases can be considered sort of impurity, like chemical and biological impurities [GESAMP, 1991].

The time of MFW construction is characteristic for: the increased level of noise, the release of harmful and biogenic compounds from seabed sediments, the renewed suspension of solid particles, and disturbances in the transport of sediments [Otremba and Andrulewicz, 2008]. On the other hand, the operating phase brings modifications of physical fields resulting from the transmission of the produced electric energy to inland receivers. The scale of these modifications is difficult to assess, due to limited knowledge about characteristics of natural physical fields in the seawater space. Nevertheless, there are some indications that marine organisms make use of physical fields both in mutual communication and directional orientation [15, 34, 36, 8, 40, 32, 22, 11, 39, 26, 30]. The physical fields create in water bodies a special climate in which marine organisms got used to live.

The analyses presented in the article base on current technical assumptions concerning the designed maritime wind farms which investors include to their submissions for authorisation for construction. They also take into account the knowledge about natural environmental conditions and the information gained from construction of similar wind farms in other maritime areas.

Disturbances of natural physical fields

The maritime space, as related to the management of live marine resources and taking into account introduction of large scale technical constructions, should be understood as the space penetrated by numerous physical fields, including electric, magnetic, electromagnetic and acoustic fields. Each of these fields is characterised by a component of natural origin and a component of anthropogenic origin resulting from technical activity. Along with depending on such traditional elements as transport and fishery, the component of technical origin is being more and more dependent on new forms of activity connected with the economic development of the Baltic Sea region, constituted by 8 EU countries and Russia and linked together via the maritime space. Focusing attention on issues concerning maritime wind farms makes it possible to notice certain phenomena connected with the modification of physical fields. For instance, it is the acoustic field which is most heavily disturbed during construction (in particular when the technology based on driving piles into the seabed to keep up the towers of the wind power plants is applied), while during the operation the most disturbed fields are the magnetic, electric and electromagnetic fields (due to the presence of networks of cables for electric energy transmission).

Modification of electromagnetic field

The electromagnetic field represents energy transmission in the form of electromagnetic waves, therefore it would be natural to express it as a function presenting the amount of wave energy around a given wavelength which penetrates in space the unit area in the unit time in relation to the unit wavelength (provided that the integral of this function over all wavelengths gives the wave power per the penetrated unit surface). In practice, the electromagnetic field is expressed using the RMS values of one component of this field, i.e. either the magnetic field, or the electric field. In the non-conductive space the constant electric field is referred to as the electrostatic field. In contrast, in the conductive space, such as sea water, the electric field can exist as generated by the motion of electric charges and rapid changes of the magnetic field. The former case refers to the electric field which exists in the vicinity of electrodes submerged in the sea depth. This situation has place when the electric energy transmission system makes use of direct current (HVDC) in a so-called electrode solution (this subject will be discussed in Section 2.3). In the latter case, the electric field being a consequence of magnetic field changes is generated by natural changes of the geomagnetic field caused by processes taking place inside the Earth and the flow of protons emitted by the Sun surface in the terrestrial space. Information can be found in the literature that some marine organisms also generate the electric field and use it to mutual communication and for consumption purposes [17]. The existence of the natural electromagnetic field in the sea depth has been confirmed experimentally, but the information about the strength of this field is highly incomplete. This strength is likely to range from several tens of microvolt per metre to several hundreds of millivolt per metre [22].

In case of wind farms, remarkable modifications of the electromagnetic field can be expected along the transmission lines if the AC method of electric energy transmission is adopted. According to the three-phase method of electric energy production, transmission and distribution which is in use in power engineering, it should be assumed that the transmission lines are composed of single cables with three cores inside, or three single-core cables coupled into one bundle or aligned at a distance from each other. In the steady state, i.e. when the strength of the electric current does not change, the electromagnetic wave emitted by the transmission line cables will be a superposition of three waves of frequency 50 Hz shifted by the phase of 120^o with respect to each other. Laboratory tests performed by the authors have not brought the evidence which would confirm the effect of seawater on the propagation of electromagnetic waves of frequency 50 Hz. Consequently, spatial distributions of the electromagnetic field in the seawater should be similar to those measured in the air. Moreover, it was noticed that the induction calculated for a rectilinear conductor with direct current is the same as that measured for the alternating current of 50 Hz frequency the RMS value of which is the same as the strength of the current in the DC conductor. Fig.3 shows the measured and calculated distributions of the electromagnetic field, which were estimated in laboratory conditions by measuring the magnetic component of this field generated by an AC conductor of RMS strength equal to 8,6 A, and by a bundle of two conductors with equal currents of 8,6 A, phase shifted by 120^o with respect to each other. In case of a bundle of three AC conductors with currents of equal strengths and phase shifted by 120^o, the electromagnetic field disappears (full mutual compensation of the fields generated by particular conductors takes place). In contrast, for a three-core cable used for transmission of three-phase current (axes of conductors situated at vertices of a triangle having an edge of several centimetres), the distribution of the electromagnetic field at a small distance is complicated (as superposition of the fields generated by cores which conduct different-phase currents, and additionally disturbed by the presence of metals in the electric current cores and the wrapper). At a distance of an order of ten diameters of the cable, the field does not practically exist. But switching off the current in one or two cores increases the field induction to the level observed when the current flows only through one core.

