Stressor-specific Guidance Document: Electromagnetic Fields

The guidance documents are intended to be available for regulators and advisors as they carry out their decision-making and for developers and their consultants as they prepare consenting and licensing applications. This stressor-specific document presents an overview of the scientific information that is known for electromagnetic fields.[1] It is not intended to replace any regulatory requirements or prescribe action for a particular risk.

Introduction to Stressor

Anthropogenic electromagnetic fields (EMFs) are emitted from various types of infrastructure in the marine environment such as subsea cables for power and communications, bridges, and tunnels. These emissions may affect several species of marine animals, like those that use the Earth's natural magnetic fields for orientation, navigation, and/or hunting. This includes some species of elasmobranchs, crustaceans, cetaceans, fish, and sea turtles. Figure 1 shows an abbreviated version of where this stressor fits within the guidance document framework.

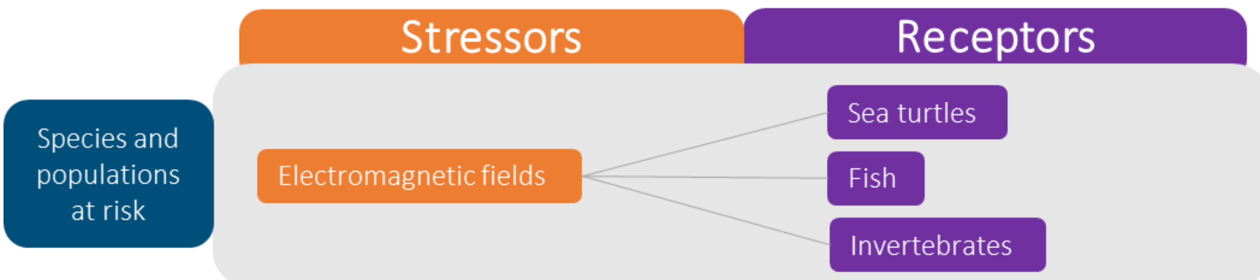

Figure 1. Portion of the guidance document framework depicting electromagnetic fields and key receptors, which are relevant under the regulatory category of species and populations at risk. The full framework can be found in the background guidance document.[1]

Marine renewable energy (MRE) systems emit EMFs from power cables, moving parts of devices, and subsea substations/transformers. These EMFs may affect sensitive species at individual or population levels by causing animals to be attracted to or avoid areas, and/or by interfering with natural magnetic fields used for orientation, navigation, and hunting. However, the impact to animals depends on factors such as the intensity and levels of EMFs emitted (depending on parameters like type of cable or cable configuration and type of burial, armoring, or insulation), local geomagnetic fields, and surrounding environmental factors and the sensitivity of the species to EMF. To accurately assess the environmental impact from EMFs, these factors and others need to be considered, as shown in Figure 2.

[1] This stressor-specific document should be read in conjunction with the background guidance document, which can be found on *Tethys*: https://tethys.pnnl.gov/guidance-documents.

