Research & Reviews: Journal of Ecology and Environmental Sciences
e-ISSN:2347-7830
p-ISSN:2347-7822

A Review of the Evidence of Electromagnetic Field (Emf) Effects on Marine Organisms

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Review Article

Received: 12/08/2016

Accepted: 23/11/2016

Published: 28/11/2016

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Keywords: Electromagnetic fields, Marine organisms, Marine environment, Subsea, Renewable energy, Marine species, *Prionace glauca*

ABSTRACT

Electromagnetic fields (EMFs) emitted from subsea cables have become a common feature of the marine environment with the global expansion of marine renewable energy developments (MREDs). Yet there are very few assessments of potential EMF effects on the behaviour or biology of marine organisms. The limited literature often has conflicting evidence and no standardised testing methodology. The uncertainty is concerning for stakeholders, such as fishers, who are dependent upon the predictability of marine organisms. This paper aimed to critically review the available literature on EMFs to conclude if marine species are at a significant biological risk of contact with energised subsea cables. Presently, there is no evidence of a significant threat to marine organisms encountering subsea cables.

INTRODUCTION

Every location upon Earth has a characteristic background magnetic field within a range of 25-50 microteslas (μT) dependent upon exact positioning [1]. Electromagnetic fields (EMFs) from offshore alternating current (AC) and direct current (DC) subsea power cables are increasingly being generated as part of marine renewable energy developments (MREDs) for example, the 2010 Wave Hub 18 km cable off Plymouth, UK [1-5]. Globally, wind power is the most advanced MRED, accompanied by the greatest number of subsea power cables [6]. Electricity generated offshore frequently passes through a network of subsea cables before being redirected to land often via a single cable **(Figure 1)**. Dipolar magnetic fields are generated when an electric currents pulses through an energised cable **(Figure 2)**. Protective sheathing prevents electric fields but not magnetic fields emanating from subsea cables. A secondary electric field is induced by an object or organism moving through the magnetic field [2,7-9]. The larger the organism, the larger the induced electric field [8,10]. There has been some modelling of generated EMFs. If **Figure 2** represented an industry standard 33 kV AC cable buried at one metre depth, then an EMF of 1.5 μT would penetrate the seabed, declining to 0.03 μT in the sea, assuming a constant saline conductivity [2,10]. There are slight variation in the magnetic field produced dependent upon whether the cable uses DC, AC or if a bipolar cable is used rather than the standard unipolar design; the main differences being AC fields cyclically alternate direction [1].

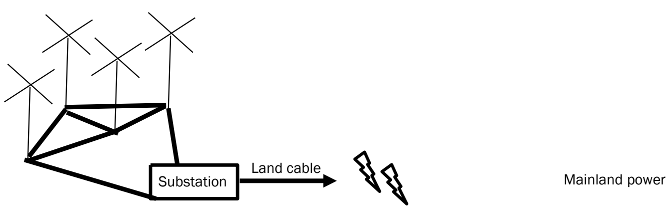

Figure 1. Representation of an offshore wind farm with a connecting network of subsea cables linking to an offshore substation before electricity is redirected through a cable to land.

e-ISSN:2347-7830
p-ISSN:2347-7822

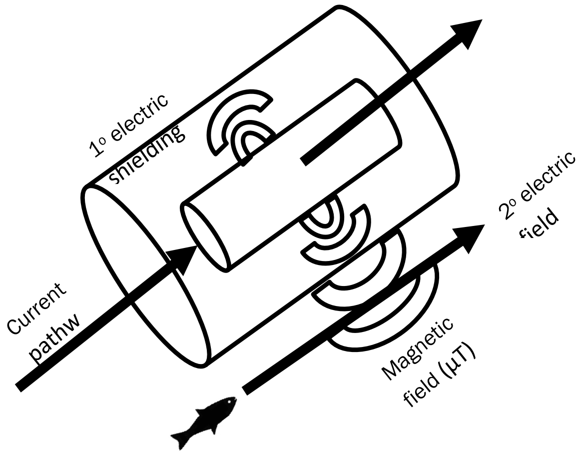

Figure 2. Representation of how an EMF is generated from a partially shielded subsea cable.

