Moving from scientific research to consenting guidance for MRE environmental risk

Andrea E. Copping, Deborah J. Rose, Mikaela C. Freeman

Abstract—**Potential environmental effects from tidal and wave devices are of concern to regulators, advisors, and other stakeholders in many nations. Monitoring results from early deployments and the first commercial arrays, coupled with targeted research studies, are providing a growing base of knowledge of how components of tidal turbines and wave energy converters might interact with marine animals and habitats. Efforts are underway to organize and direct these findings towards facilitating consenting that allays concerns and allows the marine renewable energy (MRE) industry to move forward. The OES-Environmental international initiative has developed scientific evidence bases for several key interactions from MRE devices, organized around stressors (portions of MRE systems that may cause injury or stress to the marine ecosystem), and receptors (the animals, habitats, and ecosystem processes that may be affected). This paper summarizes the evidence bases for four stressors (underwater noise, electromagnetic fields, habitat change, and changes in oceanographic systems) and presents the process of moving from the scientific knowledge into guidance documents to support the regulatory process. The guidance documents will serve as a broad guide that can be used internationally to look at stressor-receptor interactions of interest within a regulatory context. The evidence bases and guidance documents aim to assist MRE developers, regulators, and advisors with project scoping, consenting, and licensing processes.**

Keywords— **marine renewable energy, environmental effects, stressor-receptors, risk retirement, consenting**

I. Introduction

The marine renewable energy (MRE) industry faces significant technical and financial challenges to development, as well as continuing concerns about potential environmental effects, driven largely by scientific uncertainty around interactions. Regulators, advisors, and other stakeholders are often concerned about the environmental impact of wave or tidal energy devices on sensitive species, habitats, livelihoods from the ocean, or cultural resources. Early deployments and targeted research studies have defined stressors - portions of MRE systems that may cause injury or stress to the marine ecosystem - and receptors - the animals and habitats that may be affected - which has helped to quantify the level of uncertainty and identify additional research required to understand and mitigate risks [1]. Evidence to date shows that some of these potential risks are expected to be minimal or non-existent, especially for small numbers of operational devices [2]. Understanding these risks can aid environmental consenting of MRE devices.

Despite a growing knowledge base and extensive ongoing environmental monitoring and data collection, barriers to consenting and deploying projects remain [3]. In addition, data collected by scientists may not be presented in a way that is accessible to regulators, advisors, and developers and they are not always publicly available. Making this information accessible so that it is relevant across MRE projects, as well as easy to interpret, is key for industry-wide progress. OES-Environmental[1] has worked to forge these connections through synthesizing current environmental data for key stressor-receptor interactions [2], [4], compiling evidence bases for key stressors, and developing regulatory guidance documents, in order to move the industry forward in an environmentally responsible manner.

Critical to this work are the concepts of risk retirement and data transferability. Risk retirement is the process of identifying which interactions of MRE devices and the environment are better understood and can be considered low risk, and therefore do not need to be fully investigated for every project (Fig. 1) [3]. Application of the risk retirement pathway has been more fully described by [5] in a general sense and for key stressors in [3], [6]. To assess the ability to retire a risk, existing data and information from consented projects and research from comparable offshore industries or experimental studies should be used (Step 2 in Fig. 1). Applying these existing datasets,

This work is supported by the US Department of Energy, Energy Efficiency and Renewable Energy Water Power Technologies Office to Pacific Northwest National Laboratory under contract DE-AC05-76RL01830, as well as financial support from the International Energy Agency—Ocean Energy Systems.

A. E. Copping is with Pacific Northwest National Laboratory in Seattle, WA. (e-mail: andrea.copping@pnnl.gov).

D. J. Rose is with Pacific Northwest National Laboratory in Seattle, WA. (e-mail: deborah.rose@pnnl.gov).

M. C. Freeman is with Pacific Northwest National Laboratory in Seattle, WA. (e-mail: mikaela.freeman@pnnl.gov).

[1] OES-Environmental was established by the International Energy Agency Ocean Energy Systems in 2010 to examine environmental effects of marine renewable energy (MRE) development around the world. As of 2021, sixteen nations participate in OES-Environmental. More information about OES-Environmental is available at https://tethys.pnnl.gov/about-oes-environmental.

