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PNNL- 29996

Risk Retirement for Environmental Effects of Marine Renewable Energy

May 2020

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U.S. DEPARTMENT OF ENERGY
Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

PACIFIC NORTHWEST NATIONAL LABORATORY
operated by
BATTELLE
for the
UNITED STATES DEPARTMENT OF ENERGY
under Contract DE-AC05-76RL01830

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Summary

Over the last couple of decades scientists, engineers, regulators, developers, and other stakeholders have examined and identified six key environmental interactions, or potential risks, for the marine renewable energy (MRE) industry: animals colliding with turbines; effects of underwater noise from the operation of MRE devices on marine animals; effects of electromagnetic fields (EMF) from power cables on marine animals; changes in seabed or water column habitats from installation and operation of MRE systems; displacement or barrier effects from MRE arrays that may keep animals from critical habitats, and; changes in circulation and sediment transport from MRE device operation (Kropp 2013; Copping et al. 2016; Copping and Grear 2018). Uncertainty remains about these potential interactions between MRE devices and the marine environment, which has led to scrutiny from regulators and other stakeholders that has created barriers to consenting/permitting (hereafter "consenting") MRE devices and high costs for environmental monitoring. However, there is a growing body of knowledge that can aid the advancement of the MRE industry in the face of such challenges.

To help the MRE industry move forward, OES-Environmental has developed a process for facilitating consenting for small numbers of MRE devices so that each potential risk may not need to be investigated for every project. This process, called "risk retirement," helps determine which interactions of MRE devices and the marine environment are low risk and may be "retired," and which need further data collection and research, or new mitigation measures to increase understanding and limit impacts.

To aid in the determination of a risk being retired, OES-Environmental has put forth a risk retirement pathway. The pathway begins with describing an MRE project and potential environmental interactions, then progresses through five stages to determine if the risk can be retired or if more information or mitigation is needed. The five stages are as follows:

- **Define risk:** Determine if a likely/plausible risk exists for a particular project.
- **Examine existing data:** Determine whether sufficient data exists to demonstrate whether the risk is acceptable.
- **Collect additional data:** Collect additional data to determine whether the risk is acceptable.
- **Apply existing mitigation:** Apply existing mitigation measures to determine whether the risk can be mitigated.
- **Test novel mitigation:** Test novel mitigation measures to determine whether the risk can be mitigated.

The risk retirement process has been discussed with and found to be largely supported by the MRE community including developers, regulators, researchers, consultants, and other stakeholders. This report explains the concept of risk retirement, documents outreach and engagement efforts to gather feedback and test the concept, and examines future steps to increase the ability to retire risks throughout the MRE industry. Successful implementation of the risk retirement process within the international MRE community will accomplish the following:

- Reduce the amount of uncertainty regarding environmental effects of MRE deployments and add to the existing knowledge base;
- Facilitate consenting processes for both regulators and developers to reduce time and costs;
- Promote public understanding and acceptance of MRE projects; and

- Allow for resources to be dedicated to interactions that require further exploration and understanding.

Acknowledgements

This project is funded by the U.S. Department of Energy (DOE) Water Power Technologies Office (WPTO) under Task 1.7.0.601: *International Environmental Data Sharing Initiative (OES-Environmental Project & Tethys Database).*

We are grateful for the continuing support we receive from the U.S. Department of Energy's Energy Efficiency and Renewable Energy Water Power Technologies Office, particularly the help that Samantha Eaves provides us. We are also very grateful for the support we receive from International Energy Agency - Ocean Energy Systems (OES) and the continuing guidance from the OES Executive Committee and support from the 15 other OES-Environmental nations and their representatives.

We thank the many marine renewable energy researchers, government regulators and resource managers, marine energy developers, consultants, and stakeholders who have given generously of their time and thoughts in helping develop this material. We are indebted to the Pacific Northwest National Laboratory (PNNL) team who support this effort including Alicia Gorton, Lenaïg Hemery, Hayley Farr, Jonathan Whiting, Deborah Rose, Levy Tugade, Lysel Garavelli, and Amy Woodbury. Ian Hutchinson, Jennifer Fox, Gareth Davies, and the rest of their team at Aquatera Limited have been an indispensable part of this effort.

Preface

OES-Environmental (formerly Annex IV) was established by the International Energy Agency Ocean Energy Systems (OES) in January 2010 to examine environmental effects of marine renewable energy (MRE) development. The United States leads the OES-Environmental effort, with Pacific Northwest National Laboratory (PNNL) serving as the Operating Agent and partnered with the U.S. Department of Energy (DOE), the U.S. Bureau of Ocean Energy Management (BOEM), and the U.S. National Oceanic and Atmospheric Administration (NOAA). Currently, there are 15 partner nations for the OES-Environmental effort: Australia, Canada, China, Denmark, France, India, Ireland, Japan, Norway, Portugal, South Africa, Spain, Sweden, United Kingdom, and U.S. PNNL implements OES-Environmental using *Tethys* as the platform on which OES-Environmental activities are coordinated and archived. PNNL develops and maintains the *Tethys* knowledge management system that provides open access to information about the potential environmental effects of MRE.

The MRE industry is relatively new and has faced regulatory challenges associated with potential environmental effects that are not well understood. OES-Environmental is mobilizing information and practitioners from OES nations to coordinate research that can progress the industry in an environmentally responsible manner. During the third phase of OES-Environmental, the focus has been on data transferability (Copping et al. 2020a) and risk retirement (Copping et al. 2020b).

Acronyms and Abbreviations

BMP	best management practices
BOEM	Bureau of Ocean Energy Management
DOE	U.S. Department of Energy
EMF	electromagnetic field
IEC TC	International Electrical Commission Technical Committee
MRE	marine renewable energy
NOAA	National Oceanic and Atmospheric Administration
OES	Ocean Energy Systems
PNNL	Pacific Northwest National Laboratory
WEC	wave energy converter

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1.0 Introduction

What do we mean by "risk retirement" (from Copping et al. 2020c).

This [report] discusses a process for facilitating consenting for small numbers of MRE devices (one or two most likely), whereby each potential risk need not be fully investigated for every project. Rather we recommend that MRE developers rely on what is known from already consented projects, from related research studies, or from findings from analogous offshore industries. When larger arrays of MRE devices are planned, or when new information comes to light, these risks can be revisited and new decisions about the level of risk down-scoping or retirement can be made.