It is well established that many organisms including elasmobranchs, some bony fish, decapods, marine mammals and turtles can detect both natural and artificial EMFs, which many species use for directional movement, foraging and migration [1,7,9,11-14]. Electroreceptive species indirectly sense a magnetic field by the movement of water through a magnetic field, thus creating an induced detectable electric field, whilst other species use the magnetic deposits in their own tissues, as in the central nervous system of *Anguilla* [9,11,12,15]. There are concerns over the distinct lack of empirical evidence surrounding the ecological impacts of EMFs [7,13,15]. The effects of EMFs need to be quantified for a range of species, most notably those threatened elasmobranchs with magneto-sensitive ampullae of Lorenzini, that are known to be influenced by magnetic fields when foraging [13,16,17,18]. In addition, the European Marine Strategy Framework Directive requires new energy developments, including associated EMFs to fall below adverse levels for 'good environmental status' by 2020 [19].

The current review aims to answer several key questions. What effects do EMFs have on behaviour and physiology of marine organisms? Are these EMF effects significant enough to be classed as biological effects? Finally, what are the key knowledge gaps surrounding EMFs that are needed for effective future MRED planning?

Behavioural and Physiological Impacts of Emfs on Marine Organisms

Studies regarding behavioural impacts from EMFs appear to single-mindedly focus upon adults of commercially important benthic species [7]. There are far fewer studies in physiological impacts of EMF exposure upon marine organisms [1]. Several studies provide empirical evidence of behavioural and physiological impacts **(Table 1)** only a few assess invertebrate responses [15,20,21]. Magnetic field strength varied with no set standard between studies, **(Table 1)**, whereas natural magnetic levels are 50 µT in the Baltic, a key MRED area [11,20]. Laboratory experimental setups used magnetic strengths far greater than those using cables in *situ*, with the exception of the study upon blue sharks *(Prionace glauca)* that used actual magnets rather than side-effect magnetic fields from a cable [15,18,22].

Table 1. Example range of species in groupings that have been assessed for responses to EMFs and the range of microteslas (µT) they are exposed to. 'Untested' signifies the impact was not tested for. 'Lab cond.' signifies laboratory conditions as described in the research method.

Species assessed	Location	Exposed EMF (µT)	Behaviour impact	Physiological impact
Rock crab (*Metacarcinus anthonyi*)	California	46-80	None found	Untested
Rock crab (*Cancer productus*)	California	46-80	None found	Untested
Round crab (*Rhithropanopeus harrisii*)	Lab cond.	3700	Untested	None found
Dungeness crab (*Cancer magister*)	Lab cond.	314-1,103	Attraction to EMF and increased activity	Untested
Shrimp (*Crangon crangon*)	Lab cond.	3700	Untested	None found
Blue mussel (*Mytilus edulis*)	Lab cond.	3700	Untested	None found on gonads or fitness
Isopod (*Saduria entomon*)	Lab cond.	3700	Untested	None found
Flounder (*Plathicthys flesus*)	Lab cond.	3000-3700	Untested	None found
Coho salmon (*Oncorhynchus kisutch*)	Lab cond.	3000	Predator avoidance behaviour	None found
Atlantic halibut (*Hippoglossus hippoglossus*)	Lab cond.	3000	None found	None found on larval development
California halibut (*Paralichthys californicus*)	Lab cond.	3000	None found	None found on larval development

European eel (*Anguilla anguilla*)	Baltic Sea	>5 at 60 m distance	Decreased swim speed	None found
Japanese eel (*Anguilla japonica*)	Lab cond.	13-19	Untested	Decreased heart rate
Blue shark (*Prionace glauca*)	NE Atlantic	464,000-885,000	Attraction to magnet	Untested

One of the most controlled in situ experiments observed behaviour of male and female rock crabs (*Metacarcinus anthonyi and Cancer productus*). One legal-sized crab was placed per box along an energised subsea cable and along an un-energised cable seven metres away in Las Flores Canyon, California over 24-hour trials [16]. Behaviour was found not to be significantly affected by proximity to an energised cable **(Table 1)**. Other factors that may have influenced behaviour, such as visual cues and algae growing upon the cables were meticulously removed. Similarly, two remotely operated vehicles (ROVs) found that a subsea cable had no significant effect upon the associated megafaunal assemblage of a glass sponge habitat. Some magneto-sensitive decapoda were noted less frequently in range of the cable's EMF but this was most likely due to the lack of refugia in the crushed sponge as arthropoda were significantly correlated to sponge cover [23].

