Stressor-specific Guidance Document: Underwater Noise

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 underwater noise.[1] *It is not intended to replace any regulatory requirements or prescribe action for a particular risk. This document is intended to be read in conjunction with the background document.*

Introduction to Stressor

Animals in the marine environment rely on sound for communication, social interaction, orientation and navigation, foraging, and evasion. Ambient underwater sound conditions are made up of animal vocalizations and other behavior, tidal currents and waves, and wind and other weather conditions. Anthropogenic sources, such as shipping, boating, and other industrial activities, also contribute to underwater noise in the marine environment (Duarte et al. 2021). The noise associated with such activities may affect animals that rely on sound, such as marine mammals, fish, sea turtles, and invertebrates; however, the extent to which marine animals detect sound varies by frequency and taxonomy. Figure 1 shows an abbreviated version of where this stressor fits within the guidance document framework.

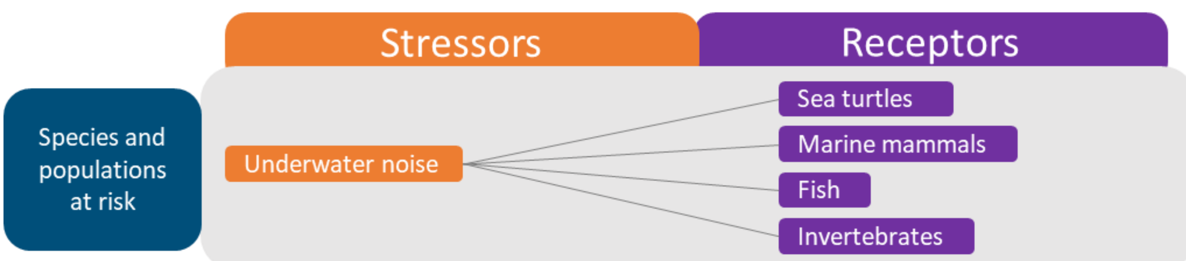


Figure 1. Portion of the guidance document framework depicting underwater noise and key receptors, which are relevant under the regulatory category of species and populations at risk. The full framework can be found in the background guidance document.

Underwater noise from marine renewable energy (MRE) developments may come from construction and maintenance activities, as well as from operational devices and their components. Impacts from anthropogenic sources of noise may include stress, behavioral changes (such as avoidance), physical injuries, temporary or permanent impacts to hearing ability in marine animals, or masking of other important cues in the marine environment. While construction and maintenance activities may create loud underwater noise, there are methods to manage or mitigate such noise and these activities are usually of relatively short duration. Noise from operational MRE devices is lower in amplitude than some sources of anthropogenic noise and natural sounds (Figure 2). To understand the potential effects of underwater noise from operational MRE devices on marine animals, an assessment is needed of the ambient noise environment, frequency and levels at which key marine species receive sound, and noise output from the device. This will allow noise output from the device to be assessed and related to effects on marine animals.

[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.