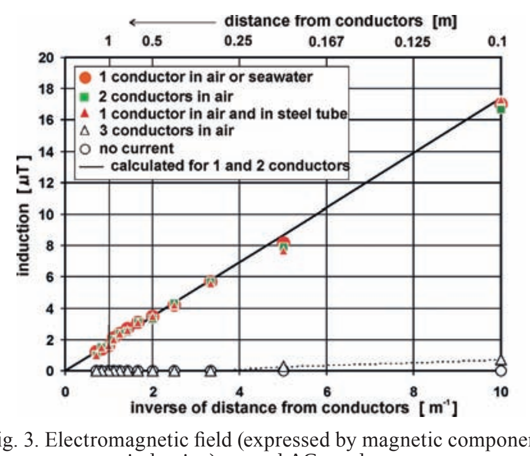


Fig. 3. Electromagnetic field (expressed by magnetic component – induction) around AC conductors

The electric component of the electromagnetic field generated by 50 Hz AC conductors also exists, which results from the theory of electromagnetism expressed by Maxwell equations. However, it is difficult to measure in such a conductive medium as seawater. The report on the electromagnetic field in the vicinity underwater electric power cables, elaborated by the Centre for Marine and Coastal Studies in USA (COWRIE) [6], gives the following relation between the electric field and the magnetic field:

$$E = k\,2\,\pi f B$$

where:
E – strength of electric field, in V/m
f – frequency of electric current, in Hz
B – induction of magnetic field, in T (Tesla)
k – constant, in m-1

The constant k has not been defined so far for all types of waters. The past analyses of the electric field generated in seawater by an AC conductor assumed $k = 1\ m^{-1}$ [30]. Consequently, the current literature information concerning the electric component of the electromagnetic field in seawater is of solely qualitative nature.

Modification of electric field

The sea depth is the medium which conducts the electric current, therefore electrostatic fields do not exist in it. Nevertheless, electric fields having the form of small-range fluctuations can be recorded in the sea depth. These fields are generated by sea currents, spatial changes of temperature and salinity, or by moving vessels [18]. They can also be generated by marine organisms as a form of their physiological behaviour [17]. The strength of these fields does not exceed 1 mV/m [11].

The way in which the electric energy generated in the maritime areas its transmitted to inland transmission networks can become an issue of high importance for functioning of the marine ecosystem. Here, possible options of transmission systems make use of either direct or alternating current. In case of direct current, choice can be made between the electrode version (with energy transmission via the sea depth – like, for instance, in the Baltic Cable system used between Sweden and Germany), and the version with a return cable, to replace the electrodes, and the water depth (like in the SwePol Link system used between Sweden and Poland). Both versions – with electrode and return cable – can be used in a monopolar or bipolar solution (two main cables on the opposite potentials with respect to the electrodes or the return cable). In each case the modification of the seawater space will take a different course.

Unlike the modification of the electric component of the electromagnetic field, the electric field is modified when the electric energy is transmitted using direct current (HVDC), but only in the electrode solution. Figure 4a shows approximate curves of the relation between the electric field strength and the distance from the electrode, calculated by the authors based on a simplified model of the electrode – a sphere with equivalent surface. This model gives a solution in the form (2).

$$E = \frac{I\rho}{4\pi}\left(d + \sqrt{\frac{S}{4\pi}}\right)^{-2}$$

where:
E – strength of electric field, in V/m
d – distance from electrode, in m
I – strength of electric current, in A
ρ - specific resistance of water, in Ω•m
S – surface of electrode, in m^2

The curves shown in Fig. 4a, have made the basis for calculating the electric voltage drop for different fish profile lengths in relation to their distance from the electrode. Results of these calculations are shown in Fig. 4b. In direct vicinity of the electrode the voltage reaches values of an order of 1 V and can be perceived by marine organisms [22].