The intent of the process is to provide assistance to regulators in their decision-making and to inform the MRE community of what is likely to be required for consenting small developments, as well as to help distinguish between perceived and actual risk to the marine environment.

Risk retirement will not take the place of existing regulatory processes, nor will it completely replace the need for all data collection before and after MRE device deployment; these data are needed to verify risk retirement findings and add to the overall knowledge base.

Consequences of increased anthropogenic greenhouse gases in the earth's atmosphere, such as rising sea level (Marcos and Amores, 2014) and escalating frequencies and intensities of extreme weather events (Stott et al. 2016), are well known. To combat these effects, many countries are limiting emissions and have turned to increasing the use of renewable energy (Wilberforce et al. 2019). Marine renewable energy (MRE), a broad term that refers to the various ways to generate electricity from the world's oceans, seas, and rivers, has great potential for large-scale energy generation globally. The MRE industry is still in the early stages of development, with wave and tidal current energy being the most advanced and expected to contribute significantly to the supply of energy in the future (Lewis et al. 2011). For example, a 2015 estimate of global wave energy resource potential ranges from 16,000 to 18,500 TWh/yr (Reguero et al. 2015). Even with its enormous potential for global energy generation, as of 2018 MRE contributed less than 0.02% to the total global renewable energy capacity (International Renewable Energy Agency 2019).

A major barrier for the development of the MRE industry is the uncertainty surrounding potential environmental effects of wave and tidal devices and arrays of devices and if they pose an intolerable risk to marine animals, surrounding habitats, or ecosystem processes. Facing such uncertainty, regulators often rely on the precautionary principle to justify extensive requests for data collection and may deny the necessary licenses to deploy and operate MRE devices (Gibbs and Browman 2015). This creates increased scrutiny of the MRE industry leading to a slower consenting/permitting (hereafter "consenting") process, increased costs due to expensive monitoring requirements, and few devices deployed in the water. However, knowledge of potential effects of MRE has increased rapidly in the past decade due to more monitoring efforts around deployed devices and research studies, especially those that have focused on direct interactions and the environments in which MRE devices are deployed. From these stem indications that many environmental effects are likely to be insignificant at the scale of single MRE devices or small arrays (Copping et al. 2016).

Based on the current state of the science, certain interactions between MRE devices and the marine environment could be “retired” for small numbers of MRE devices. This concept of “risk retirement” allows for interactions that are low risk or pose little threat to be retired and for continued research and monitoring efforts to focus on those interactions that may be considered higher risk (see Box 1). This process of risk retirement, developed by PNNL and OES-Environmental, aims to aid regulators in consenting MRE projects, reduce the financial burden of extensive monitoring requirements on developers, decrease timelines for consenting processes, add to the existing knowledge base, and promote public understanding and acceptance of MRE projects (Copping 2018; Copping et al. 2020b).

1.1 MRE Stressors on the Marine Environment

After the publication of the *2016 State of the Science Report* (Copping et al. 2016), and as a result of extensive discussions with relevant stakeholders, six stressors between MRE devices and the marine environment (receptors) were identified as those most commonly associated with consenting processes that are challenging for both sing MRE devices and arrays:

1) Collision risk: The potential for marine animals to collide with tidal or river turbine blades, resulting in injury or death is a primary concern for consenting turbines. There is a high degree of uncertainty around the probability and the consequence of collision, especially for populations afforded special protection.

2) Underwater noise: The potential for the acoustic output from operational wave or tidal devices to mask the ability of marine mammals and fish to communicate and navigate remains uncertain, as does the potential to cause physical harm or to alter animal behavior. Noise from installation, particularly pile driving, may cause short-term harm; the risks that this report focuses on are the longer-term operational sound of devices.

3) Electromagnetic fields (EMF): EMFs are generated in the oceans as electricity is transmitted through cables or from moving parts of machines. EMFs emitted from power export cables and energized portions of MRE devices are thought to potentially affect EMF-sensitive species by interrupting their orientation, navigation, and/or hunting. Cables have been deployed in the ocean for many decades, but uncertainty remains around the effects of cables associated with MRE devices due to the lack of monitoring data available around MRE devices.

4) Changes in habitat: Placement of MRE devices in the marine environment may alter or eliminate surrounding habitat, which can reduce the extent of the habitat, add new habitats, and affect the behavior of marine organisms. Habitat changes, including the effects of fish and other organisms aggregating around devices and buoys, are well-studied in the marine environment from other industries, and the small footprint of MRE devices are unlikely to affect animals or habitats differently than those from other industries, but regulators and stakeholders continue to express concern.

5) Changes in oceanographic systems: MRE devices may alter natural water flows and remove energy from oceanographic systems, which could result in changes in sediment transport, water quality, and other effects on farfield habitats. Numerical models provide the best estimates of potential effects; however, any potential effect from a small number of devices will be lost in the natural variability of the system. Once larger arrays are in operation, field data will be needed to validate the models.

6) <u>Displacement of marine animal populations</u>: While the placement of single MRE devices in the marine environment is unlikely to cause displacement of marine animal populations, as larger arrays are deployed, there are concerns that animals could be displaced from critical foraging, mating, rearing, or resting habitats (DOE/EERE 2009; Boehlert and Gill 2010; Dolman and Simmonds 2010). Large arrays might also cause a barrier effect, preventing animals from crossing a line of devices, navigating around an array, or crossing a cable to reach their preferred or essential habitats.

Based on existing evidence and engagement from the MRE community (including developers, regulators, researchers, and consultants), four of the six stressor-receptor interactions listed above appear to be suitable for retirement for small numbers of devices: (1) effects of underwater noise generated by MRE devices on fish and marine mammals; (2) EMF emitted by export power cables on certain marine species; (3) changes in benthic and pelagic habitats; and (4) changes in oceanographic systems as a result of MRE operation.

1.2 Background on Risk Retirement

Risk can be defined as the likelihood of an adverse outcome from an action and can be evaluated by the probability of the occurrence of an event, as well as its resulting consequence (Copping et al. 2016). The components of risk (the probability of occurrence and consequence of occurrence) are fundamental to the process by which regulators evaluate project compliance with environmental statutes. Through interactions with U.S. regulators and the international MRE community, a process for risk retirement has been developed to inform a set of solutions as to which potential effects or risks from MRE may no longer be of concern. The term "risk retirement" has been used by a variety of technology-focused development programs. One example comes from geotechnical risk management where risk retirement is used to describe sufficient understanding for stressor-receptor interactions that eases the need to carry out detailed investigations for each proposed project (National Academies of Sciences, Engineering, and Medicine 2018). The term has also been used by the MRE community to signify that certain low-risk interactions between marine animals or habitats and MRE devices or systems might not need to be fully investigated at each project site, and that data and information from previous or existing MRE projects, targeted research studies, and results from comparable industries can be used to inform siting and consenting (Copping et al. 2016; Robertson et al. 2018). Moving towards risk retirement allows regulators to consent and license MRE projects more willingly than currently available by alleviating the needs for detailed investigations for each proposed project and allows the MRE community to focus on more prominent risks (such as collision risk).