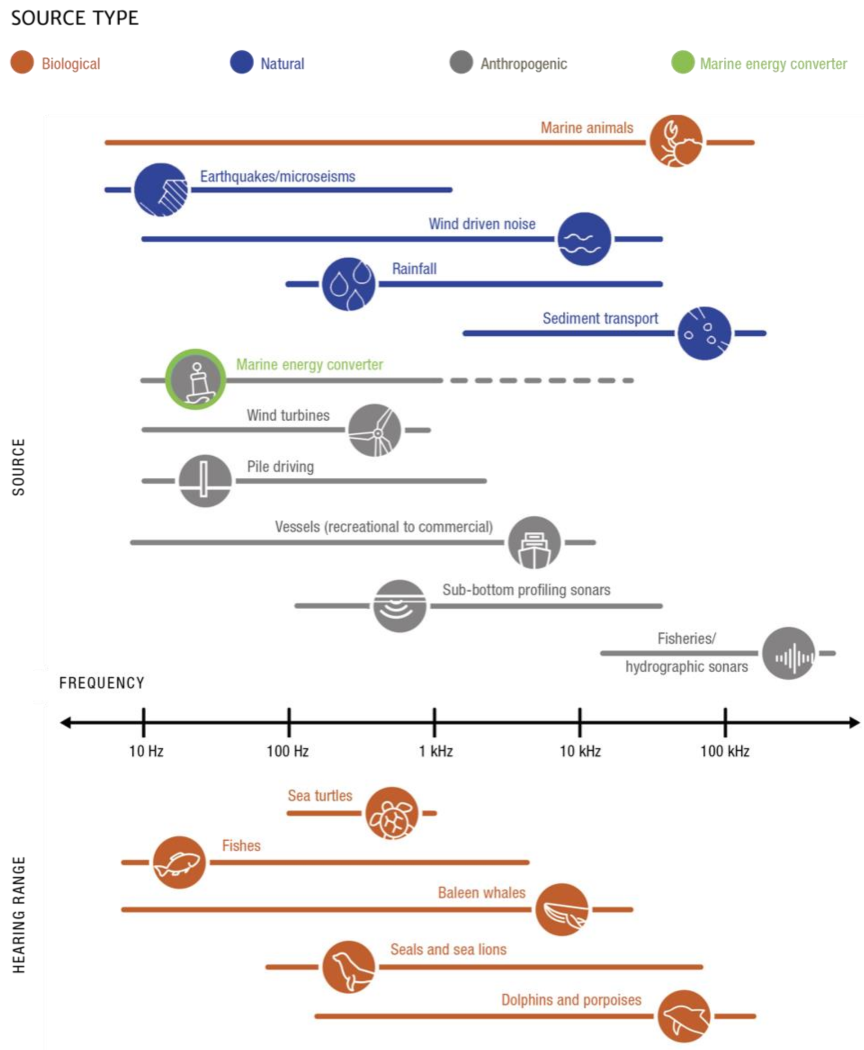


Figure 2. Comparison of underwater noise levels emitted from a variety of anthropogenic and natural sources in relation to hearing ranges of marine animals. For sources, the horizontal bars denote the frequencies associated with the most energetic sound they generate. Many of these sources produce less energetic sound outside of the indicated range. In the case of marine energy converters, the dashed line at higher frequencies conveys scientific uncertainties about the upper frequency limit of their radiated noise. For hearing ranges, the horizontal bars correspond to the full range of frequencies likely audible to the groups of animals. Information in this figure is drawn from resources including Discovery of Sound in the Sea (DOSITS) and similar figures, such as presented in Scholik-Schlomer (2015). (Illustration by Rose Perry) Additional information on anthropogenic sources of noise can be found in Duarte et al. (2021).

Existing Data and Information

2020 State of the Science

Chapter 4 of the 2020 State of the Science Report (Polagye and Bassett 2020) covers underwater noise in detail. It synthesizes research and findings from current MRE projects to provide a comprehensive look at the status of knowledge for impacts from underwater noise.

Evidence Base

OES-Environmental has developed an evidence base of key research papers and monitoring reports for underwater noise that support the understanding and risk retirement for small numbers of MRE devices[2]. The evidence base has been reviewed by international subject

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

matter experts in workshop settings and can be accessed on *Tethys*[3]: Underwater Noise Evidence Base. A limited number of the studies included in the underwater noise evidence base are shown at the end of this document in the Additional Information section (Table 1).

Monitoring Datasets Discoverability Matrix

OES-Environmental has also developed the Monitoring Datasets Discoverability Matrix, an interactive tool that allows the user to locate datasets by stressor, receptor, and other specifications for underwater noise, 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. These are compiled from OES-Environmental Metadata, which provides links and contacts to existing datasets from MRE projects and research studies. The metadata includes information solicited from developers and researchers on environmental monitoring for MRE, which is updated annually.