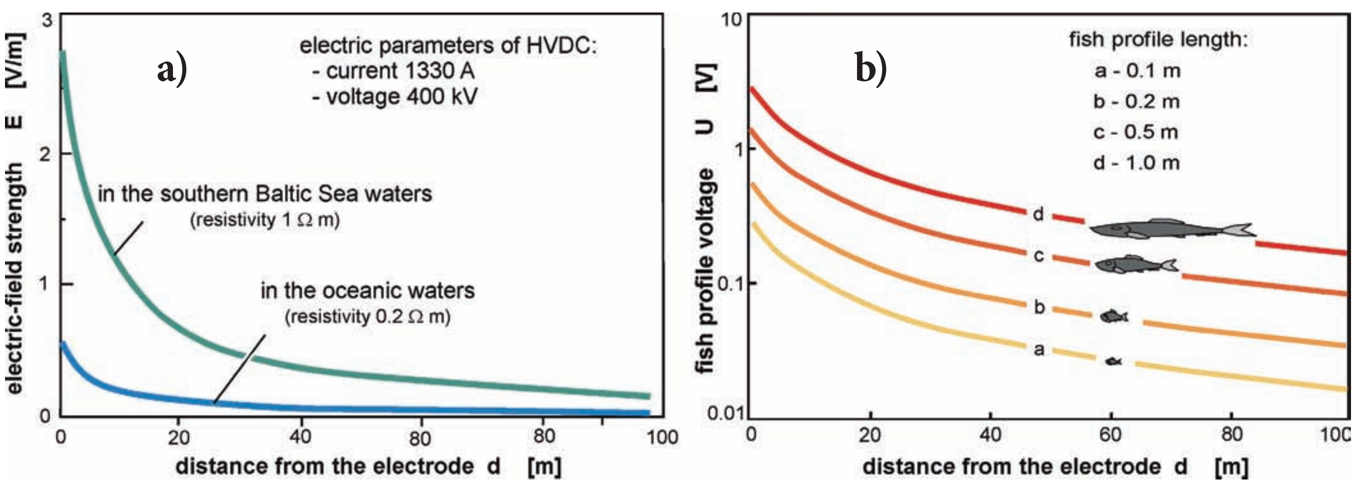
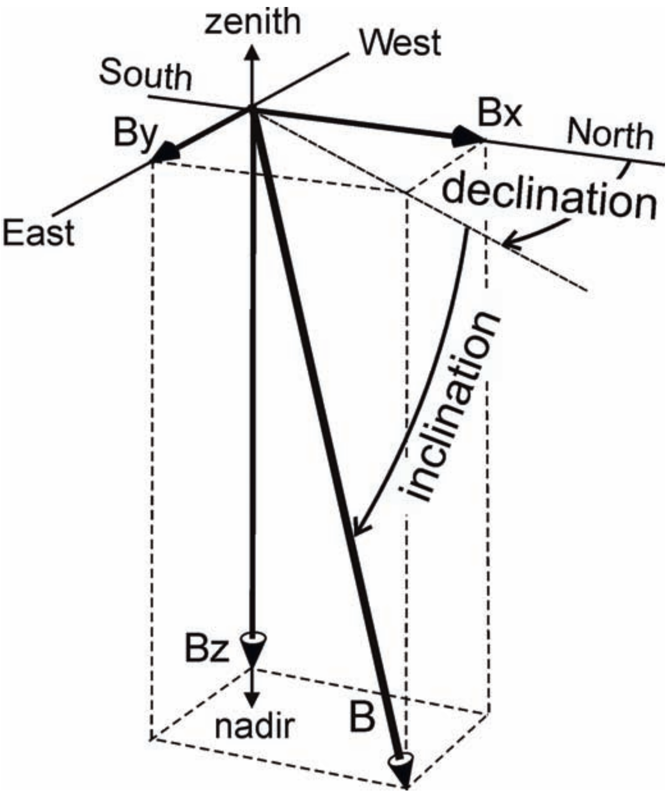


Fig. 4. Electric field generated by the electric current flowing in the seawater depth (a) and fish profile voltage in this field (b) in the vicinity of the electric power transmission system electrode in HVDC solution (relations calculated by authors using the model in which the electrode surface S = 450 m2 is represented by the surface of an equivalent sphere).

In case of the SwePol Link system used between Poland and Sweden, the electrode solution was replaced by that with a return cable. A real motivation for this modification was to avoid problems connected with the release of molecular chlorine on the positive electrode during the operation of the HVDC system (on the Swedish side), and not to introduce the electric field to the sea depth [39].



Modification of magnetic field

Like for electric field generation, the problem of modification of the magnetic field of the Earth is related to high-power electric energy transmission systems making use of direct current. The disadvantage with respect to the electric field is the presence of electrodes, while the main problem for the magnetic field is the electric current flowing in the cables. In preset transmission systems the strength of the electric current equals approximately 1300 A, which leads to the generation of a relatively strong magnetic field in the vicinity of the cables. This field superimposes onto the natural field of the Earth. Here, of high importance is the modification of the direction of the natural Earth's field which is used for orientation by some marine organisms in their consumption and procreation oriented migrations. The intensity and direction of the magnetic field is given by a vector quantity – strength of the magnetic field, or magnetic induction (in water the induction is proportional to the strength of the magnetic field, and the proportionality coefficient is the magnetic permeability of the medium). The natural field is most often characterised by the value of its horizontal component, and the declination and inclination (Fig. 5). In the electrode solution, modification of the natural Earth's field is stronger than in the solution with the return cable. If the cables are situated close to each other, the modification becomes negligibly small at as such short distance as a few metres. Sample inclination and declination changes are shown in Fig. 5, as compared to the referential one-day fluctuations of the natural Earth's field (recorded at the Geophysical Station at Hel).

Changes of the magnetic fields in the vicinity of the transmission system can confuse organisms approaching this zone [15, 31, 34,]. The dimension of the zone (distance, at which the modification decreases by 10 times) does not exceed several tens of meters. The behaviour of organisms in the rapidly changing spatial magnetic field has not been precisely identified yet, therefore in cases of concentration of larger numbers of HVDC systems their remarkably unfavourable effect on migrations of certain species of marine fauna cannot be excluded.