Contrastingly, swimming speed of acoustically tagged migrating *Anguilla anguilla* significantly decreased north and south of a Baltic Sea 130 KV power cable, delaying eels on average by 40 minutes [22]. The Westerberg and Lagenfelt [22] study had a high return rate of 46 out of 60 tagged eels although this was a relatively small sample for an entire migratory stock. Yet a 40-minute delay in a 7000 km migration, with only two eels turning back, could not be considered a significantly detrimental biological effect. Baltic Sea *SwePol* cables did not exceed natural 50 µT at a 20 m distance but migratory species such as eels would be in a strongly altered magnetic field within 3 m to the cables [11,20,24]. In a similarly designed study that used 50 pop-up satellite tags, Atlantic salmon, *Salmo salar*, predominately used a depth of <20 m in Scottish waters resulting in a high likelihood of encountering MREDs [25]. These studies suggested that proximity plays a key role in the chances of an effect upon the organism happening.

The current review paper struggled to find any EMF studies spanning more than one life stage, which was crucial for determining effects upon catadromous and anadromous species. A three-year freshwater study found that juvenile *Anguilla anguilla* were not significantly more attracted into fyke nets with 1000 µT magnets than control nets. Interestingly, the other seven freshwater lake fish species in the 2004 study were caught 50% more in magnetised traps [26]. The differing response to EMFs between life stages is of particular interest for those marine species with a benthic life stage with a greater cable encounter likelihood, such as eels [7]. It cannot be eliminated that the different results were an artefact of different methodologies and not due to different life stage sensitivities [12].

Regarding physiology, American eels *Anguilla rostrata* and marine, farmed and riverine *Anguilla japonica* all displayed the same response to electric and magneto-sensitive conditioning, characterised by a decreased heart rate in response to a power density of 0.11×10−3 pW/cm3 or 13-16 µT EMF [27,28]. Significantly these studies suggested that Japanese eels are sensitive to EMFs at different life stages, which could have implications for other catadromous fish, in particular their European and American cousins.

In comparison to *Anguilla anguilla*, the blue shark *Prionace glauca* was found to reduce swim speed and be attracted to magnetised fishing hooks ironically originally intended as a shark deterrent **(Table 1)** [18]. This attraction effect could potentially be used to predict elasmobranch behaviour to cable EMFs. However, elasmobranchs detect and respond differently to EMFs compared to salmonids or anguillids hence comparisons are not ubiquitously appropriate [8] .

It is also unknown whether EMF receptors of organisms outweigh other senses such as sight and smell. If not is the cause of concern then diminished? [8]. Nonetheless, cable EMFs generally dissipate greater than one metre's distance so animals largely need to be in close proximity for much chance of an effect [10,15,24]. However, EMFs from different cables can interact; cables fixed in the same orientation have an additive EMF effect, opposite directions have a subtractive effect and diagonal angles create a difficult assessment [8]. Furthermore, wave energy converters with coil and magnet structures could potentially exacerbate EMFs from standard subsea cables [14]. Ecological Risk Assessments (ERAs) based upon weighted evidence can provide a supplement, but not a replacement, to direct sampling when time is scarce [29]. An ERA for a wind farm in Kattegat Bay, Scandinavia found no significant risk to endangered Gadus morhua populations during operation as cod were found to be aggregated near power cables energised or not; although exposure effects to EMFs could not be quantified [29].