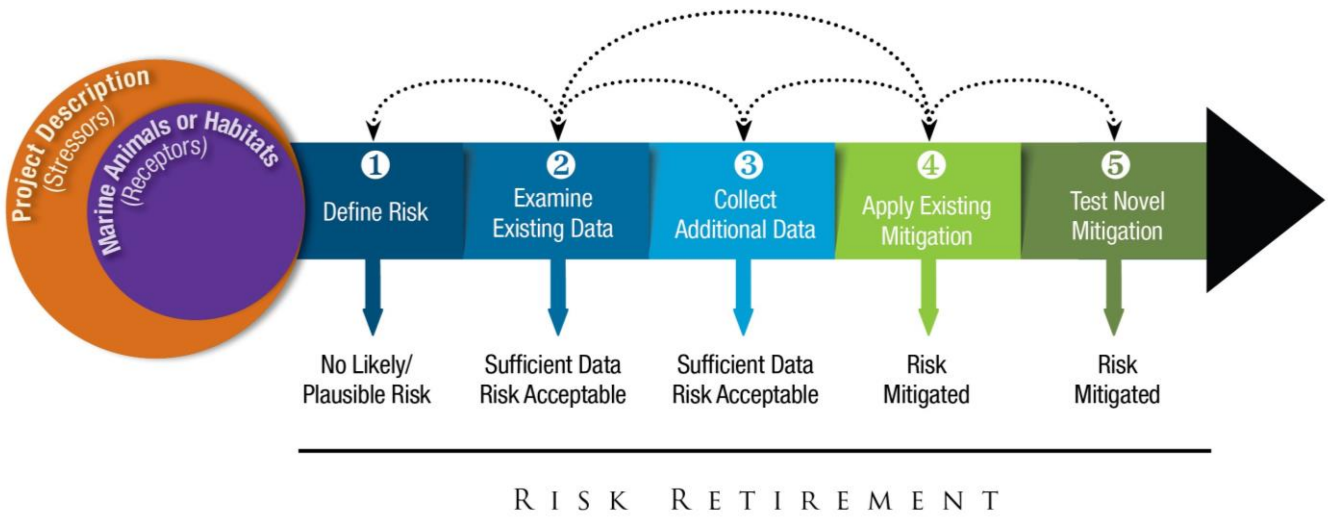

Fig. 1. The risk retirement pathway. A series of steps is shown that provide points at which to evaluate if there is a likely risk or if data or mitigation measures are sufficient to determine that a risk can be retired for a specific marine renewable energy project. If none of the steps can determine the risk to be insignificant, the project may need to be redesigned or perhaps abandoned.

analyses, and learning appropriately is a key consideration of the data transferability process [7], [8]. Combining the principles of data transferability with the risk retirement process for key stressors could help satisfy regulatory requirements, reduce costs to the MRE industry, and allow efforts to be focused on topics with the greatest level of risk and remaining uncertainty [5].

This paper describes the process of curating the evidence bases, summarizes results for four key stressors, details the development of the guidance documents, and provides examples of potential uses for this information to bridge the gap between scientific knowledge and consenting practice.

II. METHODS

The development of the guidance documents has been a natural step in OES-Environmental's work on risk retirement and data transferability. Foundational to the guidance documents is the compilation and evaluation of the evidence bases.

A. *Evidence bases and assessment of risk*

The evidence bases have been developed for key stressors for which significant evidence indicates that the risks may be low for small numbers of devices [5]. These stressors are: underwater noise, electromagnetic fields (EMFs), habitat change, and changes in oceanographic systems. The evidence bases are comprised of key documents, including peer reviewed papers, reports, and research studies, that are central to understanding potential impacts for each stressor. The collection is updated annually. An extensive literature review on each stressor was carried out, followed by review, evaluation, and input from selected experts across industry, government, and academia at several international conferences and online workshops.

Based on the data and information presented, selected experts provided feedback on the ability to retire risk for small numbers of devices (one to three), identified information gaps to be addressed, and put forth recommendations for additional research and data collection.

B. *Guidance documents*

Moving from scientific knowledge to application in consenting processes, the guidance documents aim to provide a broad guide that can be used internationally to look at stressor-receptor interactions of interest within a regulatory context. The guidance documents have been developed in collaboration with OES-Environmental's international partners.