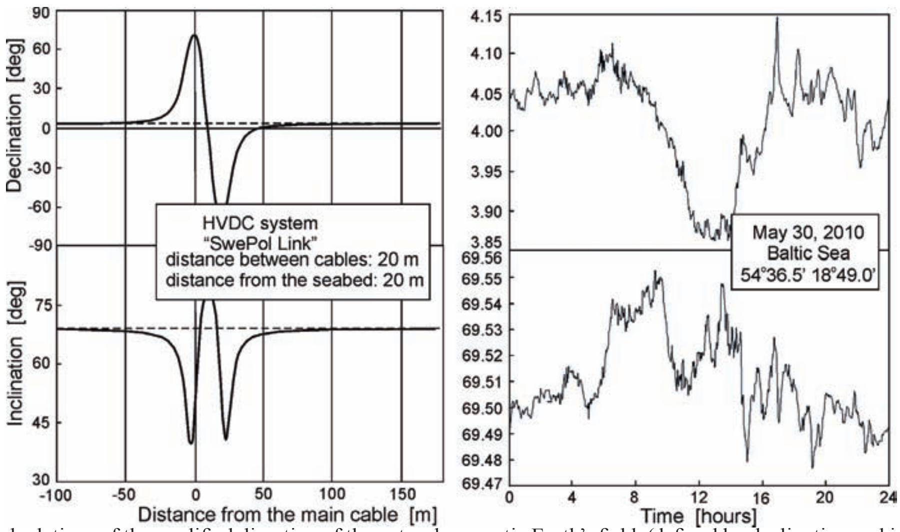


Fig. 5. Sample authors' calculations of the modified direction of the natural magnetic Earth's field (defined by declination and inclination) in the vicinity of the HVDC transmission systems (20 m over cables distributed at a distance of 20 m) in monopolar solution with return cable (like in SwePol Link system), as compared to one-day fluctuations of the natural Earth's field - data obtained from the Geological Institute Observatory at Hel

When the main cable is carefully positioned with respect to the return cable, i.e. close and parallel to it, the scale of the measurable modification of the magnetic field is small, of an order of a few metres, due to mutual neutralisation of the fields.

Modification of acoustic field

The sea depth is naturally penetrated by sounds the origin of which can be marine organisms, wind, surface waves, rainfalls, lightning, migration of ice, motion of sediments due to the action of sea currents, and volcanic and seismic activity [7; 38; 20; McDonald et al., 2006] .

Along with the sounds of natural origin, sounds being the result of human activity are also propagated in the sea. Basic sources of these sounds include: ships, ferries, hydrofoil boats, yachts, battle ships, airplanes, facilities for underwater navigation and fish shoal search, sea depth research and monitoring systems, installations for search and/or exploration of gas, crude oil, and minerals, wind farms, pipelines, etc. [23; 24].

The influence of sounds on marine organisms depends on spectral density of the sound intensity level, or more briefly: the sound spectrum. This function, expressed in decibels (dB), is proportional to the strength of the acoustic wave penetrating the unit surface (expressed by default as the square of the effective acoustic pressure) in the water depth with respect to the quantity proportional to the strength expressed by the acoustic pressure equal to 1 square micropascal (μPa^2) per unit frequency expressed in hertz (Hz). Consequently, the vertical axis of spectral diagrams is labelled by the unit "dB re 1 μPa^2 / Hz", while the unit on the horizontal axis is "Hz" [37]. A characteristic feature of the spectrum diagram presented in this way is that integrating the spectrum curve within given frequency limits gives a quantity proportional to the strength of the flow of sounds penetrating the unit surface in water environment within these frequency limits (in units: "dB re 1 μPa^2"). The logarithmic scale is justified by physiological features of the organ of hearing.

The spectral range of audibility of seawater animals differs. Some animals can produce and receive low frequency sounds (infrasounds, vibrations), while other – high frequency sounds (ultrasounds) [25]. Depending on propagation conditions in the sea, the spectrum of the generated sound is subject to transformation, which increases with the increasing distance from the source. This effect explains the phenomenon of dispersion (different sound speeds for different frequencies) and absorption of the sound energy, which also depends on frequency. In the water depth, dispersion and absorption of sounds is affected by: (1) the distribution of temperature, salinity, and density of water, (2) the presence of gas bubbles and the level of sea surface undulation [19], and (3) the presence and contents of some chemical compounds [9]. As far as the effect of the seabed is concerned, significant factors are: its shape, type of material composing it, and the layer structure of the sediments [5]. Particular water regions are characteristic for a natural acoustic field to which marine organisms have been adapted [1].

Technical activity in the sea introduces new sounds which modify the "underwater acoustic climate". The acoustic field generated by a source has the form of spatial distribution of the abovementioned spectrum of sound intensity level.

One of the examined cases of technical activity leading to remarkable disturbances of the natural acoustic field is mounting wind farm towers, so-called monopiles, on the seabed. The noise generated during this operation has pulse nature (it disappears within a few seconds). Figure 6 shows the spectrogram of this sound at a place distant by almost 2 km from its source. The spectrogram illustrates the process of decay of the sound generated during monopile driving. It reveals that fast decay of strength of the acoustic wave is accompanied by changes of its spectrum, which stabilises after about one second, taking the shape of the natural acoustic background.

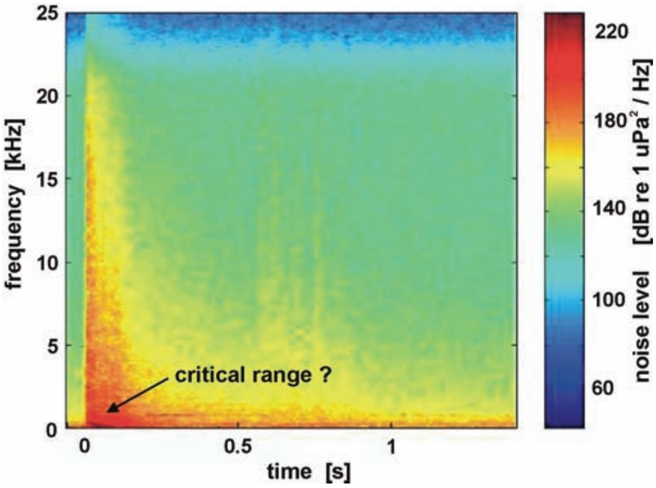


Fig. 6. Sample modification of the acoustic field by the noise generated by activities during wind farm construction (at a distance of 1881 m). Vertical axis represents the acoustic frequency, while the horizontal axis shows the time elapse.