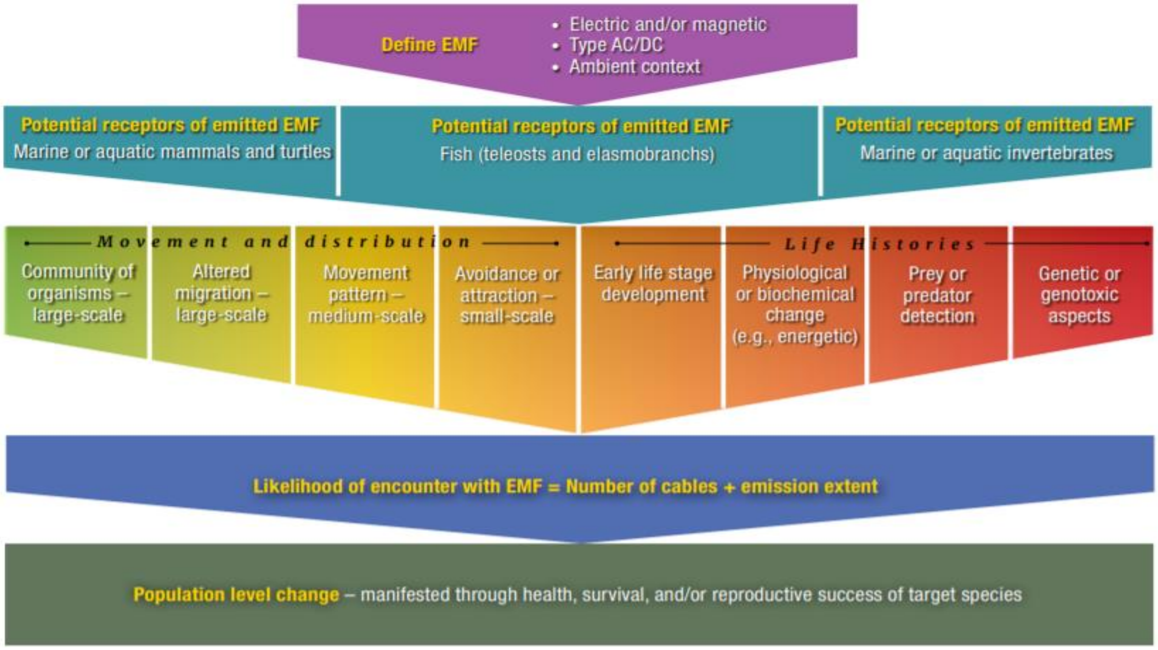

Figure 2. Key elements that need to be considered when assessing the environmental impact of electromagnetic fields. From Gill and Desender (2020), graphic by Robin Ricks.

Existing Data and Information

2020 State of the Science

Chapter 5 of the 2020 State of the Science Report (Gill and Desender 2020) describes EMF in detail, synthesizing research and findings from MRE devices to provide a comprehensive look at the status of knowledge for impacts from EMF.

Evidence Base

OES-Environmental has developed an evidence base of key research papers and monitoring reports for EMF that support the understanding and risk retirement for small numbers of MRE devices[2]. The evidence base has been reviewed by international subject matter experts in workshop settings, and can be accessed on *Tethys*[3]: EMF Evidence Base. A limited number of the studies included in the EMF evidence base are shown at the end of this document in the Additional Information section (Table 1).

Monitoring Datasets Discoverability Matrix

OES-Environmental has developed the Monitoring Datasets Discoverability Matrix, an interactive tool that can be used to locate datasets by stressor, receptor, and other specifications, as shown in Figure 3. In addition to the research studies and key documents included in the evidence base, the matrix includes baseline and post-installation monitoring reports compiled from OES-Environmental Metadata, providing links and contacts to existing datasets from MRE projects and research studies. The metadata includes information solicited from developers and researchers involved in environmental monitoring projects for MRE, which is updated annually.

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[2] For the purposes of risk retirement, small developments have been defined as one to four devices.
[3] *Tethys* is the U.S. Department of Energy's online platform that aims to facilitate the exchange of data and information on the environmental effects of wind and MRE, and serves as a commons for the OES-Environmental initiative. *Tethys* is developed and maintained by the Pacific Northwest National Laboratory.