The guidance documents include the following components (Fig. 2):

1) A background document that includes:
   - Descriptions of four regulatory categories relevant for MRE consenting and licensing that occur in some form in virtually every nation: species and populations at risk; habitat loss or alteration; effects on water quality; and effects on social and economic systems.
   - A framework that describes the application of risk retirement to consenting processes.
2) Stressor-specific documents on electromagnetic fields (EMF), underwater noise, habitat change, changes in oceanographic systems, collision risk, entanglement, and displacement.
3) Country-specific guidance documents for each of the participating OES-Environmental countries.

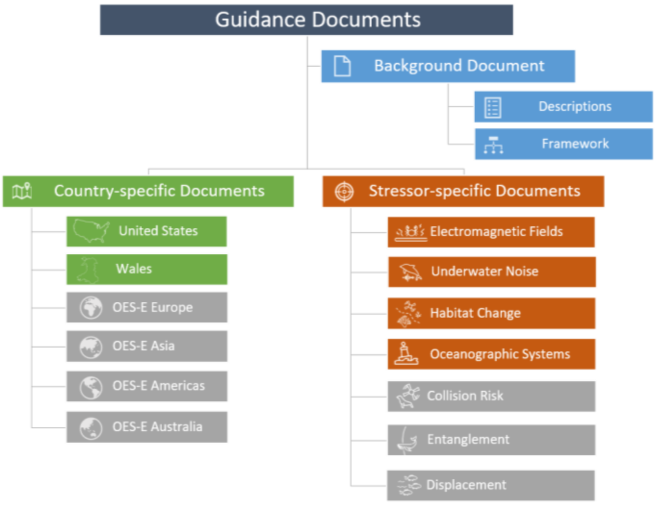

Fig. 2. Overview of the components of the guidance documents. Coloured boxes indicate guidance documents that have been completed. Boxes in grey are yet to be drafted and indicate the next steps to be taken in the development of the guidance documents.

III. Results

A. Evidence bases and assessment of risk

The evidence bases consist of 29 documents for underwater noise; 16 documents for EMF; 58 documents for habitat change; and 23 documents for changes in oceanographic systems (Fig. 3).

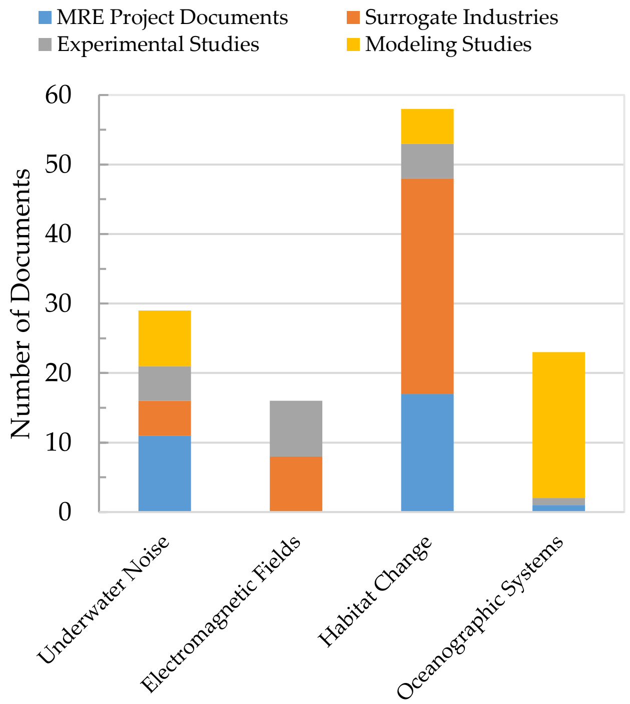

Fig. 3. Types of documents in each evidence base.

1) Underwater Noise[2]

Based on examining the evidence base for underwater noise, there is consensus that the risk from underwater noise can be retired for single devices or small arrays [3]. Underwater noise from MRE device operation falls below existing regulatory thresholds and guidance established in the United States for marine mammals and fish [9], [10], and is often below the frequency at which marine mammals hear [11]. An international specification for measuring underwater noise from MRE devices ensures that comparable measurements can be made across projects [12]. Knowledge gaps that will further elucidate the application of existing information for new consent applications include: understanding behavioral responses of marine animals to noise; verification of noise propagation models as the industry moves toward arrays; distinguishing between ambient noise and MRE noise in an area; and an assessment of cumulative effects of noise in an area [3].