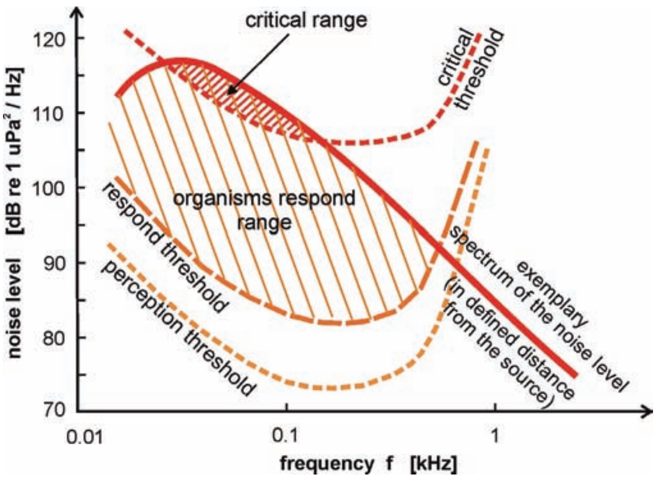


Fig. 7. Illustrative presentation of thresholds and intervals of sound perception by a marine organism (collected from different sources).

The susceptibility of an organism to sounds is characterised by the limit (threshold) of the sound intensity level, beyond which this organism reacts in a certain way (Fig. 7). Here, the limit of harmfulness (disorientation/"stunning") can be named, along with the limit of reaction (escape or avoiding) and the limit of harmless perception (easy adaptation).

The measure of harmfulness of the acoustic field is the size of the critical area being the fragment of the diagram area limited by the line of the measured spectrum of sound intensity level and the harmfulness limit (Fig. 6).

Discussion

Fully quantitative evaluation of the level of modification of physical fields in the water depth in certain phases of construction and operation of maritime wind farms would only be possible if comprehensive information on natural physical fields in spatial and time approach was available. Modification of the magnetic field can be characterised relatively well, but also in this case full characteristic is only possible when the architecture of the electric energy transmission network is known.

The largest modification of the magnetic field will take place when the so-called electrode solution is adopted, while the smallest one will be brought by solutions with a return cable, provided that the cables will be positioned at a small distance from each other. However, when the cables are close to each other, their small displacements will lead to large changes in spatial distribution of the magnetic field. Laying cables at a larger distance will result in larger permanent modification of the magnetic field, but their displacement will generate smaller changes of this modification.

Modification of the electromagnetic field can be characterised by its magnetic component, i.e. magnetic induction adequate to the RMS value of the electric current strength. In the steady state, i.e. without fast fluctuations of the electric current strength, spatial distribution of the induction can be determined using the same methods as those used for direct current. The modification of the electromagnetic field expressed by its electric component is negligibly small, incomparably smaller than modification of the (constant) electric field taking place during electric energy transmission in the electrode solution, although even in that case the modification reaches a measurable range only in the vicinity of the electrodes (up to several tens of meters).

The past research of modifications of the natural acoustic field introduced by different forms of technical activity at the stage of wind farm construction was rather fragmentary, which makes formulating uncompromising evaluations on their effect on the environment impossible. Direct and large effect on the acoustic field will undoubtedly take place in the construction phase – here, the noise problem during monopile driving is named (this problem is likely to be of lethal significance in certain areas of the sea). It is not clear to which extent the acoustic field is modified due to sea occupation by wind farms and the resultant "shift" of navigation to narrow channels with intensified ship traffic increasing the intensity of the anthropogenic noise along the shipping lanes. Rough illustration of this space occupation vs. navigation is shown in Fig. 8.

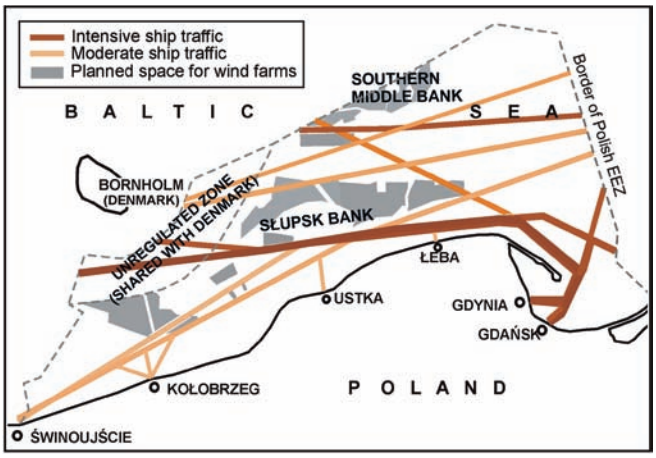


Fig. 8. Sea transport lanes [28], as compared to the areas of planned maritime wind farms.

In the case of maritime wind farm construction, the above described interference into the natural physical fields connected with electricity is accompanied by the interference into other fields referring to: sea currents, light, or even temperature and/or salinity.