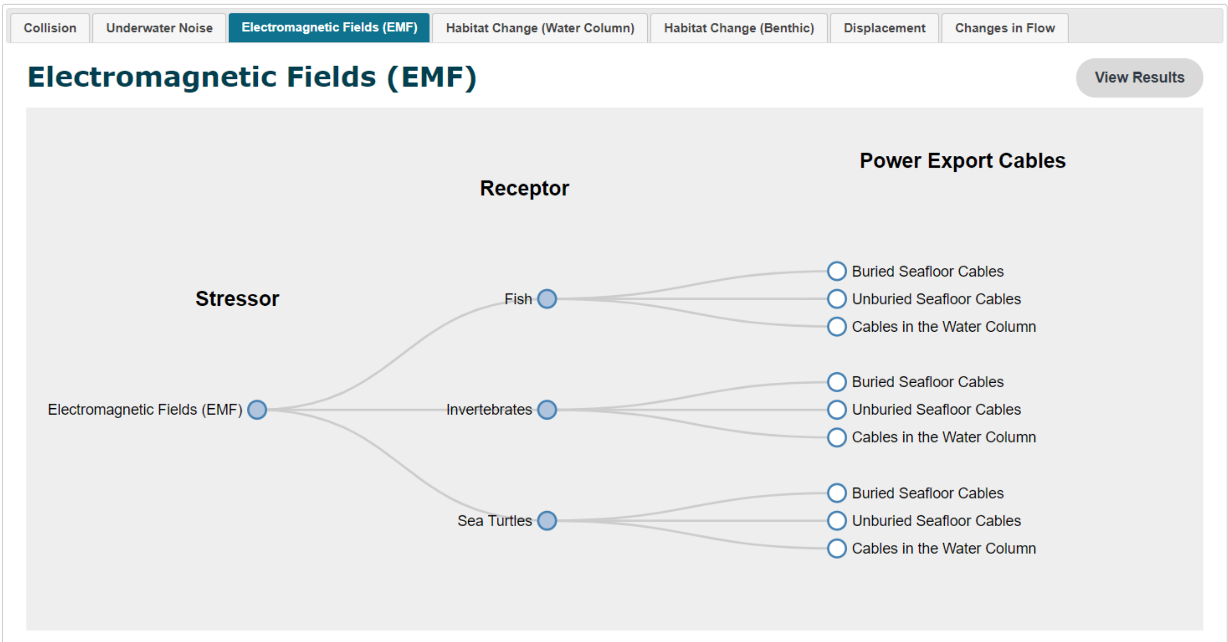

Figure 3. Screenshot of the Monitoring Datasets Discoverability Matrix selections for EMF on *Tethys*.

Management Measures Tool

The Management Measures Tool has been developed by OES-Environmental to show management (or mitigation) measures from past or current MRE projects as a reference to help manage potential risks from future projects. The tool can be filtered by technology (tidal or wave), management measures, project phase, stressor, and/or receptor. An example of management measures returned for EMF is shown in Figure 4 below.

Filter by Technology: - Any - **Management Measure:** - Any - **Project Phase:** - Any - **Stressor:** EMF **Receptor:** - Any -

Search: Apply Reset

Technology	Project Phase	Stressor	Receptor	Management Measure	Implications of Measure	Advantages	Challenges	Project Documents
Wave, Tidal	Operation & Maintenance	**EMF** Impacts of electromagnetic fields from subsea cables on sensitive species.	**Fish** Migratory fish, elasmobranchs	**Design feature** Install cable protection/ armor/ rock placement/ other cable protection.	Reduces the level of EMF to surrounding water column and therefore any potential effects. Reduces 'snagging risk' for vessels and may create habitat for species. Potential for adverse impacts on surrounding benthic habitats and sensitive species, e.g....**Read more**	Reduce the level of EMF to surrounding water column and therefore any potential effects. Reduces 'snagging risk' for vessels. Creation of artificial habitat.	The implication of this measure may have an impact on surrounding benthic habitats and sensitive species Creation of artificial habitat may cause aggregation effect causing greater impact of EMF. Increased cost to project. Reduced possibilities of decommissioning in future.	**Orbital Marine Power 2014, Foubister 2005, McGrath 2013, Federal Energy Regulatory Commission (FERC) 2020**
Wave, Tidal	Operation & Maintenance	**EMF** Impacts of electromagnetic fields from landfall cables on sensitive species.	**Marine Mammals** Marine Mammals	**Design feature** Bury cables where possible and viable.	n/a			**McGrath 2013**

Figure 4. Screenshot of the Management Measures Tool selections for EMF.