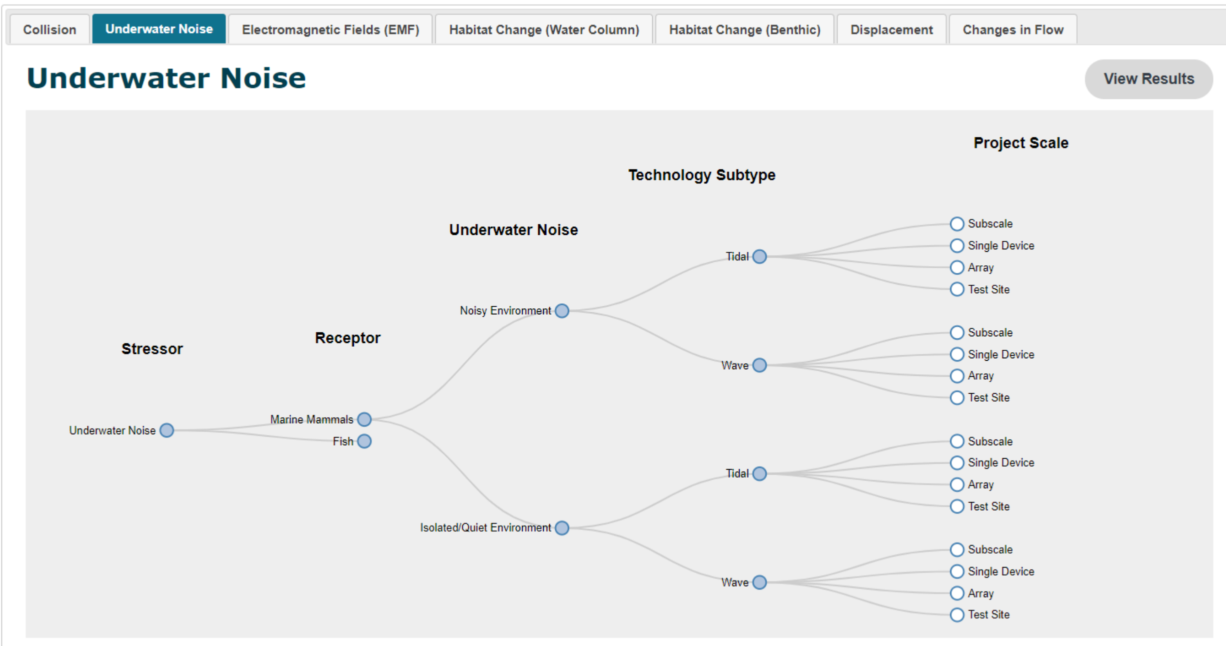


Figure 3. Screenshot of the Monitoring Datasets Discoverability Matrix selections for underwater noise on *Tethys*. Selections under fish mirror those shown for marine mammals.