2) Electromagnetic Fields[3]

Also based on expert opinion, the risk from EMFs emitted from export power cables from single devices or small arrays can also be considered retired. The level of power carried in MRE cables is very small compared to offshore wind farms, and cable burial (where possible) is an effective method of separating sensitive animals from cables and reducing EMF emissions [3]. Reviewers identified that in addition to the evidence base for EMF, a database should be developed to catalogue EMF emissions by cable type and power level exported from MRE devices. Cumulative effects for EMF will also need to be considered as the industry scales up to larger MRE developments.

3) Habitat Change[4]

The evidence base for habitat change was considered in multiple categories due to the variability in impacts on habitats: effects of installation/removal on the benthos, changes in community composition, artificial reef effects, and indirect effects. The consensus was that risks from habitat change could be retired for single devices or small arrays, as impacts are spatially limited, recovery is relatively rapid, and changes in species composition have not been shown to have negative effects (e.g., [13]) [3]. In particular, experts stated that habitat change should be considered a low risk and should not prevent installation if devices are sited to avoid critical or rare habitats. Key knowledge gaps include: the absence of good surrogates for high-energy tidal habitats; the impact of artificial reef effects on the broader food web and ecosystem; and the effects of MRE device decommissioning.

[2] The full evidence base for underwater noise is available at https://tethys.pnnl.gov/underwater-noise-evidence-base

[3] The full evidence base for EMF is available at https://tethys.pnnl.gov/emf-evidence-base

[4] The full evidence base for habitat change is available at https://tethys.pnnl.gov/habitat-change-evidence-base

4) Changes in Oceanographic Systems[5]

The evidence base for changes in oceanographic systems consists of the results of numerical modelling studies without field validation. Changes in water circulation and flushing times in estuaries due to the presence of tidal devices, decreases in wave heights from operational WECs, and changes in sediment transport from tidal and wave devices can theoretically occur. However, the magnitude of changes from small numbers of devices (one to three) will be lower than the natural variability of the system, so that field measurements will not provide useful outcomes. Numerical models can be used to predict future changes in oceanographic processes that may result from the deployment and operation of large arrays, but as yet these predictions cannot be verified as no large arrays have been deployed.

B. Guidance documents

The guidance documents contain the information and recommendations to apply the concept of risk retirement to regulatory processes all along the path from scoping through consenting and licensing, by creating links between scientific information on environmental effects and the relevant legislation or regulations. The documents contain several components (Fig. 2), all of which are tailored for regulators, advisors, and developers to simplify their search for data with which to assess potential effects and will aid in the process of consenting. All components, including high resolution figures, are available online at https://tethys.pnnl.gov/guidance-documents.

The background document provides an introduction to the guidance documents, intended purpose, and an overview of risk retirement. This document includes descriptions of the four regulatory categories (species and/or populations at risk, habitat alteration or loss, effects on water quality, and social and economic impacts), with relevant information for consenting including baseline data/research needs and potential risks. It also includes a framework for applying risk retirement to consenting processes, highlighting additional tools and resources developed by OES-Environmental to gather relevant data and information (Fig. 4).

The country-specific documents are being developed for each of the participating OES-Environmental countries[6]. These documents, prepared by experts in each nation, provide an overview of country-specific consenting information including regulatory jurisdictions relevant for licensing or authorizing MRE projects, statutes, policies for implementation for each of