Tethys Knowledge Base

The *Tethys* Knowledge Base hosts thousands of documents about the environmental effects of MRE. All documents associated with EMFs can be found here.

Pathway to Risk Retirement

The evidence base to date suggests that the impacts of EMFs from small-scale MRE developments are limited, and the risk to EMF-sensitive species is low. Laboratory and field studies indicate that EMFs are unlikely to harm sensitive species at the levels emitted from MRE power cables (see Additional Information, Table 1). In addition, EMFs from MRE are lower than those from other anthropogenic EMF emissions, including offshore wind power export cables (Thomsen et al. 2015). Overall, there is a general consensus among the scientific community that EMFs from small-scale MRE developments are not harmful and do not pose a risk to marine animals, and therefore should not inhibit the installation of devices or require extensive monitoring (Copping et al. 2020a, Copping et al. 2020b, Gill and Desender 2020).

Some uncertainties remain, and more studies will increase understanding as the MRE industry moves to array-scale development that will have increased EMF emission levels. A complete list of remaining uncertainties and research needs is available in Chapter 5 of the State of the Science Report (Gill and Desender 2020). Key examples include the need to:

- Develop affordable methods and equipment to simultaneously measure E- and B-fields with the necessary sensitivity and accuracy for comparability.
- Validate existing models with EMF measurements from deployed MRE devices and power transmission cables.
- Conduct laboratory studies of species response to EMFs at different intensities and durations to determine the thresholds for species-specific and life stage-specific dose responses.
- Increase understanding on the interaction of pelagic species (e.g., sharks, marine mammals, or fishes) with dynamic cables (i.e., cables in the water column).
- Carry out long-term, in situ studies to address the question of the effects of chronic EMF exposure on egg development, hatching success, and larval fitness.

Recommendations

Sharing of data and information across the MRE industry and other industries that deploy subsea transmission cables will benefit general understanding of EMF effects, including the future cumulative effects of EMFs in the ocean. As the MRE industry progresses, it will be important to consider local conditions, existing sources of EMF, and sensitive species, to understand and minimize the risks posed by EMFs. Risk from EMF for small numbers of devices can be retired, and studies of EMF at each new proposed project site may not be needed. However, any data collected around projects and other deployments will continue to inform understanding of cumulative risks and accurate modeling of EMF for arrays.

Additional Information

The evidence base for EMF can be found at https://tethys.pnnl.gov/emf-evidence-base.

Table 1. A selection of studies from the evidence base for EMF effects on marine animals, in chronological order, adapted from Copping et al. 2020a. These projects and research studies examined undersea cables and surrogates including energized power cables, telecommunications cables, and other electrical infrastructure.

Project/Research Study	Location	Cable or EMF source	EMF measurements	Conclusion
Sub-Sea Power Cables And The Migration Behaviour Of The European Eel (Westerberg and Lagenfelt 2008)	Eastern Sweden	130 kV AC cable, unburied.	Acoustic tags were used to track small movements across energized cable.	Eels swam more slowly, but effect was not significant and no evidence of barrier effect.
EMF-Sensitive Fish Response to EM Emissions from Sub-Sea Electricity Cables of the Type Used by the Offshore Renewable Energy Industry (Gill et al. 2009)	Western Scotland	125 kV AC cable, buried 0.5-1 m deep.	Mesocosms were used with both energized and control cables.	No evidence of significant positive or negative effect on catsharks (dogfish). Benthic skates responded to EMF in cable.
MaRVEN - Environmental Impacts of Noise, Vibrations and Electromagnetic Emissions from Marine Renewable Energy (Thomsen et al. 2015)	North Sea, Belgium	AC cables (infield and export), buried 1.0-1.05 m deep.	Measured EMF from offshore wind turbine and export cables during power generation through drifting and sledge towing.	EMF from wind turbine was considerably weaker than EMF from export cables to shore. The electric fields from the AC cables were within the range of detection by sensitive receptor species, but the magnetic field emitted was at the lower end, potentially outside the detectable range. EMF at biologically relevant levels can be observed.
Assessment of potential impacts of electromagnetic fields from undersea cable on migratory fish behavior (Kavet et al. 2016)	San Francisco Bay, U.S.	200 kV DC cable, buried.	Tagged fish to track movement and used magnetometer surveys to measure EMF.	Fish (green and white sturgeon, salmon, steelhead smolt) did not appear to be affected. There were large magnetic signatures from bridges and other infrastructure that the cable could not be distinguished from.
Renewable Energy in situ Power Cable Observation (Love et al. 2017)	California, U.S.	35 kV AC power transmission cable, buried.	Surveyed marine life along an existing pipe, cable, and sandy bottom (control). Placed transects along each.	No response from fish or macroinvertebrates to EMF. Did not find any biologically significant differences among fish and invertebrate communities between pipe, energized cable, and sandy bottom. EMF produced by the energized cables diminished to background levels about 1 m away from the cable.
Electromagnetic Field (EMF) Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables (Hutchison et al. 2018)	Northeast U.S.	300 kV DC, buried.	Employed an enclosure with animals using acoustic telemetry tags and variable power (0, 100, and 330 MW).	American lobster had a statistically significant, but subtle change in behavior in response to EMF and Little skate had a statistically significant behavioral response to EMF from cable, but the EMF from the cable did not act as a barrier to movement for either species.