OES-Environmental developed a risk retirement pathway (see Section 2.0) to guide the application of risk retirement for MRE projects. The pathway provides a structure to organize evidence, allows experts to evaluate whether a risk can be retired, provides a process to aid regulators that consent MRE projects, and delivers a means to consistently apply datasets from consented projects to inform proposed projects. The risk retirement process, including the pathway, is applicable to any set of stressor-receptor interactions. There will always be the need for site-specific data collection to ensure that the assumptions made through these processes are correct, as well as to understand marine animals and habitats that are specific to the MRE project location.

Efforts to develop a process for risk retirement began in 2017 with a focus on data transferability (Copping et al. 2020a). Through discussions with regulators and the MRE industry, it became clear that data transferability would help achieve a larger goal of risk retirement and play a key role in the process. In 2019, the risk retirement pathway was developed by PNNL with feedback from Aquatera Ltd. and the OES-Environmental country analysts for the purpose of determining if potential risks for MRE projects can be retired and to aid regulators in consenting MRE projects. The risk retirement pathway is described in Section 2.0. The evidence base for risk retirement of the four stressors suitable for retirement is provided in Section 3.0. A discussion of outreach and engagement efforts and feedback from the MRE community is provided in Section 4.0. Next steps and conclusions are summarized in Section 5.0

2.0 Risk Retirement Pathway

The risk retirement pathway (Fig. 1) is a systematic process used to identify and evaluate the level of risk associated with a proposed MRE project and the potential to retire such risk. The pathway aims to lower consenting challenges and barriers to enable the advancement of the MRE industry. It does so by assessing potential risks to differentiate perceived and actual risk and to strike a balance between environmental precaution and the actual effects of an MRE development.

The risk retirement pathway begins with describing the specific project of interest such as site characteristics, number of devices, etc. (Fig. 1, orange circle) in order to determine any potential stressors that may affect the surrounding marine environment. Receptors (i.e., marine animals, habitats, and ecosystem processes) present in the project area must also be identified (Fig. 1, purple circle).

Once project details are defined, the risk retirement pathway moves into a series of stage gates. At each stage there is an “offramp” that provides an opportunity to consider the risk “retired.” If the risk cannot be retired within a stage, the risk moves down the pathway to the next stage. The dotted arrows at the top of the figure represent the examination of available data and mitigation measures to provide feedback among and between steps. In addition to applying existing data to inform the risk retirement process, there may also be a need for additional monitoring data, studies, and/or development of novel mitigation measures. A particular risk can only be considered retired if the available data or mitigation measures are sufficient for an informed decision on risk retirement to be made. While the use of the risk retirement pathway must be tested in practice to determine its effectiveness, it is envisioned that it will be helpful when applied at multiple steps of developing and consenting for MRE projects.

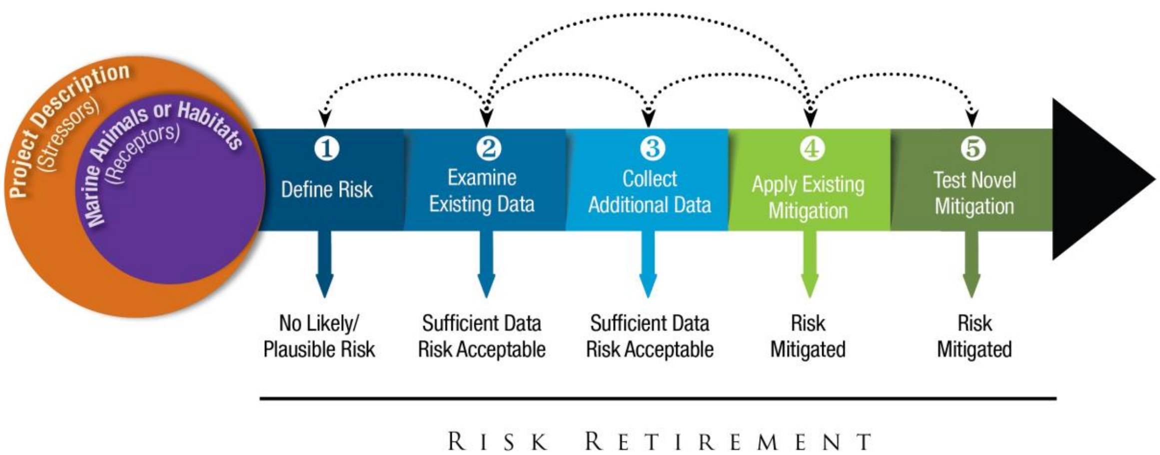

Figure 1. Risk retirement pathway. The pathway defines the process for examining a risk and assessing if the potential risk can be retired or will require additional data, information, or mitigation. The dotted arrow lines represent the feedback loops between each stage of the pathway and the downward arrows at the bottom of each stage indicate the off ramps where a risk might be considered retired.

The first stage in the risk retirement pathway is to define any potential environmental risks, or stressor-receptor interactions, of the MRE project. For example, a tidal turbine that is bottom-mounted, or placed on the seabed, may alter the benthic habitat (stressor) and therefore affect the surrounding marine animals (receptors) by creating an artificial reef or by decreasing potential habitat (Iglesias et al. 2018). The second stage in the risk retirement pathway requires the examination of existing data in order to determine whether sufficient data is available to demonstrate if the risk is acceptable or not. Such data may come from research studies on MRE environmental effects, as well as data or results of monitoring surveys from other MRE projects or analogous industries that can be transferred for use in a similar project (see Section 2.1). If substantial data from previous MRE projects is available and determines the risk acceptable, then the risk can be retired. If there is not enough evidence to retire the risk, it moves to the next stage. The third stage of the risk retirement pathway is to collect additional data and information for the targeted project. During this stage, project developers will need to collect additional data that can support an assessment of the risk. After additional data is collected, results should be assessed to determine the significance of the risk. If the risk is acceptable, it can be retired. If, after examining and collecting additional data, the risk still cannot be retired, it moves to the next stage. The fourth stage relates to applying existing mitigation. In order to do so, existing mitigation measures should be examined to determine if any are proven to mitigate the risk. If so, the mitigation can be applied, and the risk can be retired. If there are no proven mitigation measures to decrease or mitigate the risk, the risk enters the final stage. In the fifth stage, novel mitigation measures are developed and tested to determine whether the risk can be mitigated. If so, the risk can be retired.