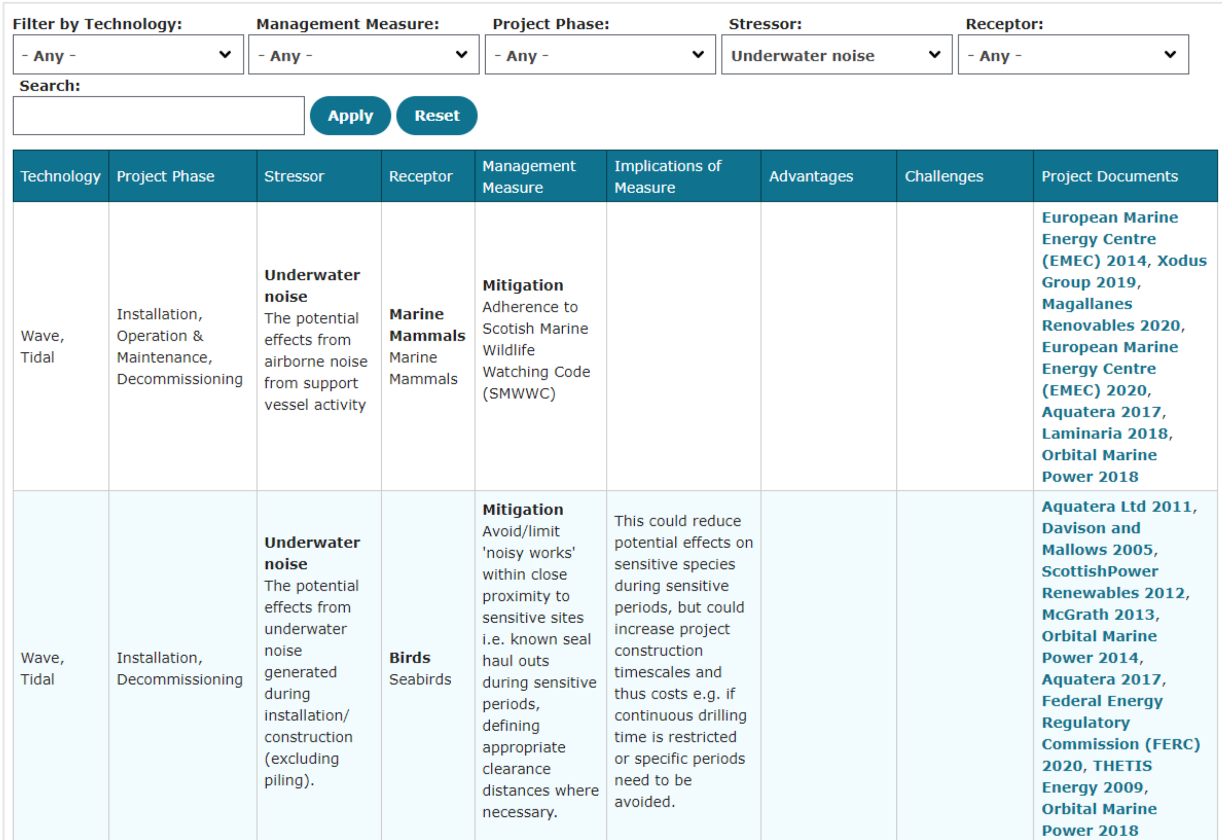
Management Measures Tool

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 underwater noise is shown in Figure 4 below.

***Tethys* Knowledge Base**

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

[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.



Filter by Technology: - Any - | Management Measure: - Any - | Project Phase: - Any - | Stressor: Underwater noise | Receptor: - Any -

Search: [Apply] [Reset]

Technology	Project Phase	Stressor	Receptor	Management Measure	Implications of Measure	Advantages	Challenges	Project Documents
Wave, Tidal	Installation, Operation & Maintenance, Decommissioning	**Underwater noise** The potential effects from airborne noise from support vessel activity	**Marine Mammals** Marine Mammals	**Mitigation** Adherence to Scotish Marine Wildlife Watching Code (SMWWC)				European Marine Energy Centre (EMEC) 2014, Xodus Group 2019, Magallanes Renovables 2020, European Marine Energy Centre (EMEC) 2020, Aquatera 2017, Laminaria 2018, Orbital Marine Power 2018
Wave, Tidal	Installation, Decommissioning	**Underwater noise** The potential effects from underwater noise generated during installation/ construction (excluding piling).	**Birds** Seabirds	**Mitigation** Avoid/limit 'noisy works' within close proximity to sensitive sites i.e. known seal haul outs during sensitive periods, defining appropriate clearance distances where necessary.	This could reduce potential effects on sensitive species during sensitive periods, but could increase project construction timescales and thus costs e.g. if continuous drilling time is restricted or specific periods need to be avoided.			Aquatera Ltd 2011, Davison and Mallows 2005, ScottishPower Renewables 2012, McGrath 2013, Orbital Marine Power 2014, Aquatera 2017, Federal Energy Regulatory Commission (FERC) 2020, THETIS Energy 2009, Orbital Marine Power 2018

Figure 4. Screenshot of the Management Measures Tool selections for underwater noise.