As far as the sea currents are concerned, no sea currents with remarkably high impact on the existence of the Baltic ecosystem are localised in the area of the planned farms. Here, coastal regions would be of relatively high importance, where the dominance of currents in eastern direction is observed and their effect will include erosion of cliff coastlines, on the one hand, and supplying low beach lines with the eroded material, on the others. The Slupsk Furrow, which is also free of plans to situate wind farms in there, is a susceptible region, as it forms a channel along which water masses are relocated to supply eastern regions of the Baltic Sea with the salt and well-oxygenated waters coming from the North Sea.

Periodical changes of the optical field which would take place during maritime wind farm construction and be of certain importance for functioning of the marine ecosystem cannot be excluded. Light in the sea determines life processes taking place both in the water depth and on shallow seabed areas. When penetrating the water depth, the light is the source of energy which controls the primary production, this way providing food for marine organisms and also, to a large extent, the photosynthetic oxygen in the atmosphere. Introducing large scale technical constructions to maritime areas is connected with fracturing of the seabed structure, and the resultant transfer of suspensions, in volume and quality depending on the type of sediments in the area of construction activities, to the water depth. The presence of suspensions, in turn, leads to the modification of real optical properties of the seawater and, as a further consequence, to volumetric and spectral modifications of transfer of radiation energy to the water depth. So far, the scale of this phenomenon in relation to MFW's has not been assessed.

The diffusive light coming out from the sea carries the information on processes taking place in the sea depth, therefore modification of natural optical characteristics of the seawater can be a source of errors in the operation of algorithms used in remote sea examinations for interpreting images of its surface.

As far as the occupation of the maritime space by the wind farms is concerned, this problem also refers to protected areas (Fig. 9) and fishery (Fig. 10). There is no spatial conflict with the protected areas, but it is not entirely clear whether direct vicinity of the wind farms affects, or not, the object of protection (the population of wintering birds, for instance) or whether installing electric cables introduces, or not, periodical disturbances in the protected area (spawning ground, for instance). In case of fishery, on the other hand, a conflict exists in the Pomeranian Bay region. This conflict is of spatial nature and is measured by the mass of catch. There are no assessments on possible losses in fishery being a result of the interference into migration routes and the areas of reproduction, consumption and fry growing [3].

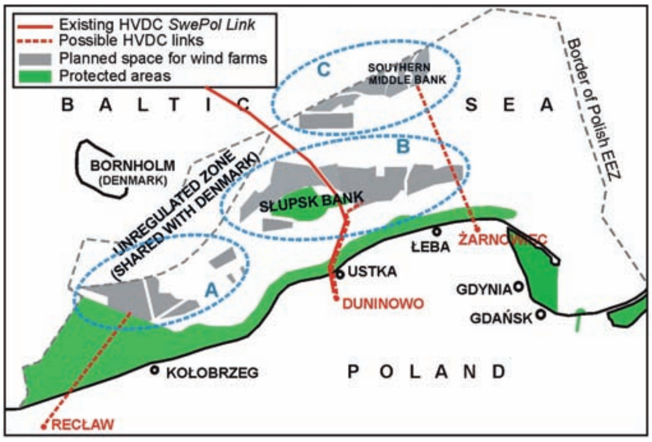


Fig. 9. Predicted external technical infrastructure of maritime wind farms, as compared to the protected areas[4].

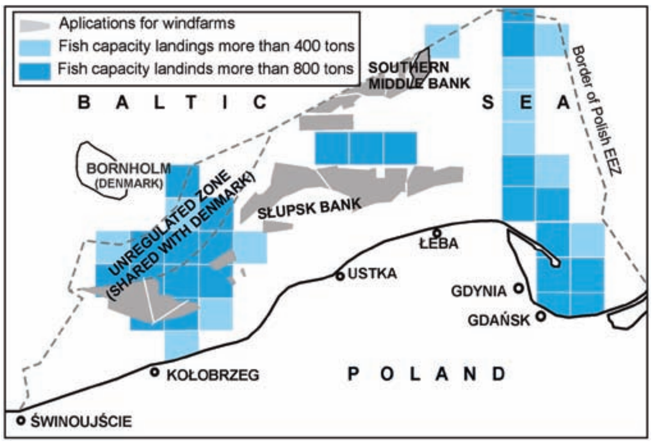


Fig. 10. Areas of intensive fishing [3], as compared to the areas selected for construction of maritime wind farms.

The article discusses issues related to physical fields understood as space penetration by different energy forms, such as: electromagnetic waves, acoustic waves, photons of light, motions of sea currents and, in case of the space situated above the sea, also wind speed fields. Since the temperature, density, and salinity are physical quantities, their spatial distributions are also considered physical fields in some cases. Consequently, for such understanding of physical fields their list could be extended to all descriptions which characterise the seawater space in a vector or scalar way.

The presented analyses of the effect of wind farms on natural physical fields make a contribution to a wider discussion about the effect of investment projects of this type on the entire natural environment. The knowledge gained from analysing modifications of natural physical fields couples the introduction of large scale constructions into maritime areas with the resultant environmental effects. Collecting comprehensive information on interactions between physical fields and organisms, and on the scale of modifications of natural physical fields connected with the introduction of large scale constructions into maritime areas will make the basis for easier and more accurate evaluation of the effect of these constructions on functioning of the environment, including its natural and economic values. At present, full and detailed evaluation of types an scales of threats generated for the environment by construction and operation of maritime wind farms is still very difficult [3].