If a risk proceeds through the entire pathway and still cannot be determined to be retired, the project may require additional investigation, a redesign of the technology, or the project may possibly need to relocated or even be abandoned.

It is important to note that once a risk is considered “retired” it is not completely eliminated. If necessary, retired risks can and should be reexamined if new information comes to light or as larger commercial arrays of tidal turbines and wave energy converters (WECs) are deployed.

A key aspect of the risk retirement process is ensuring that data and information from consenting MRE projects are catalogued and accessible for future projects. This is especially crucial to stage two of the risk retirement pathway as existing data are assessed for their application to the project in question. Our understanding of potential risks is increased as research from MRE, environmental monitoring of consented MRE projects, and lessons from other industries (such as offshore wind, oil and gas, etc.) are shared and compared across the industry. OES-Environmental developed a process to transfer such data and information from consented MRE projects (or analogous industries) to aid consenting for future projects (Copping et al. 2020a). This concept of data transferability – where learning, research, analyses, and datasets from one project or location are used to inform a future project and aid in consenting processes – works simultaneously within the risk retirement process to make examining existing data and information easier and to provide guidance for developers and regulators (Freeman et al. 2018). The data transferability process includes a data transferability framework, a data collection consistency table, a monitoring datasets discoverability matrix, and best management practices (Fig. 2). Transferring data, knowledge, and information between MRE projects and from analogous industries can help decrease uncertainty of environmental effects and reduce the need for costly monitoring for each new MRE project.

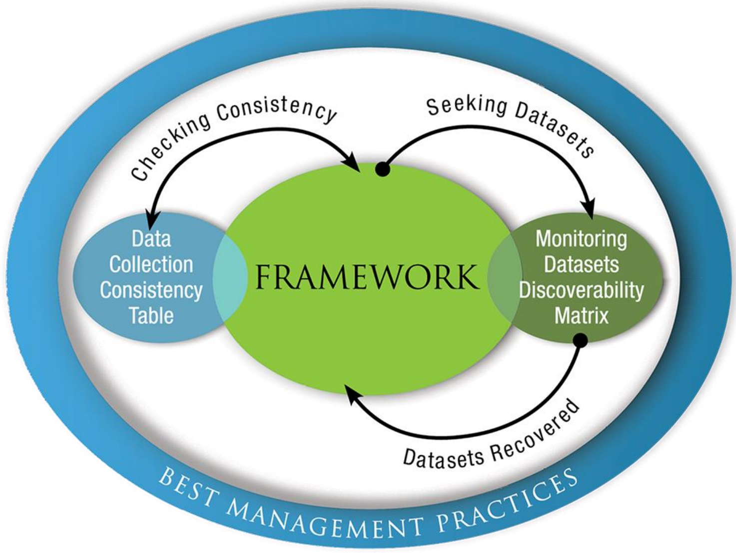

Figure 2. Data transferability process. The process includes the data transferability framework, data collection consistency table, monitoring datasets discoverability matrix, and best management practices that work together to aid the transfer of data from one project or location to a future project.

More in-depth information on the data transferability process can be found in the *Data Transferability and Collection Consistency in Marine Renewable Energy* report (Copping et al. 2020a). Additional information such as links to relevant workshop presentations, recordings, and reports can be found on the *Tethys* Data Transferability page.

3.0 Evidence Base for Risk Retirement

Risk retirement remains a theoretical construct until it is applied to stressor-receptor interactions in consenting MRE projects. Until then, four stressors (underwater noise, EMF, habitat changes, and changes in oceanographic systems) appear suitable for retirement and have been chosen by OES-Environmental for cataloguing and evaluating evidence to test the risk retirement process. In 2018 and 2019, OES-Environmental focused on assessing risk retirement for underwater noise and EMF. In 2020, OES-Environmental is focusing on assessing habitat changes and changes in oceanographic systems. Up-to-date literature related to the interactions of these four stressors with the marine environment have been reviewed and assembled to create an evidence base for risk retirement. The evidence base was drawn from an extensive literature review, review compilations (Copping et al. 2013; Copping et al. 2016; O'Hagan 2016; Copping et al. 2020b), and assessments of MRE deployments and operations throughout OES-Environmental nations.

Evidence from research studies and monitoring data collected around MRE deployments suggest that risks from EMF and underwater noise may be retired for small numbers of MRE devices. The evidence bases for these two stressors were accumulated and applied to a series of hypothetical MRE projects against which the existing information could be tested. The evidence base for EMF and underwater noise are presented below.

3.1 EMF Evidence Base

Although the Earth has a naturally occurring, static geomagnetic field, the addition of anthropogenic EMF signatures in the marine environment may affect certain organisms. Currently there are no regulatory thresholds or guidelines for "acceptable" levels of EMF emissions in the marine environment. However, addressing anthropogenic EMF emissions is not a novel challenge as many subsea cables, bridges, and tunnels have been deployed in the marine environment and currently provide measurable electromagnetic signatures in the ocean. The evidence base is presented in Table 1 with a summary of the results below.

Several species can detect EMF, mainly electro- or magneto-sensitive species such as sharks, skates, and rays, as well as some benthic and perhaps pelagic crustaceans, mollusks, sea turtles, and some groups of fish (Gill et al. 2014). EMF emitted from MRE devices have the potential to cause modifications in behavior including avoidance or attraction (Westerberg and Lagenfelt 2008), changes in hunting or feeding activities (Gill et al. 2009), physiological or developmental alterations in certain species (Woodruff et al. 2012, 2013; Fey et al. 2019), and in some animals possibly impair their ability to detect and respond to the natural field (Gill et al. 2014).

The evidence base for EMF effects of MRE projects largely comes from laboratory settings or general EMF field experiments, not directly linked to MRE projects. While the MRE industry is in the early stage of development, few devices have been cabled to shore and those that have generally do not carry significant amounts of power. However, previous research from well-established industries (such as offshore wind and oil and gas) that emit EMF in the marine environment (Gill, 2005; Öhman et al. 2007) have shown that cables from such industries emit greater amounts of EMF than any MRE device (Normandeau et al. 2011; Polagye et al. 2011).