Table 2. EMF measurements taken around high-voltage alternative current (AC) and direct current (DC) subsea cables since 2016. The distances above the seafloor were extracted from studies when provided. The EMF extent refers to the distance that EMF is measurable in relation to the ambient fields perpendicular to the cable axis. From Gill and Desender 2020.

Cable	Current	Location	Magnetic Field (B-field)	Electric Field (E-field)	Extent EMF	Reference
2 - 2.4 amps 0.98 - 1.59 amps, 60 Hz	DC AC	South Florida (U.S.)	Max: 150 µT Mean: 30 nT 2.2m above seafloor	Max: 60 µV/m 4m above cable	10s m (estimated) AC>DC	Dhanak et al. (2016)
Trans Bay Cable (200kV, 400 MW, 85 km)	DC	San Francisco Bay, California (U.S.)	1.15 – 1.2 µT 3 m above seafloor	n/a	<40 m	Kavet et al. (2016)
Basslink (500kV, 237 MW, 290 km)	DC	Bass Strait, Tasmania (Australia)	58.3 µT	5.8 µV/m	15 – 20 m	Sherwood et al. (2016)
Cross Sound (300kV, 330 MW, 40 km)	DC	Connecticut (U.S.)	DC: 0.4 – 18.7 µT AC: max 0.15 µT	AC: max 0.7 µV/m	AC-DC B-fields: 5 – 10 m	Hutchison et al. (2018)
Neptune (500kV, 660 MW, 105 km)	DC	New Jersey (U.S.)	DC: 1.3 – 20.7 µT AC: max 0.04 µT	DC: 0.4 µV/m	AC: max: E-fields up to 100 m	Hutchison et al. (2018)
Sea2shore (502 amps, 30 MW, 32 km)	AC	Rhode Island (U.S.)	0.05 – 0.3 µT	1-25 µV/m	AC: B-field up to 10m AC: E-field up to 50 m (estimated)	Hutchison et al. (2018)

References

Copping, A.E., Freeman, M.C., Gorton, A.E., Hemery, L.G. 2020a. Risk Retirement—Decreasing Uncertainty and Informing Consenting Processes for Marine Renewable Energy Development. Journal of Marine Science and Engineering, 8(3), 172. Available online: https://tethys.pnnl.gov/publications/risk-retirement-decreasing-uncertainty-informing-consenting-processes-marine-renewable

Copping, A.E., M.C. Freeman, A.M Gorton, and L.G. Hemery. 2020b. Risk Retirement and Data Transferability for Marine Renewable Energy. In A.E. Copping and L.G. Hemery (Eds.), OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). (pp. 263-279). Available online: https://tethys.pnnl.gov/publications/state-of-the-science-2020-chapter-13-risk-retirement

