Stressor-specific Guidance Document: Entanglement

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 entanglement.[1] It is not intended to replace any regulatory requirements or prescribe action for a particular risk.

Introduction to Stressor

Loose mooring lines, fishing gear, and marine cables used for anthropogenic activities at sea have the potential to wrap around, entrap, and/or entangle marine animals. This can alter or inhibit movement, cause injuries when an animal tries to free itself (Moore et al. 2006; Robbins et al. 2015), or lead to death if the animal is prevented from going up for air, escaping predators, or feeding (Duncan et al. 2017; Schrey and Vauk 1987). The species of most concern for entanglement risk are large marine mammals, particularly migratory whales during transit and feeding (Benjamins et al. 2014). In addition, other species potentially at risk include large pelagic elasmobranchs (such as sharks), as well as diving seabirds, sea turtles, and large fish. Figure 1 shows an abbreviated version of where this stressor fits within the guidance document framework.

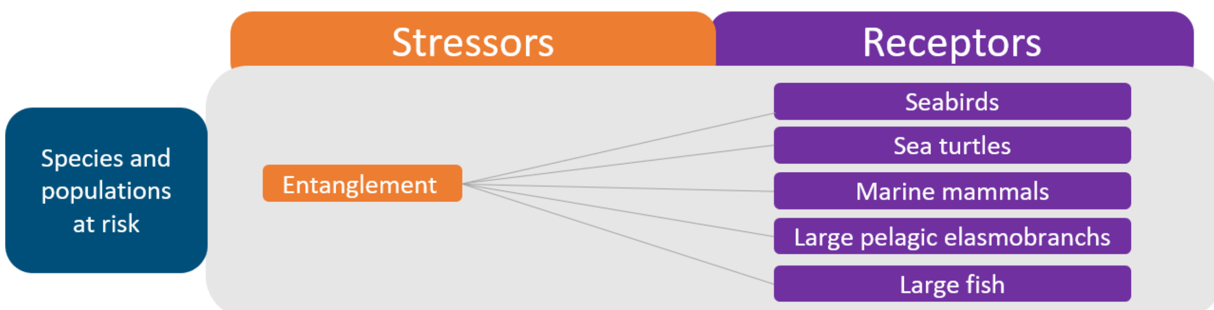

Figure 1. Portion of the guidance document framework depicting entanglement and key receptors, which are relevant under the regulatory category of species and populations at risk. The full framework can be found in the background guidance document.[1]

Some marine renewable energy (MRE) systems (e.g., those with floating components or those positioned in the water column) have mooring lines and subsea cables within the water column (Figure 2).[2] The potential for the lines and cables to become an entanglement hazard for marine animals has been raised by some regulators and stakeholders. MRE devices may have unique mooring and anchoring systems depending on the technology type. For example, tidal kites have turbines, lines, and cables that can be highly dynamic (Mademlis et al. 2020). In the case of tidal kites, model results predict most marine mammals will not encounter the device when it is operating and if an encounter happens the tether is likely to remain taut (Minesto 2016). While there has been no evidence of entanglement with MRE systems to date, the potential for this risk may vary depending on line or cable configuration, depth, location, device type, physical characteristics of the line or cable (e.g., type, dimension, weight, bend ratio, etc.), and animal behavior and size (Sparling et al. 2013).

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[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.

[2] Other MRE systems, mainly bottom-mounted devices, may have cables laid across the seafloor (rather than lines or cables in the water column) and therefore will not constitute an entanglement risk.

The types of entanglement can be classified as primary or secondary. Primary entanglement is defined as the direct impact from contact between device mooring lines and cables and marine animals, whereas secondary entanglement occurs when debris or fishing gear that was lost or abandoned by another industry becomes attached or caught on MRE devices, mooring lines, or cables and can affect marine fauna. Lines and cables associated with MRE devices are taut with no loose ends, and cannot form a loop, therefore providing no entrapment method for entangling marine animals. However, the potential effect of entanglement from MRE systems to marine animals will need to be demonstrated with numerical models, and empirical data collected for validation of the models, particularly at the large array scale.