Many laboratory and field studies have shown that electro- or magneto-sensitive marine species are aware of the presence of EMF yet show no significant changes in behavior, including various crustacean species (Woodruff et al. 2013; Love et al. 2017; Hutchison et al. 2018; Taormina 2019), European eels (Westerberg and Lagenfelt 2008), several invertebrate species (Love et al. 2016), several fish species (Kavet and Klimey 2016; Love et al. 2016; Kilfoyle et al. 2018; Wyman et al. 2018), and several species of electro-sensitive elasmobranchs (Gill et al. 2009; Love et al. 2016; Hutchison et al. 2018). Laboratory and field studies on freshwater fish species (Bevelhimer et al. 2015; Dunlop et al. 2016) indicate that even large amounts of EMF appear to cause no harmful effects.

Table 1. Selected studies from the evidence base for EMF effects on marine animals (Copping et al. 2020b). These outcomes are based on research studies that examined undersea cables and surrogates associated with energized power cables, telecommunications cables, and other electrical infrastructure.

Project/Research Study	Cable or EMF source	EMF measurements	Conclusion	Reference
Sub-Sea Power Cables And The Migration Behaviour Of The European Eel (East Sweden; 2008)	130 kV AC cable, unburied.	Acoustic tags were used to track small movements across energized cable.	Eels swam more slowly, but effect was small and no evidence of barrier effect.	Westerber and Lagenfelt (2008)
EMF-Sensitive Fish Response to EM Emissions from Sub-Sea Electricity Cables of the Type Used by the Offshore Renewable Energy Industry (West Scotland; 2009)	125 kV AC cable, buried 0.5-1 m deep.	Mesocosms were used with both energized and control cables.	No evidence of positive or negative effect on catsharks (dogfish). Benthic skates responded to EMF in cable.	Gill et al. (2009)
Effects of Electromagnetic Fields on Fish and Invertebrates	Helmholz coil in laboratory	Assessed the response of coho salmon, Atlantic halibut, California halibut, Dungeness crab, and American lobster to elevated EMF at 3 mT (3000 µT).	Little evidence to indicate distinct or extreme behavioral responses. Several developmental and physiological responses were observed in the fish exposures, although most were not statistically significant. Several movement and activity responses were observed in the crab experiments. There may be possible developmental and behavioral responses to even small environmental effects; however, further replication is needed in the laboratory as well as field verification.	Schultz et al. (2010)
Effects of Electromagnetic Fields on Fish and Invertebrates	Helmholz coil in laboratory	Assessed response of Atlantic halibut, Dungeness crab, and American lobster to maximum EMF strength	Based on the initial laboratory screening studies, the weight of evidence to date for the three tested species showed relatively few behavioral responses that would indicate explicit avoidance or	Woodruff et al. (2013)

		between 1.0-1.2 mT direct current DC.	attraction to an approximate 1.1 mT DC EMF intensity.	
Effects of Electromagnetic Fields on Behavior of Largemouth Bass and Pallid Sturgeon in an Experimental Pond Setting	N/A	Assessed movements of largemouth bass (*Micropterus salmoides*) and pallid sturgeon (*Scaphirhyncus albus)* in mesocosm experiments in a freshwater pond. Fish experienced alternating 2-hr periods in which an underwater energized AC coil was alternately powered on and off (2,450 µT).	No consistent significant differences in location or activity relative to the location of the coil for largemouth bass and pallid sturgeon as a result of exposure to EMF.	Bevelhimer et al. (2015)
MaRVEN - Environmental Impacts of Noise, Vibrations and Electromagnetic Emissions from Marine Renewable Energy (North Sea, Belgium; 2015)	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.	Thomsen et al. (2015)
Limited influence of a wind power project submarine cable on a Laurentian Great Lakes fish community (Kingston, Canada; 2015)	245 kV AC cable, buried (nearshore section) and unburied.	Nearshore electrofishing and deeper-water fisheries acoustic surveys done along transects at varying distances to the cable.	EMF impacts to species are likely minimal.	Dunlop et al. (2016)
Assessment of potential impacts of electromagnetic fields from undersea cable on migratory fish behavior (San Francisco Bay, U.S.; 2016)	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.	Kavet et al. (2016)
Renewable Energy in situ Power Cable Observation (California, U.S.; 2016)	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	Love et al. (2016)

			background levels about 1 m away from the cable.	
Assessing potential impacts of energized submarine power cables on crab harvests (Santa Barbara channel and Puget Sound, U.S.)	35 kV AC power cable, unburied (Santa Barbara, California) and 69 kV AC power cable, unburied (Puget Sound, Washington)	Four test conditions with baited commercial traps.	Both rock crab (Santa Barbara) and Dungeness crab (Puget Sound) crossed unburied cable to traps.	Love et al. (2017)
Electromagnetic Field (EMF) Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables (Northeast U.S.; 2018)	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.	Hutchison et al. (2018)
Behavioral responses by migrating juvenile salmonids to a subsea high-voltage DC power cable (San Francisco Bay, U.S.; 2018)	200 kV DC cable, buried.	Tagged Chinook salmon smolts and tracked movement both before and after energization of Trans Bay Cable.	Smolts successfully migrated through the bay before and after cable energization without significant differences and energization was not associated with crossing the cable (or successfully exiting the system).	Wyman et al. (2018)
Effects of EMF emissions from undersea electric cables on coral reef fish (Florida, U.S.; 2018)	AC (60 Hz cable) and DC cable, unburied.	Used blind randomized sequences of AC (60 Hz cable) and DC cable off (ambient) or on (energized) with in-situ observations of fish abundance and behavior.	No behavioral changes noted in immediate response to alterations in EMF and no statistical differences in fish abundance among power states.	Kilfoyle et al. (2018)
Effect of low frequency electromagnetic field on the behavior and bioenergetics of the polychaete Hediste diversicolor (2019)	N/A	Assessed the effect of an EMF of value typically recorded in the vicinity of submarine cables (50 Hz, 1 mT) on the behavior and bioenergetics of the polychaete *Hediste diversicolor*.	No avoidance or attraction behavior to EMF was shown. Food consumption and respiration rates were not affected. The burrowing activity was enhanced in EMF treatment, indicating a stimulating effect on bioturbation potential, and ammonia excretion rate was significantly reduced in EMF treatment, but the mechanisms behind this effect were unclear. This is the first study demonstrating the effects of environmentally realistic EMF values on the behavior and physiology of marine	Jakubowska et al. (2019)

	invertebrates, thus there is a need for more research.