DISCUSSION

Based upon the literature reviewed here, there does not appear to be enough empirical evidence to suggest a significantly detrimental biological effect upon marine organisms from EMFs; although it is clear many species can detect and respond to artificial magnetic fields [15,18,22,26]. This recent result is in agreement with an earlier review of static magnetic fields upon marine biological systems [1]. Generally, there is a low risk to the majority of the benthic assemblage that would have the greatest likelihood of subsea cable interaction excluding cartilaginous fish that are capable of using EMFs for prey detection [11,13,18,30-32]. This may be of some comfort to fishers who depend upon predicting the movement behaviour of target species, such as Atlantic halibut, *Hippoglossus hippoglossus* [33]. Yet there are very few experiments upon invertebrates and the few species that have been investigated often have detection thresholds above what would be found near a cable [13].

There may be the opportunity for species to become habituated to operational EMFs [30]. However, thus far no study has a long enough temporal scale to demonstrate this, but several invertebrates and a flounder were able to survive 3700 μT past one month, with *Mytilus edulis* surviving three months [20]. A three-month timescale is still not adequate to assess any long term effects that may later manifest; studies should extend across a test subject's lifespan, although this not always feasible for longer-lived species.

Although there is a degree of industry standardisation, larger cables can have greater EMFs so should have individual impact assessments [8,10,13]. If funding is available, EMFs could be accurately modelled as long as the manufacturer design, burial depth, cable layout and degree of magnetic shielding are known [7,8]. Questioned whether it would it be easier for manufacturers to fully shield EMFs in future cable designs. However, this would be unfeasible due to high material costs and the practicalities of such a venture that is not required by legislation [5,8]. The ever-expanding MRED sector highlights the significant gap for marine biodiversity protection beyond national jurisdiction in the United Nations Convention on the Law of the Sea [34]. Cable burial in a non-magnetic substratum still created the secondary induced electric field, suggesting this was not an effective mitigation option [and chemical sensors, or acoustic tags would likely be the most feasible option for behaviour experiments. However, the use of AUVs can be expensive and requires a degree of water clarity to be effective. Furthermore, both acoustic tags and AUVs cannot assess physiological impacts, which would require laboratory sampling. It was logical to conclude that the worst outcome for the future would be if cable manufacturers disregarded the best available scientific advice regarding the potential effects of subsea cables. Presently, there is insufficient evidence to suggest biological impacts upon marine organisms from EMFs. Nonetheless, there is a significant gap in understanding of any long-term impacts marine organisms might face.

REFERENCES

1. Bochert R and Zettler ML. Effect of electromagnetic fields on marine organisms, in Offshore Wind Energy. Springer. 2006;223-234.
2. Cmacs J. Cowrie Phase 1 Report: A Baseline Assessment of Electromagnetic Fields Generated by Offshore Windfarm Cables. Centre for Marine and Coastal Studies (CMACS) 2003.
3. Boehlert GW and Gil AB. Environmental and ecological effects of ocean renewable energy development: a current synthesis. 2010.
4. Sheehan EV, et al. The Twenty-third International Offshore and Polar Engineering Conference. International Society of Offshore and Polar Engineers; 2013.
5. Balmori A. Anthropogenic radiofrequency electromagnetic fields as an emerging threat to wildlife orientation. Science of the Total Environment. 2015;518:58-60.
6. Inger R, et al. Marine renewable energy: potential benefits to biodiversity? An urgent call for research. Journal of Applied Ecology. 2009;46:1145-1153.
7. Tricas T and Gill AB. Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo; 2011.
8. Gill AB, et al. Potential interactions between diadromous fishes of UK conservation importance and the electromagnetic fields and subsea noise from marine renewable energy developments. Journal of fish biology. 81;2011:664-695.
9. Gill AB, et al. Marine Renewable Energy, Electromagnetic (EM) Fields and EM-Sensitive Animals, in Marine Renewable Energy Technology and Environmental Interactions. Springer. 2014;61-79.
10. Gill AB. and Bartlett MD. Literature review on the potential effects of electromagnetic fields and subsea noise from marine renewable energy developments on Atlantic salmon, sea trout and European eel. Scottish Natural Heritage Commissioned Report; 2011.
11. Gill AB. Offshore renewable energy: ecological implications of generating electricity in the coastal zone. Journal of Applied Ecology. 2005;42:605-615.
12. Öhman MC, et al. Offshore windmills and the effects of electromagnetic fields on fish. A journal of the Human Environment. 2007;36:630-633.
13. Gay ME. Spatial analysis of fish distribution in relation to offshore wind farm developments. MSc thesis. Cranfield University; 2012.
14. Witt MJ, et al. Assessing wave energy effects on biodiversity: the Wave Hub experience. Philosophical Transactions of the Royal Society of London A: Mathematical, Physical and Engineering Sciences. 2012;370:502-529.
15. Hanson M, et al. Magnetic material in European eel (*Anguilla anguilla*). Comparative Biochemistry and Physiology Part A: Physiology. 1984;77:221-224.