Conclusions

Constructing wind farms in maritime areas is one of forms of technical activity which interferes into natural physical fields. Since there is much evidence that marine organisms feel and use physical fields, the large scale of the above type of investment projects can be a source of justified concern about correct functioning of the marine ecosystem.

The issues of physical fields in the maritime space are analysed in a different way than that applied in air analyses. First of all, standards laid down for inland areas are not in force for the marine environment. Moreover, the acoustics of the sea differs from that of the atmosphere, mostly by the fact that the water is almost incompressible, as compared with the air. Issues related to electricity should also be analysed using different methods, as the water is an electrolyte. The issue of light in the sea requires special approach, as the light penetrates the water depth to as little as ten to twenty metres (several tens of meters in very transparent oceanic waters), thus defining the so-called photic zone, i.e. the layer of primary production being the origin of the trophic chain of life in the entire seawater space.

The designed sets of wind farms will produce electric energy which will then be transmitted to the Polish coastland, or to the set of cables and devices linking wind farms in the Polish maritime areas with those situated in the areas of other countries. It is not clear so far whether the direct current solution (HVDC), or the alternating current solution (HVAC) will be adopted. The internal connecting structure (cables, concentration nodes, transformers) will most likely base on the three-phase solution HVAC, while the external connecting infrastructure will be, entirely or in part, based on the electrode solution HVDC or that with the return cable. Therefore disturbances of natural physical fields will be observed in different types of fields, depending on the adopted energy transmission techniques: in the HVDC solution it will be the electric field (only in the electrode version) and the magnetic field, while in the solution HVAC it will be the electromagnetic field measured by the magnetic component of 50 Hz frequency.

Disturbance of the acoustic field in the sea during wind farm operation will be generated by windmill blades and the electric current generator. In the construction phase, disturbances in the scale harmful for the environment will take place during driving piles into the seabed for wind plant towers.

At the present stage of research of disturbances of natural physical fields and the effect of physical fields on marine organisms, and in the context of high uncertainty regarding the types of future technical solutions, current evaluations of the effect of wind farms on the sea environment can only have a conditional nature, i.e. refer to certain structural solutions and seabed areas occupied by them. It is advisable to collect, for referential purposes (further comparisons performed during the operation of the devices), the data about the environment in the area of the planned farms, including the data on natural fluctuations of physical fields.

Bibliography

1. Andrew, R. K., Howe B. M., Mercer J. A., Dzieciuch M. A.: Ocean ambient sound: Comparing the 1960's with the 1990's for a receiver off the California coast, Acoustic Research Letters Online 3 (2), pp.65-70, (2002)

2. Andrulewicz E., Napierska D., Otremba Z.: The environmental effects of the installation and functioning of the submarine SwePol Link HVDC transmission line: A case study of the Polish Maritime area of the Baltic Sea, Journal of Sea Research 49, pp.337-345, (2003)

3. Andrulewicz E., Pelczarski W.. Kuzebski E., Szymanek L., Grygiel W.: Fishery and new concepts of the use of sea space – an example of the Polish Maritime areas, Proc. Conf. ICES ASC, Bergen, 17-21.09.2012, (2012)

4. BALANCE (Baltic Sea Management – Nature Conservation and Sustainable Development of the Ecosystem through Spatial Planning): Towards an Assessment of Ecological Coherence of the Marine Protected Areas Network in the Baltic Sea Region, BALANCE Interim Report No. 25, (2007)

5. Buckingham M. J., Wave propagation, stress relaxation, and grain-to-grain shearing in saturated, unconsolidated marine sediments, J. Acoust. Soc. Am. 108, pp.2796-2815 (2000)

6. CMACS (Centre for Marine and Coastal Studies): A Baseline Assessment of Electromagnetic Fields Generated by Offshore Windfarm Cables, COWRIE Technical Report EMF 01-2002 66. Birkenhead, England, UK, (2003) http://www.offshorewind.co.uk/Assets/COWRIE_EMF_Research_Report.pdf

7. Dietz R. S. & Sheehy M. J.: Transpacific detection of myojin volcanic explosions by underwater sound. Bulletin of the Geological Society 2, pp.942-956 (1954).

8. Enger, P.S. Electroreception. In: Døving, K. & Reimers, E. (eds.): Fish physiology, John Grieg Publishing, Bergen, Norway, (1992)

9. Francois R. E. & Garrison G. R.: Sound absorption based on ocean measurements. Part II: Boric acid contribution and equation for total absorption, J. Acoust. Soc. Am. 72, pp.1879-1890 (1982).

10. GESAMP (Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection): GESAMP Reports and Studies, No.47, (1991)

11. Gill A.B.: Gloyne-Phillips I., Neal K. J., Kimber J. A.: The potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electricity and magnetically sensitive marine organisms – a review, COWRIE 1.5 Electromagnetic Field Review, (2005)

12. Ginalski A.: The network Natura 2000 on Polish Maritime areas, (in Polish) , Konferencja Instytutu na rzecz Ekorozwoju, Warsaw, February 15, 2011 (2011)

13. IMGW: Atlas of the Baltic Sea, (in Polish) collective work edited by A. Majewski and Z. Lauer, Instytut Meteorologii i Gospodarki Wodnej, Warsaw (1994)

14. IMGW: Southern Baltic Sea – annual characteristic of selected elements of the environment, (in Polish), Instytut Meteorologii i Gospodarki Wodnej - Oddział Morski w Gdyni, (1987-2012)