3.2 Underwater Noise Evidence Base

Underwater noise from operational MRE devices may impact marine animals by inducing changes in behavior including avoiding or being attracted to an area, interrupting communication and navigation (Clark et al. 2009; OSPAR 2009), and in extreme cases involving underwater construction, causing temporary or permanent hearing shifts or damage to sensitive tissues (Popper et al. 2003; Finneran 2015). Most MRE devices are constructed using low-noise foundation installation and decommissioning technologies (Verfuß 2014) to limit their effects on the marine environment. The ability for marine animals to detect underwater noise from MRE devices depends on the species, the distance between the animal and the device, and the frequency and amplitude of the device's output (Wilson et al. 2007). The evidence base is presented in Table 2 with a summary of the results below.

In the U.S., regulatory thresholds for underwater noise have been developed for marine mammals and for fish (Tetra Tech 2013; National Marnie Fisheries Service 2018). Additionally, the International Electrotechnical Commission Technical Committee (IEC TC) 114 developed standards, Technical Specification 62600-40, for measuring underwater noise emitted by MRE devices (International Electrotechnical Commission 2019). These thresholds and standards can be applied during the MRE consenting process to aid regulators as they evaluate the potential risk of underwater noise from operational MRE devices on marine animals.

Underwater noise measured at several MRE projects (Columbia Power Technologies SeaRay, the SCHOTTEL Instream Turbine, and the Wello Penguin) demonstrate that operational noise from MRE devices may not be detectable above ambient noise and nearby anthropogenic sources (Bassett et al. 2011; Beharie and Side 2012; Schmitt et al. 2015). Measurements taken at other MRE projects show that there may not be substantial disturbance or injury to marine animals from underwater noise emitted by MRE devices, as seen from the research studies at the WaveRoller (Cruz et al. 2015), Paimpol Brehat tidal turbine site (Lossent et al. 2018), and the Minesto Strangford Lough site (Schmitt et al. 2018). Furthermore, underwater noise monitoring can be used to check for both the health of the device and for monitoring noise levels, especially as things such as broken bearings may emit more noise than operation itself (Polagye et al. 2017a).

Table 2. Selected studies from the evidence base for MRE underwater noise effects on marine animals (Copping et al. 2020b). These outcomes are based on deployments of single devices or small arrays of tidal or river turbines, or WECs, as well as selected research studies. The outcomes are compared to the U.S. threshold for underwater sound levels.

Project	Device	Noise measurements	Conclusion	Relation to U.S. underwater sound threshold	Reference
Verdant Power Roosevelt Island Tidal Energy Project (RITE) (New York, U.S.; 2006-2008)	Tidal turbine array	Operational noise of the array, which included six bottom mounted turbines, was up to 145 re 1 µPa at 1 m from the array.	More noise was output than expected due to a broken blade on one turbine and another failing turbine.	Remains under threshold for broadband sound	Verdant Power (2010)
Columbia Power Technologies SeaRay™ (Washington, U.S.; 2011-2012)	WEC	Operational noise of 1/7th scale wave buoy varied from background noise levels at 116 dB re 1µPa^2 to intermittent peaks at 126 dB re 1µPa^2.	Sound was not detectable above ambient noise levels. With the acoustic signature of the SeaRay™, which is a broadband source, the noise levels are subject to masking by stronger sources in its vicinity.	N/A	Bassett et al. (2011)
Research study for OpenHydro at Admiralty Inlet (Puget Sound, U.S.; device never deployed)	Tidal turbine	95th percentile operating condition for the OpenHydro turbine was used in this laboratory experience—sound pressure level (SPL) of 159 dB re 1 µPa, which corresponds to the source level (nominal received level at 1 m from the sound source).	Conducted laboratory exposure experiments of juvenile Chinook salmon and showed that exposure to a worse than worst case acoustic dose of turbine sound does not result in changes to hearing thresholds or biologically significant tissue damage. Collectively, this means that Chinook salmon may be at a relatively low risk of injury from sound produced by tidal turbines located in or near their migration path. Study showed that harbor porpoise in area may be habituated to high levels of ambient noise due to omnipresent vessel traffic.	N/A	Collar et al. (2012)
WaveRoller at WavEc (Peniche, Portugal; 2012-2014)	WEC	Operational noise of bottom-mounted oscillating wave surge converter prototype peaked at 121 dB re 1µPa. Average broadband sound pressure level (SPL) measured with Hydrophone 2	Calculating the sound exposure level (SEL) of the WaveRoller sound, which is150 dB re 1µPa^2-s, shows that no injury to cetaceans is expected. The results indicate that the frequency ranges at which the device operates overlap those used by some low and	Remains under threshold for broadband sound	Cruz et al. (2015)

		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.	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 (Paimpol Brehat, France; 2013 – 2014)	Tidal turbine	SPL ranged from 118 to 152 dB re1 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 is improbable within the area of greatest potential impact. Permanent threshold shifts (PTS) and temporary threshold shifts (TTS) risks are 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.	Remains under threshold for broadband sound	Lossent et al. (2018)
Schottel instream tidal turbine (Strangford Lough, Northern Ireland; 2014)	Tidal turbine	Highest noise levels were around 100 re µPa^2/Hz at 9 m from the turbine.	Sounds levels are on the same order as natural and anthropogenic background noise measured.	N/A	Schmitt et al. (2015)
ORPC Cobscook Bay Tidal Energy Project (Maine, U.S.; 2013-2017)	Tidal turbine	Operational noise less than 100 dB re µPa^2/Hz at 10 m, at 200 – 500 m from the turbine.	Sound was not detectable above ambient noise levels.	N/A	Ocean Renewable Power Company Maine (2014)
Minesto AB Tidal Kite (Strangford Narrows, Northern Ireland; 2016)	Tidal kite	Sound levels for the ¼ scale tidal kite tested at different speeds ranged from 70 dB re µPa at the lowest frequencies up to a peak of around 105 dB re µPa at 500 Hz.	Sound levels remain below thresholds for marine mammals and fish.	Remains under threshold for broadband sound	Schmitt et al. (2018)
Fred. Olsen Bolt Lifesaver at US Navy Wave Energy Test Site (WETS) (O'ahu, U.S.; 2016-2018)	WEC	Operational noise of floating point absorber wave device was 114 dB re 1µPa for median broadband SPL and mean levels as high as 159 dB re 1µPa were infrequently observed. At one point during the study,	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 1µPa) for only 1% of the	Operational sounds from device remain under threshold for broadband sound	Polagye et al. (2017b)