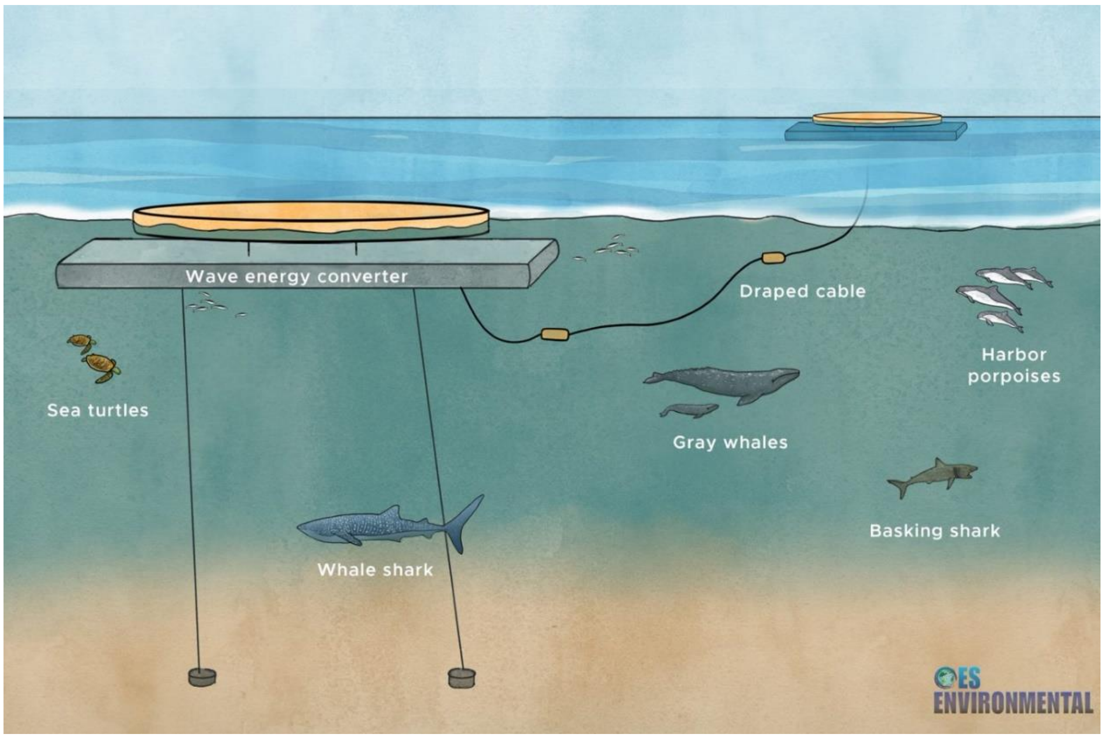

Figure 2. Example of an MRE device mooring system and cables and the marine megafauna and turtles that may interact with them. (Illustration by Rose Perry and Stephanie King)

Existing Data and Information

2020 State of the Science

Chapter 8 of the 2020 State of the Science Report (Garavelli 2020) covers entanglement in detail. It synthesizes research and findings from current MRE projects to provide a comprehensive look at the status of knowledge for mooring systems and subsea cables.

Evidence Base

OES-Environmental has developed an evidence base of key research papers and monitoring reports for entanglement that supports understanding of this risk and can be accessed on *Tethys*[3]: Entanglement Evidence Base. A limited number of the studies included in the entanglement evidence base are shown at the end of this document in the Additional Information section (Table 1).

[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.