15. Karlsson, L.: Migration of European silver eels, Anguilla anguilla. Orientation to the earth's magnetic field and pulpmill effluents particularly in the Baltic, Acta Universitatis Upsaliensis 745, pp.5-24, (1984)

16. Medwin H. & Clay C. S.: Fundamentals of Acoustical Oceanography, Academic, Boston, 1998MTBiGW (Ministry of Transport Construction and Maritime Economy): Map of potential places selected for location of wind farms in the exclusive economic zone, (in Polish)

17. Moller, P.: Electric Fishes: History and Behavior, Chapman & Hall, (1995)

18. Nakamura, T., Hirose, C., Hirose, R., Hirooka, S., Sasaki, H.: Observation of electric fields in the shallow sea using the stainless steel electrode antenna system, Physics and Chemistry of the Earth, Parts A/B/C Vol. 31, Issues 4-9, 2006, pp.352-355.

19. Norton G.V. Novarini J.C.: On the relative role of sea-surface roughness and bubble plumes in shallow-water propagation in the low-kilohertz region, J. Acoust. Soc. Am. 110, pp.2946-2955, (2001)

20. Nedwell J., Langworthy J, Howell D.: Assessment of sub-sea acoustic noise and vibration from offshore wind turbines and its impact on marine wildlife; initial measurements of underwater noise during construction of offshore wind farms, and comparison with background noise, Report No. 544 R 0424, (2003)

21. Otremba, Z., Andrulewicz, E.: Environmental Concerns Related to Existing and Planned Technical Installations in the Baltic Sea, Polish J. of Environ. Stud. Vol.17, pp.173-179, (2008)

22. Poleo, A.B.S., Johannessen, H. F., Harboe, M.:. High Voltage Direct Current (HVDC) seacables and sea electrodes: effects on marine life, University of Oslo, (2001)

23. Popper, A.N., Hastings, M.C.: The effects of anthropogenic sources of sound on fishes, Journal of Fish Biology, Vol. 75, Issue 3, pp.455-489. (2009a)

24. Popper, A.N., Hastings, M.C.: The effects of human-generated sound of fish, Integrative Zoology, 4, pp.43-52, (2009b)

25. Potter J.R., Delory E "Noise sources in the sea and the impact for those who live there" Acoustics and Vibration Asia ,98, Singapore, (1998)

26. Rochalska, M.,. The influence of electromagnetic fields on flora and fauna, Medycyna Pracy 60, pp.43- 50, (2009)

27. Żygowska E.: Conditions for development of marine wind power industry in Poland, (in Polish), PSEW (Polskie Stowarzyszenie Energetyki Wiatrowej), I Międzynarodowy Kongres Morski w Szczecinie, 13 June 2013, (2013)

28. Ruskule A., Kuris M, Leiputė G,, Vetemaa M., Zableckis S.: Ship traffic in the Baltic Sea and port development, Chapter in: See the Baltic Sea, Ed.: Sea in Baltic Environmental Forum – Latvia (BEF-Latvia), (2009)

29. Shields M.A., Woolf D.K., Grist E.P.M., Kerr S.A., Jackson A.C., Harris R.E., Bel M., Beharie R., Want A., Osalusi E., Gibb S.W., Side J.: Marine renewable energy: The ecological implications of altering the hydrodynamics of the marine environment, Ocean & Coastal Management 54, pp.2-9, (2011)

30. Slater M.,: The prediction of electromagnetic fields generated by submarine power cables, Oregon Wave Energy Trust, 0905-00-007, (2010)

31. Slater M., Jones R., Schultz A.. Electromagnetic Field Study, Ed: Oregon Wave Energy Trust, (2010) www.oregonwave.org

32. SNBF (Swedish National Board of Fisheries):. Telemetriförsök med blankål vid HVDC polkabel (Telemetric try of detection of silver eels at HVDC cable), (1997)

33. South Baltic Program: South Baltic Offshore Wind Energy Regions: Offshore wind energy in Poland, http://www.southbaltic-offshore.eu/regions-poland.html

34. Souza, J.J., Poluhowich, J.J., Guerra, R.J.: Orientation responses of American eels, Anguilla rostrata, to varying magnetic field, Comp. Biochem. Physiol. 90A, pp.57-61, (1988)

35. Stryjecki M.: Foundation for Sustainable Energy, Legal, political and infrastructural conditions for development of marine wind power industry in Poland, (in Polish), Konf. Morska Energetyka, Słupsk - 21 January, 2013, (2013)

36. Tesch, F.W., Wendt, T., Influence of geomagnetism on the activity and orientation of eel, Anguilla, as evident from laboratory experiment. Aq. Ecol. Freshw. Fish. 1, pp.52-60, (1992)

37. Urick, R J.: Principles of Underwater Sound, 3rd Edition. New York. McGraw-Hill, 1983.

38. Wenz G. M.: Acoustic ambient noise in the ocean: spectra and sources, J. Acoust. Soc. Am. 34, pp.1936-1956 (1962).

39. Westerberg H., Lagenfelt I., Andersson I., Wahlberg M., Sparrevik E.: Impact of the SwePol Link on fish and fisheries, Swedish Agency for Marine and Water Management, (2007) (in Swedish and Polish)

40. Wiltschko, R., Wiltschko, W.: Magnetic orientation in animals, Springer-Verlag, Berlin, (1995).

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