		the WEC had a damaged bearing, which coupled with the operational noise reached 124 dB re 1µPa.	deployment. These exceedance events are dominated by non-propagating flow noise and sources unrelated to the Lifesaver.		
Wello Oy at EMEC (Orkney, U.K.; 2017-2019)	WEC	The measured sound pressure levels of this floating rotating mass WEC's cooling system, which included two cooling fans and one pump, suggests a source level of 140.5 dB re 1µPa at 1 m.	Expected that ambient background noise levels will be reached within about 10 m of the device.	Remains under threshold for broadband sound	Beharie and Side (2012)

4.0 Outreach and Engagement

OES-Environmental conducted extensive outreach and engagement with the MRE community, including in-person and online workshops, webinars, and conference presentations. The feedback collected through these efforts was used to develop the risk retirement pathway and application of risk retirement for the MRE industry.

4.1 Regulator Workshops

Beginning in May 2019 a series of online workshops, that built on previous U.S. regulator workshops on the concept of data transferability (Copping et al. 2020a), engaged U.S. regulators to introduce the concept of risk retirement and the pathway as well as to show how these concepts work together to aid consenting processes for MRE. The workshops presented the concept of risk retirement, discussed how data transferability plays a role in risk retirement, assessed case studies for data transferability, and laid out the process and pathway to receive feedback and begin discussions on the ability to retire risks. Attendees of the workshops included ten state and federal regulators from several jurisdictions (Hawaii, Oregon, New York; BOEM, DOE, and NOAA).

Overall, the regulators liked the idea of risk retirement and data transferability and thought this provides a good opportunity to work collectively to learn more and increase understanding. Additional comments included:

- the importance of emphasizing that this is guidance and not a one-size-fits all approach;
- the need to manage developer’s expectations for risk retirement as the decision will still fall with regulators; and
- the acknowledgement that while monitoring may be burdensome there remains a need for some level of baseline data collection, especially since it is instrumental as the industry progresses.

4.2 International Expert Workshops

Three expert workshops were also held in 2019 at international conferences with the purpose of gaining expert opinions, feedback, and input on the risk retirement process from the MRE community. At all workshops, OES-Environmental presented the concept of risk retirement, the risk retirement pathway, and the evidence base for underwater noise and/or EMF, and the ability to retire these risks. The international workshops were held in Italy (around the European Wave and Tidal Energy Conference), the U.S. (at the Ocean Renewable Energy Conference), and Australia, and involved 81 MRE experts from 11 countries (Australia, Canada, France, Germany, Italy, Korea, Netherlands, Portugal, Sweden, U.K., and U.S.).

During the workshops, participants were asked to examine the risk retirement process and review the evidence base for underwater noise and/or EMF for small numbers of MRE devices. Hypothetical MRE project examples were used to showcase the risk retirement pathway for each stressor (Figures 3 and 4), assess the evidence base for retiring underwater noise and EMF, and discuss the feasibility of the approach. The predominant outcome of all three international workshops was that participants liked the concept of risk retirement and found the risk retirement pathway intuitive, easy to navigate, and useful. At the Australia workshop in particular, participants felt it fit well into the Australian environmental regulatory regime.

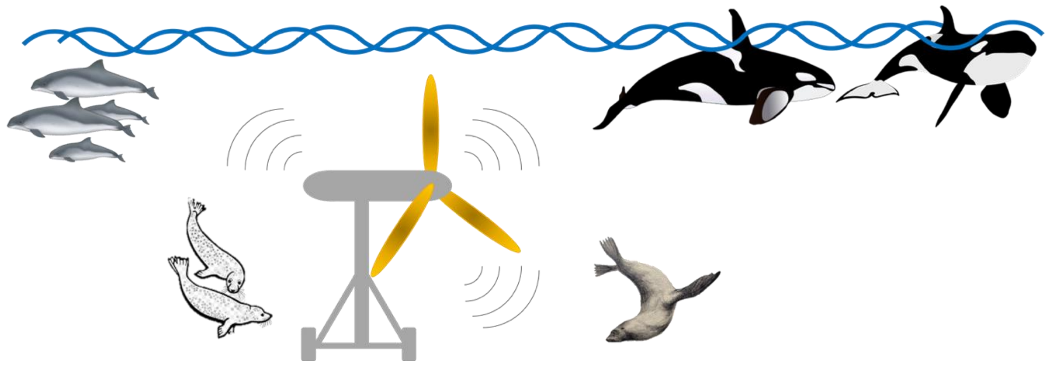

Figure 3. Hypothetical example of a tidal turbine emitting a realistic level of underwater noise in an area used by harbor porpoises, harbor seals, sea lions, and killer whales. This figure was used to represent the presence of receptors in the vicinity of the turbine and help visualize potential stressor-receptor interactions (figure not to scale).

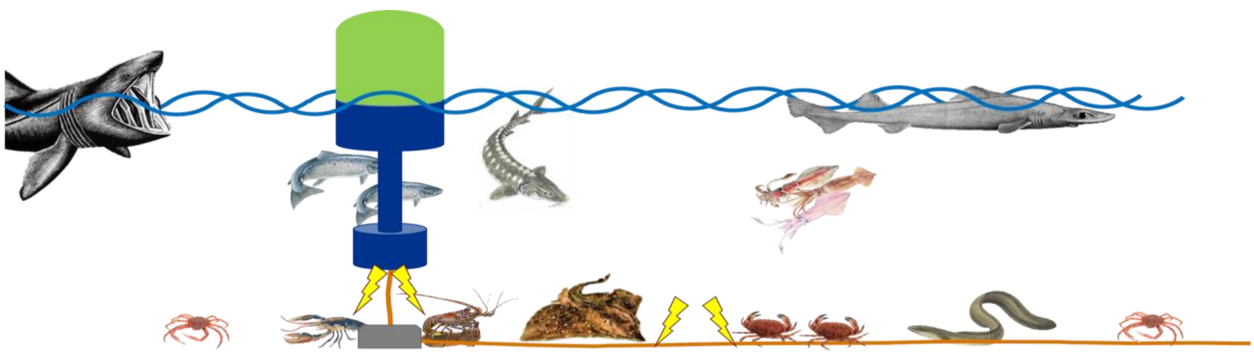

Figure 4. Hypothetical example of a wave energy converter with cables emitting EMF in an area used by sharks, skates, bony fishes, crustaceans, and other invertebrates. This figure was used to represent the presence of receptors in the vicinity of the wave energy converter and help visualize potential stressor-receptor interactions (figure not to scale).