Dhanak, M., Coulson, R., Dibiasio, C., Frankenfield, J., Henderson, E., Pugsley, D., Valdes, G. 2016. Assessment of Electromagnetic Field Emissions from Subsea Cables, paper presented at 4th Marine Energy Technology Symposium (METS), Washington DC, USA. Available online: https://tethys.pnnl.gov/publications/assessment-electromagnetic-field-emissions-subsea-cables

Gill, A., Huang, Y., Gloyne-Philips, I., Metcalfe, J., Quayle, V., Spencer, J., Wearmouth, V. 2009. COWRIE 2.0 Electromagnetic Fields (EMF) Phase 2: EMF Sensitive Fish Response to EM Emissions from Sub-sea Electricity Cables of the Type used by the Offshore Renewable Energy Industry (Report No. COWRIE-EMF-1-06). Report by Centre for Environment Fisheries and Aquaculture Science (CEFAS). Available online: https://tethys.pnnl.gov/publications/cowrie-20-electromagnetic-fields-emf-phase-2-emf-sensitive-fish-response-em-emissions

Gill, A.B., M. Desender. 2020. Risk to Animals from Electro-magnetic Fields Emitted by Electric Cables and Marine Renewable Energy Devices. In A.E. Copping and L.G. Hemery (Eds.), OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). (pp. 86-10). Available online: https://tethys.pnnl.gov/publications/state-of-the-science-2020-chapter-5-electromagnetic-fields

Hutchison, Z., Sigray, P., He, H., Gill, A., King, J., Gibson, C. 2018. Electromagnetic Field (EMF) Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables (Report No. BOEM 2018-003). Available online: https://tethys.pnnl.gov/publications/electromagnetic-field-emf-impacts-elasmobranch-shark-rays-skates-american-lobster

Kavet, R., Wyman, M., Klimley, A. 2016. Modeling Magnetic Fields from a DC Power Cable Buried Beneath San Francisco Bay Based on Empirical Measurements. Plos One, 11(2), e0148543. Available online: https://tethys.pnnl.gov/publications/modeling-magnetic-fields-dc-power-cable-buried-beneath-san-francisco-bay-based

Langenfelt, I., Westerberg, H. 2008. Sub-Sea Power Cables And The Migration Behaviour Of The European Eel. Fisheries Management and Ecology, 15(5-6), 369-375. Available online: https://tethys.pnnl.gov/publications/sub-sea-power-cables-migration-behaviour-european-eel

Love, M., Nishimoto, M., Clark, S., McCrea, M., Bull, A. 2017. Assessing potential impacts of energized submarine power cables on crab harvests. Continental Shelf Research, 151, 23-29. Available online: https://tethys.pnnl.gov/publications/assessing-potential-impacts-energized-submarine-power-cables-crab-harvests

Sherwood, J., Chidgey, S., Crockett, P., Gwyther, D., Ho, P., Stewart, S., Strong, D., Whitely, B., Williams, A. 2016. Installation and operational effects of a HVDC submarine cable in a continental shelf setting: Bass Strait, Australia. Journal of Ocean Engineering and Sciences, 1(4), 337-353. Available online: https://tethys.pnnl.gov/publications/installation-operational-effects-hvdc-submarine-cable-continental-shelf-setting-bass

Thomsen, F., Gill, A., Kosecka, M., Andersson, M., André, M., Degraer, S., Folegot, T., Gabriel, J., Judd, A., Neumann, T., Norro, A., Risch, D., Sigray, P., Wood, D., Wilson, B. 2015. MaRVEN - Environmental Impacts of Noise, Vibrations and Electromagnetic Emissions from Marine Renewable Energy (Report No. RTD-K3-2012-MRE). Report by Danish Hydraulic Institute (DHI). Available online: https://tethys.pnnl.gov/publications/marven-environmental-impacts-noise-vibrations-electromagnetic-emissions-marine