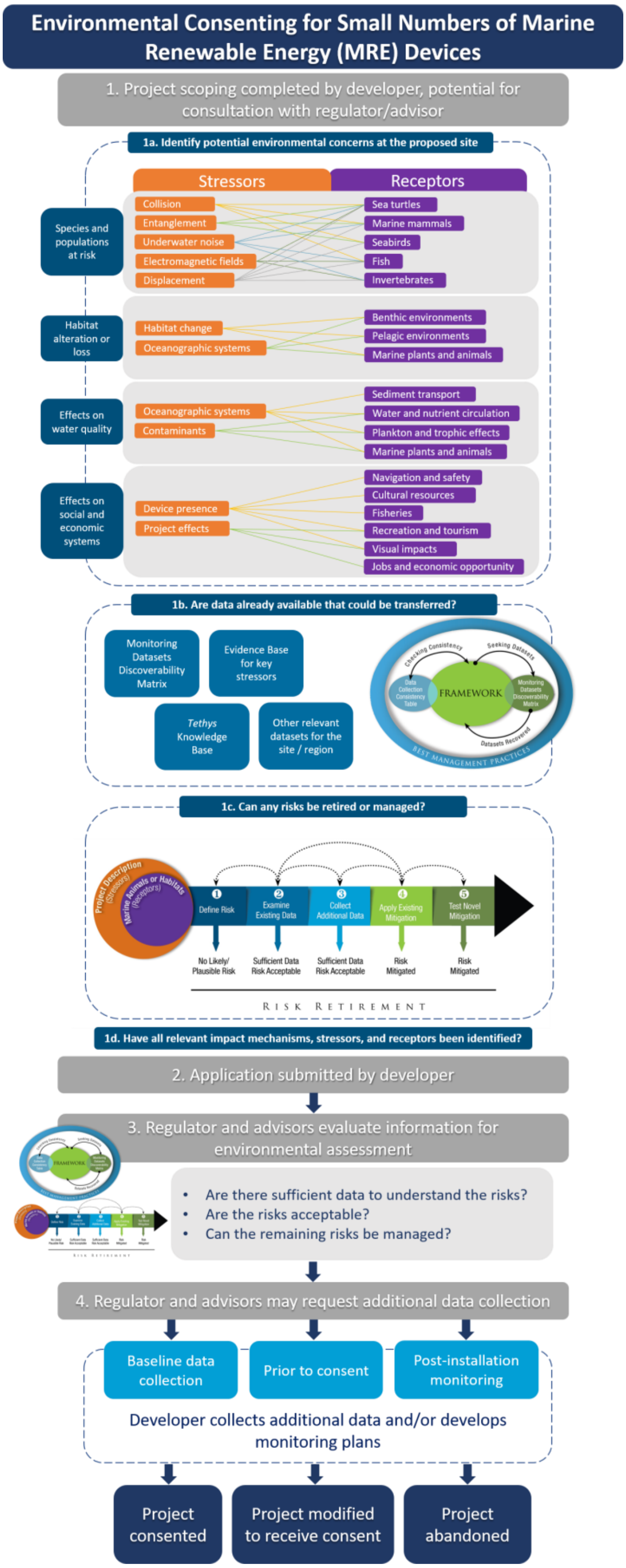

Fig 4. Guidance document framework. The framework notes key steps in the consenting process linking to risk retirement, data transferability, and relevant OES-Environmental resources.

[5] The full evidence base for changes in oceanographic systems is available at https://tethys.pnnl.gov/oceanographic-changes-evidence-base

[6] A full list of participating OES-Environmental countries can be found at https://tethys.pnnl.gov/about-oes-environmental

the four regulatory categories, and any additional approaches relevant to or useful for consenting (e.g., marine spatial planning, adaptive management, cumulative impacts assessment). While the background document allows for broad application internationally, the country-specific documents provide the details necessary for each country. An example of the types of information included for each regulatory category is shown for the United States and Wales in Table I.

Remaining stressors of importance for MRE consenting and licensing - collision risk, entanglement, and displacement - are not yet ready for consideration for risk retirement as insufficient evidence exists. When sufficient information becomes available, stressor-specific documents will be developed for these stressors in addition to those already completed for underwater noise, electromagnetic fields, habitat change, and changes in oceanographic systems. Each document will provide a "one-stop shop" for information about each stressor, including links to all available OES-Environmental resources and tools to assist regulators in making decisions about a particular stressor. Examples of the types of information included in the stressor-specific documents are shown in Table II.

TABLE I. EXAMPLE OF INFORMATION COMPILED IN COUNTRY-SPECIFIC GUIDANCE DOCUMENTS FOR THE UNITED STATES AND WALES.