Tethys Knowledge Base

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

Pathway to Risk Retirement

For many types of mooring systems at sea, loose lines may pose the greatest hazard to marine organisms. Protected megafauna (e.g., whales and sharks) may be more at risk due to their size, migration patterns, and feeding behavior (Benjamins et al. 2014). However, all MRE systems have taut lines and, for single floating devices, mooring lines occupy a relatively small space within the water column, decreasing the risk of entanglement overall (Benjamins et al. 2014; Harnois et al. 2015). In addition, developers and site operators are likely to have monitoring systems in place to detect any failure in mooring systems. These can be employed to identify a change within their systems that may negatively impact marine animals or lead to an entanglement event, allowing for remedial action to be taken quickly, if necessary. Based on the characteristics of MRE lines and cables and the possibility for marine animals to avoid them, the risk for small numbers of devices[4] is considered low or nonexistent and can be retired. Uncertainties remain about the effects from entanglement, and further studies are needed to increase our understanding, especially as the MRE industry progresses to array-scale development. A complete list of remaining uncertainties and research needs is available in Chapter 8 of the 2020 State of the Science Report (Garavelli 2020). Key examples include the need to:

- Identify large marine animals' breeding and feeding habitats and migration pathways, as well as crucial habitats for other key migratory animals.
- Understand species' abilities to perceive and navigate around device cables and mooring systems.
- Develop encounter models to aid predictions and evaluations of the risk to marine organisms. These models will need to be validated with observational data.
- Understand the cumulative effects of MRE devices and other activities occurring in the same areas, particularly for highly migratory species.
- Conduct research studies focused on MRE arrays that evaluate entanglement probability and risk with multiple mooring lines and cables present in the same area.

Recommendations

Sharing data, information, and findings across the MRE industry and other marine industries will improve the general understanding of entanglement risk, including cumulative effects from multiple MRE devices and arrays. As the MRE industry progresses, it will be important to continue to consider local conditions, existing sources of entanglement risk, and species with greater vulnerability to entanglement to understand and minimize the risks posed by MRE mooring lines and subsea cables. Whenever an MRE project is proposed or sited near vulnerable species' habitats or migratory routes, available data should be used to identify potential risks of entanglement. In the absence of existing data, further studies about habitat use, animal behavior, and the potential for entanglement may be needed. Data collected around projects and other developments will continue to inform understanding of cumulative risks and increase the knowledge about entanglement risk.

[4] For the purposes of risk retirement, small developments have been defined as one to four devices.

Additional Information

The entanglement evidence base consists of key research studies and reports that define current understanding about the risk of entanglement for marine animals. The evidence base for entanglement can be found here.

Table 1. A selection of studies from the evidence base for entanglement, in chronological order.

Project/Research Study	Location	Device Type	Entanglement Type	Conclusion
Biological and Existing Data Analysis to Inform Risk of Collision and Entanglement Hypotheses (Kropp 2013)	West Coast, US	Wave	Primary	The various mooring lines and cables associated with wave parks would be taut under most circumstances and would not have enough slack to allow a whale to become entangled.
Understanding the Potential for Marine Megafauna Entanglement Risk from Marine Renewable Energy Developments (Benjamins et al. 2014)	Scotland	Wave and tidal, offshore wind	Primary	Results suggest that for most megafauna, MRE device moorings are unlikely to pose a major threat. Some mooring designs presented a greater relative risk than others, with the greater relative risks generated by catenary moorings, particularly those containing nylon. Taut systems represented the lowest relative risk.
Assessment of Entanglement Risk to Marine Megafauna due to Offshore Renewable Energy Mooring Systems (Harnois et al. 2015)	Global	Wave, tidal, offshore wind	Primary	Results indicate that the taut configuration has the lowest relative risk of entanglement, while the highest relative risk occurs with catenary moorings with chains and nylon ropes or with catenary moorings with accessory buoys.
Humpback Whale Encounter with Offshore Wind Mooring Lines and Inter-Array Cables (Copping and Grear 2018)	US West Coast and Hawaii	Floating offshore wind	Primary	Concerns have been raised that large cetaceans might encounter lines from an offshore wind array, potentially causing harm, including entanglement, to the whales from the encounter. An animation has been developed as a method for communicating this potential risk by presenting a visual model that can be used to evaluate the biological concerns for megafauna swimming through offshore wind farms..