Effects from EMF were examined at two of the three workshops (Italy and Australia). Participants at both workshops agreed that EMF from cables carrying power to shore or draped in the water column between devices are not likely to be a risk for small numbers of MRE device. The main line of evidence was that the power carried by MRE cables is many times lower than the power carried by offshore wind energy export cables. Additionally, participants thought that burying cables, when feasible, would alleviate impacts from EMF. At the Australian workshop, it was even noted that burying cables was accepted by regulators as a measure to mitigate potential effects of EMF. Participants did note gaps in current knowledge and data needs to fully move forward with risk retirement for EMF:

- Need for basic information, such as baseline data determining electro- or magneto-sensitive species in the area;
- Increase in information about EMF-sensitive species and how MRE may impact them;
- Need for a better understanding of EMF emissions such as a database of EMF emissions (by size and types of cables used in MRE development), field measurements to improve/validate models, and increased understanding of the change in EMF emissions with power variability;
- Examine the cumulative effects of many EMF power cables as the MRE industry grows;

- Develop a regulatory threshold for EMF that can be applied internationally; and
- Need to alleviate stakeholder concerns.

Effects from underwater noise were examined at all three workshops (Italy, U.S., and Australia). Participants at all three workshops agreed that underwater noise from operation of MRE devices are not likely to be a risk for small numbers of devices. They were also in agreement that both the IEC TC 114 Level B recommendations (International Electrotechnical Commission 2019) and the U.S. regulatory thresholds (Tetra Tech 2013; National Marnie Fisheries Service 2018) provided guidance that would be useful to retire risk for single devices. Workshop participants felt that there are some data gaps and information needs that should be addressed to sufficiently understand the risk of underwater noise at potential project sites:

- Build a library of standardized noise measurements produced by MRE;
- Encourage MRE test centers to measure sound output of operational devices;
- Measure underwater sound output for each new type of MRE technology and new location using the standard procedures from IEC TC 114 (International Electrotechnical Commission 2019);
- Additional efforts in countries without regulatory thresholds should be pursued to assure the pathway becomes acceptable to regulators;
- Understand how animals use the surrounding area of the proposed MRE project to recognize any change in behavior;
- Understand propagation of sound over large distances for increased device numbers and potential need for regulation of the spacing between devices; and
- Verify that sound propagation models are fit for high-energy, high-turbulence, and high-turbidity project sites to successfully predict noise effects of future commercial developments.

Overall, feedback received from these outreach and engagement efforts showed that, in general, the concept of risk retirement and application of the risk retirement pathway are supported by numerous developers, regulators, researchers, and consultants worldwide. Participants agreed that effects from EMF could be retired for single devices or small arrays, but that the identified gaps and data needs would still require measurements to be taken and that it might be challenging for regulators to agree without any thresholds in place. Participants agreed that effects from underwater noise could be retired for single devices or small arrays and that the U.S. thresholds and IEC TC 114 recommendations aided risk retirement, but noted that there may always be a need for some level of baseline data and that cumulative effects may become a future issue due to the various sources of anthropogenic noise.

All risk retirement outreach and engagement, including the international workshops reports, can be found on the Risk Retirement page on *Tethys* (https://tethys.pnnl.gov/risk-retirement).

5.0 Next Steps and Conclusions

A major barrier for the development of the MRE industry is the uncertainty surrounding potential environmental effects of MRE devices and arrays. MRE industry regulators are often cautious when facing the uncertainty of whether MRE devices pose an intolerable risk to marine animals, surrounding habitats, or ecosystem processes, which often leads to a slower consenting process, increased costs due to expensive monitoring requirements, and few devices deployed in the water. However, knowledge of potential effects of MRE has increased rapidly in the past decade, and there are strong indications that many environmental effects are likely to be insignificant and acceptable at the scale of single MRE devices or small arrays (Copping et al. 2016).

Through OES-Environmental outreach with the MRE community, the concept of risk retirement seems useful to help move the MRE industry forward while understanding of environmental impacts of MRE devices increases. Underwater noise and EMF appear to be close for retirement for small numbers of devices, though there are several areas that may need to be improved upon. Changes in habitat and changes in oceanographic systems also warrant risk retirement but have not been fully discussed with the MRE community to date. Both collision risk and displacement of marine animals need some additional progress before risk retirement can be considered. Additional research and monitoring are currently needed for collision risk. Displacement of marine animals is not a main subject of concern yet, but will need to be addressed as large numbers, or arrays, of devices are deployed.

The risk retirement process is focused on the potential to retire risk for single MRE devices and small-scale MRE arrays based on the evidence base and knowledge from MRE deployments of small numbers of devices. In the future, as the MRE industry grows and moves to commercial-scale MRE deployments, any risk that has been deemed retired may need to be reevaluated as the impacts from large-scale arrays are likely to vary from those from single or small-scale MRE projects.

OES-Environmental's next steps in promoting risk retirement throughout the MRE industry include continuing outreach and engagement efforts (such as webinars, workshops, and conference presentations) with the MRE community in order to continue to garner support and test the applicability of the pathway to aid consenting processes. This includes outreach efforts regarding habitat changes and changes in oceanographic systems, as the potential to retire the risks associated with these stressors has not yet been discussed with the MRE community. OES-Environmental also plans to create a guidance document for each stressor to help guide regulators through applying risk retirement to specific stressors. The guidance documents will be generally applicable to the international MRE industry but will also include supporting documents that are specific to application in OES-Environmental nations.

The ultimate goal is to have the risk retirement process be incorporated and applied in some detail to proposed/future MRE projects. However, as additional datasets from consented projects become available and specific stressors are better understood, it is assumed that risk evaluation and resolution will become more routine, allowing consenting processes to proceed more expeditiously. The risk retirement process developed by PNNL and OES-Environmental aims to aid regulators in consenting MRE projects, decrease consenting timelines, reduce the financial burden on developers, add to the existing knowledge base, and promote public understanding and acceptance of MRE projects.

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