16. Love MS, et al. Identical Response of Caged Rock Crabs (Genera Metacarcinus and Cancer) to Energized and Unenergized Undersea Power Cables in Southern California. USA, Bulletin, Southern California Academy of Sciences. 2015;14:33-41.

17. Kalmijn AJ. Electro-perception in Sharks and Rays. Nature. 1966 1232-1233.

18. Porsmoguer SB, et al. Hooks equipped with magnets can increase catches of blue shark (Prionace glauca) by longline fishery. Fisheries Research. 2015;172:345-351.

19. Tasker ML, et al. Marine Strategy Framework Directive Task Group 11 Report Underwater noise and other forms of energy. European Commission Joint Research Centre/ICES Report EUR; 2010.

20. Bochert R and Zettler ML. Long-term exposure of several marine benthic animals to static magnetic fields. Bioelectromagnetics. 2001;25:498-502.

21. Wilson CS and Woodruff DL. A preliminary study on the effects of electromagnetic fields on the burial behaviour and location of the Dungeness crab, Cancer magister. Report prepared by the Pacific Northwest National Laboratory for the US Dept of Energy; 2011.

22. Westerberg H and Lagenfelt I. Sub-sea power cables and the migration behaviour of the European eel. Fisheries Management and Ecology. 2008;15:369-375.

23. Dunham A, et al. Effects of submarine power transmission cables on a glass sponge reef and associated megafaunal community. Marine environmental research. 2015;107:50-60.

24. Andrulewicz E, et al. The environmental effects of the installation and functioning of the submarine SwePol Link HVDC transmission line: a case study of the Polish Marine Area of the Baltic Sea. Journal of Sea Research. 2003;49:337-345.

25. Godfrey JD, et al. Depth use and migratory behaviour of homing Atlantic salmon (Salmo salar) in Scottish coastal waters. ICES Journal of Marine Science: Journal du Conseil. 2014;118.

26. Formicki K, et al. Effects of magnetic fields on fyke net performance. Journal of Applied Ichthyology. 2004;20:402-406.

27. Rommel Jr SA and McCleave JD. Sensitivity of American eels (*Anguilla* rostrata) and Atlantic salmon (Salmo salar) to weak electric and magnetic fields. Journal of the Fisheries Board of Canada. 1973;30:657-663.

28. Nishi T, et al. Magnetic sense in the Japanese eel, *Anguilla* japonica, as determined by conditioning and electrocardiography. Journal of Experimental Biology. 2004;207:2965-2970.

29. Hammar L, et al. Assessing ecological risks of offshore wind power on Kattegat cod. Renewable Energy. 2004;66:414-424.

30. Gill AB and Kimber JA. The potential for cooperative management of elasmobranchs and offshore renewable energy development in UK waters. Journal of the Marine Biological Association of the United Kingdom. 2005;85:1075-1081.

31. Bergström L, et al. Effects of an offshore wind farm on temporal and spatial patterns in the demersal fish community. Marine Ecology Progress Series. 2013;485:199-210.

32. Bergström L, et al. Effects of offshore wind farms on marine wildlife—a generalized impact assessment. Environmental Research Letters. 2014;9:034012.

33. Schultz IR, et al. Effects of Electromagnetic Fields on Fish and Invertebrates. Pacific Northwest National Laboratory, Washington; 2010

34. Dhanak M, et al. OCEANS 2015-Genova. IEEE. 2015.