International Standards

Under the auspices of the International Electrotechnical Commission (IEC) Technical Committee 114 (TC 114), which develops international consensus standards for marine energy conversion technologies, an international consensus Technical Specification has been published. IEC 62600-40 lays out a standardized approach for characterizing radiated noise around MRE devices (IEC 2019). The full specification is available here.

Regulatory Thresholds and Guidance

The clearest instance of regulatory thresholds for impacts from underwater noise are found in the U.S. The U.S. thresholds for marine mammals are set by the National Marine Fisheries Service (2018). National Marine Fisheries Service (2018). While there are no set thresholds for fish, interim sound exposure guidelines used in the U.S. can be found in Popper et al. (2014). These thresholds and guidance can be used as a proxy to assess the potential for impact from MRE devices and are shown at the end of this document in Additional Information, Table 2.

Pathway to Risk Retirement

The evidence base to date suggests that the impacts of underwater noise from small-scale MRE developments are limited. Underwater noise measurements from operational MRE devices show that noise levels generally fall below those likely to cause injury or harm to marine mammals and fish (see Additional Information, Tables 1 and 2) and observed *in situ* behavioral change is unlikely to be attributed solely to radiated noise. To date there is no evidence that operational MRE device noise physically or behaviorally harms marine animals. Overall, the scientific community has reached a general consensus that underwater noise from operational devices within small-scale MRE developments does not pose a risk to marine animals (Copping et al. 2020a, Copping et al. 2020b, Polagye and Bassett 2020).

Some uncertainties remain, and more studies will be useful to increase understanding. A complete list of remaining uncertainties and research needs is available in Chapter 4 of the 2020 State of the Science Report (Polagye and Bassett 2020). Key examples include the need to:

- Develop the capability to differentiate between MRE device noise and ambient noise to report accurate acoustic characteristics of MRE devices.
- Study the species-specific behavioral consequences of radiated noise from MRE devices differentiated from local ambient noise.
- Measure particle motion for noise from operational MRE devices to better understand the potential effects on fish.
- Collect comparable acoustic measurements across a broad range of MRE devices and settings, standardizing robust methods to further inform global risk identification.
- Accurately model noise from an array of MRE devices using measurements from a single device.

Recommendations

Sharing data and information across the MRE industry and other marine industries will benefit general understanding of impacts from underwater noise, including the cumulative effects of anthropogenic sources of noise in the ocean. As the MRE industry progresses, it will be important to continue to consider ambient noise levels, existing sources of noise, and sensitive species, to understand and minimize impacts from underwater noise. Risk from underwater noise for small numbers of devices can be considered retired. However, this does not replace the need for measures to minimize impacts from emissions of anthropogenic noise as required by existing regulations. If a project developer has measured device noise output and the noise falls below the levels of harm or injury to sensitive marine species in the area, extensive studies of underwater noise at each new proposed project site may not be needed. While the MRE community will benefit from the internationally accepted standard for measuring underwater noise from MRE devices, TC 114, the industry would also benefit from regulatory action levels and guidance for protecting marine animals from underwater noise.

Additional Information

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

Table 1. A selection of studies from the evidence base for underwater noise effects on marine animals, in chronological order, adapted from Copping et al. 2020a.