References

Benjamins, S.; Harnois, V.; Smith, H. C. M.; Johanning, L.; Greenhill, L.; Carter, C.; and Wilson, B. 2014. Understanding the potential for marine megafauna entanglement risk from marine renewable energy developments (Report No. 791). Report by Scottish Natural Heritage. Available online: https://tethys.pnnl.gov/publications/understanding-potential-marine-megafauna-entanglement-risk-marine-renewable-energy-0

Duncan, E. M.; Botterell, Z. L. R.; Broderick, A. C.; Galloway, T. S.; Lindeque, P. K.; Nuno, A.; Godley, B. J. 2017. A global review of marine turtle entanglement in anthropogenic debris: a baseline for further action. Endangered Species Research, 34, 431-448. Available online: https://tethys.pnnl.gov/publications/global-review-marine-turtle-entanglement-anthropogenic-debris-baseline-further-action

Garavelli, L. 2020. Understanding the Potential for Marine Megafauna Entanglement Risk from Marine Renewable Energy Developments. 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), 147-153. Available online: https://tethys.pnnl.gov/publications/state-of-the-science-2020-chapter-8-moorings

Harnois, V.; Smith, H. C. M.; Benjamins, S.; and Johanning, L. 2015. Assessment of entanglement risk to marine megafauna due to offshore renewable energy mooring systems. International Journal of Marine Energy, 11, 27-49. Available online: https://tethys.pnnl.gov/publications/assessment-entanglement-risk-marine-megafauna-due-offshore-renewable-energy-mooring

Kropp, R. 2013. Biological and Existing Data Analysis to Inform Risk of Collision and Entanglement Hypotheses. (Report No. PNNL-22804). Report by Pacific Northwest National Laboratory (PNNL). Report for US Department of Energy (DOE). Available online: https://tethys.pnnl.gov/publications/biological-existing-data-analysis-inform-risk-collision-entanglement-hypotheses

Mademlis, G.; Liu, Y.; Chen, P.; Singhroy, E. 2020. Design of Maximum Power Point Tracking for Dynamic Power Response of Tidal Undersea Kite Systems. IEEE Transactions on Industry Applications, 56(2), 2048-2060. Available online: https://tethys-engineering.pnnl.gov/publications/design-maximum-power-point-tracking-dynamic-power-response-tidal-undersea-kite-systems

Minesto. 2016. Deep Green Holyhead Deep Project Phase I (0.5 MW) - Environmental Statement (Report No. L-100194-S14-EIAS-001). Report by Minesto. Available online: https://tethys.pnnl.gov/publications/deep-green-holyhead-deep-project-phase-i-05-mw-environmental-statement

Moore, M. J.; Bogomolni, A.; Bowman, R.; Hamilton, P. K.; Harry, C. T.; Knowlton, A. R.; Landry, S.; Rotstein, D. S.; Touhey, K. 2006. Fatally entangled right whales can die extremely slowly. Paper presented at OCEANS 2006, Washington, D.C. Available online: https://tethys.pnnl.gov/publications/fatally-entangled-right-whales-can-die-extremely-slowly

Schrey, E.; Vauk, G. J. M. 1987. Records of entangled gannets (Sula bassana) at Helgoland, German Bight. Marine Pollution Bulletin, 18(6, Supplement B), 350-352. Available online: https://tethys.pnnl.gov/publications/records-entangled-gannets-sulabassana-helgoland-german-bight

Sparling, C.; Coram, A.; McConnell, B.; Thompson, D.; Hawkins, K.; and Northridge, S. 2013. Wave and Tidal Consenting Position Paper Series: Marine Mammal Impacts. Report by SMRU Consulting for Natural Environment Research Council. Available online: https://tethys.pnnl.gov/publications/wave-tidal-consenting-position-paper-series-marine-mammal-impacts

Robbins, J.; Knowlton, A. R.; Landry, S. 2015. Apparent survival of North Atlantic right whales after entanglement in fishing gear. Biological Conservation, 191, 421-427. Available online: https://tethys.pnnl.gov/publications/apparent-survival-north-atlantic-right-whales-after-entanglement-fishing-gear