Project/Research Study	Location	Device type	Noise Measurements	Conclusion
WaveRoller (2012-2014) (Cruz et al. 2015)	WavEc – Peniche, Portugal	Wave energy converter	Operational noise of bottom-mounted oscillating wave surge converter prototype peaked at 121 dB re 1 µPa. Average broadband SPL measured with Hydrophone 2 varied between 115 and 126 dB re 1 µPa rms and with Hydrophone 1 between 115 and 121 dB re 1 µPa rms. SPL values decreased over time. The noise decreased within 300 m of the device.	Calculating the sound exposure level (SEL) of the WaveRoller sound, which was 150 dB re 1 µPa²/s, showed that no injury to cetaceans is expected. The results indicated that the frequency ranges at which the device operates overlap those used by some low and midfrequency cetaceans, but only behavioral responses would be expected if the organisms swim near the WaveRoller. Additionally, no cetaceans were around the WaveRoller device, likely due to the low depth where the device was installed.
EDF and DCNS Energies OpenHydro (2013-2014) (Lossent et al. 2017)	Paimpol Brehat, France	Tidal turbine	Operational SPL ranged from 118 to 152 dB re 1 µPa at 1 m in third-octave bands at frequencies between 40 and 8192 Hz, which were measured at distances between 100-2400 m from the turbine. The acoustic footprint of the device corresponds to a 1.5 km radius disk.	Physiological injury of marine mammals, fish, and invertebrates was improbable within the area of greatest potential impact. Permanent threshold shifts (PTS) and temporary threshold shifts (TTS) risks were non-existent for all target species. Behavioral disturbance may occur up to 1 km around the device for harbor porpoises only, but is of little concern for a single turbine.
SCHOTTEL Instream Turbine (2014) (Schmitt et al. 2015)	Strangford Lough, Northern Ireland	Tidal turbine	Highest operational noise levels were around 100 re µPa2/Hz at 9 m from the turbine.	Sounds levels were on the same order as natural and anthropogenic background noise measured.
ORPC Cobscook Bay Tidal Energy Project , TidGen® (2013-2017) (ORPC Maine 2014)	Maine, United States	Tidal turbine	Operational noise less than 100 dB re µPa2/Hz at 10 m, at 200-500 m from the turbine.	Sound was not detectable above ambient noise levels.
Fred. Olsen Bolt Lifesaver (2016-2018) (Polagye et al. 2017)	U.S. Navy Wave Energy Test Site (WETS) – O'ahu, United States	Wave energy converter	Operational noise of floating point absorber wave device was 114 dB re 1 µPa for median broadband SPL, and mean levels as high as 159 dB re 1 µPa were infrequently observed. At one point during the study, the WEC had a damaged bearing, which coupled with the operational noise reached 124 dB re 1 µPa.	Operational noise levels remained below acceptable thresholds. Received levels exceeded the U.S. regulatory threshold for auditory harassment of marine mammals (broadband level of 120 dB re 1 µPa) for only 1% of the deployment. These exceedance events were dominated by non-propagating flow noise and sources unrelated to the Lifesaver.
Wello Oy, Penguin (2017-2019) (Beharie & Side 2012)	European Marine Energy Centre (EMEC) – Orkney, United Kingdom	Wave energy converter	The measured sound pressure levels of this floating rotating mass WEC's cooling system, which included two cooling fans and one pump, suggested a source level of 140.5 dB re 1 µPa at 1 m during operation.	Expected that ambient background noise levels will be reached within about 10 m of the device.

Table 2. List of US regulatory thresholds for marine mammals and guidance for fish. SELcum means cumulative sound exposure level, SPL means sound pressure level, and RMS means root mean square (RMS). Adapted from Copping et al. 2020a.

		Animals of Interest	
Source	**Measurement**	**Marine Mammals**	**Fishes**
NMFS (2018) – temporary threshold shifts (TTS)	179 dB re 1 µPa2/s (SELcum)	Low-frequency cetaceans	
	178 re 1 µPa2/s (SELcum)	Mid-frequency cetaceans	
	153 re 1 µPa2/s (SELcum)	High-frequency cetaceans	
	181 re 1 µPa2/s (SELcum)	Phocid pinnipeds	
	199 re 1 µPa2/s (SE cum)	Otariid pinnipeds	
Buehler et al. (2015); Tetra Tech Inc. (2013) – physiological effects thresholds	206 dB re 1 µPa (peak SPL)		Fish
	187 dB re 1 µPa2/s (SELcum)		Fish > 2g
	183 dB re 1 µPa2/s (SELcum)		Fish < 2g
Stadler and Woodbury (2009); Tetra Tech Inc. (2013) – behavioral effects thresholds	150 dB re 1 µPa (RMS)		Fish

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