	Relevant Statutes and Implementation			
Country	**Species and populations at risk**	**Habitat alteration or loss**	**Effects on water quality**	**Effects on social and economic systems**
United States	• Consultation with National Marine Fisheries Service (NMFS) and the U.S. Fish and Wildlife Service (FWS) required for species listed under the Endangered Species Act (ESA) Section 7 • Consultation with NMFS and FWS required for any marine mammal under the Marine Mammal Protection Act • Fish and Wildlife Coordination Act consultation with FWS • Migratory Bird Treaty consultation with FWS	• Consultation with NMFS for any project expected to adversely impact Essential Fish Habitat under the Magnuson-Stevens Fishery Conservation and Management Act • Consultation with FWS for any action that might impact fish and wildlife habitat under the Fish and Wildlife Coordination Act • Consultation with NMFS or FWS for any action that might affect designated critical habitat for an ESA-listed marine species under Section 7	• Clean Water Act Section 401 and 404 permits may be required from the U.S. Army Corps of Engineers (USACE) to cover pollution discharge and dredge and fill material • Water quality certification may be needed from designated state agencies • Nationwide Permit 52 may be needed from USACE under the Rivers and Harbors Act Section 10	• Social impact assessment required under the National Environmental Policy Act (NEPA), Magnuson-Stevens Fishery Conservation Act, Outer Continental Shelf Lands Act, and others • These acts primarily require impacts to historic and cultural uses to be considered as part of environmental assessments
Wales	• A license from Natural Resource Wales is required if there is likely to be a significant effect to a species (including disturbance, injury, or mortality) under the Wildlife and Countryside Act 1981 (as amended) • Conservation of Habitats and Species Regulations 2017 (and offshore equivalent) protects areas of biological interest for species • Marine and Coastal Access Act 2009 protects a range of species that are considered nationally important • Consideration of significant impacts to flora and fauna is required in the Environmental Impact Assessment Report under	• A license from Natural Resource Wales is required if there is likely to be a significant effect to a habitat (including disturbance or damage) under the Wildlife and Countryside Act 1981 (as amended) • Conservation of Habitats and Species Regulations 2017 (and offshore equivalent) protects habitats and areas of biological interest • Marine and Coastal Access Act 2009 protects a range of habitats and geological features that are considered nationally important	• The Water Environment Regulations 2017 (Water Framework Directive) defines the assessment process for when a Water Framework Directive (WFD) compliance assessment is required to maintain good status of water based on indicator criteria • Marine Works Regulations 2007 requires an estimate of emissions from the project and consideration of significant impacts to water in the Environmental Statement	• Marine Works Regulations 2007 requires a description of likely social and economic impacts such as population, human health and cultural heritage in the Environmental Statement • Part 3 of the Marine and Coastal Access Act 2009 requires marine renewable energy consent decisions to be made in accordance with the Welsh National Marine Plan policies, including consideration of existing uses, navigation requirements and safety zones

the Marine Works Regulations 2007

TABLE II. EXAMPLE OF INFORMATION COMPILED IN STRESSOR-SPECIFIC GUIDANCE DOCUMENTS FOR ELECTROMAGNETIC FIELDS AND HABITAT CHANGE.

Stressor	Issues	Receptors	Sample Evidence	Consensus	Recommendations
Electromagnetic Fields (EMF)	Species and populations at risk: attraction, avoidance, or interference with orientation, navigation, or hunting.	Some species of: • Elasmobranchs, • Crustaceans, • Cetaceans, • Fish, and • Sea turtles.	• In an enclosure experiment with a 300kV buried DC cable, 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. [14]	• The level of power carried by marine renewable energy (MRE) cables is much lower than offshore wind. • Risk can be retired for single devices and small arrays.	• Larger deployments may still require measurements to be taken.
Habitat Change	Habitat alteration or loss: effects of installation/ removal on benthos, changes in community composition, and artificial reef effect.	• Benthic environments. • Pelagic environments. • Marine flora and fauna.	• Diver video surveys completed before and after installation of the SeaGen tidal turbine found that observed changes in benthic community were consistent with changes at the reference station, suggesting that any changes were within natural variability. 50% of the visible surface area of the device was colonized within 2 years, fully replacing the area disturbed by the device installation. [12] • MRE devices display the same artificial reef effects as other industries, with potential for positive effect (due to increased productivity) or neutral effect (due to individual relocation) on species abundance. [15]	• Risks can be retired from habitat change for single devices and arrays as long as unique or critical habitats are avoided in siting.	• As the industry develops, impacts unique to large arrays and cumulative effects will need to be considered.

IV. CONCLUSION

The guidance documents can be used to organize and evaluate the potential impacts of MRE within a regulatory context. While in no way prescriptive, the guidance documents are intended to be a helpful tool in simplifying and streamlining consenting processes to advance the industry and ensure protection of the environment. These guidance documents should be helpful at the project level to complement and provide tools for regulators to leverage and interpret data and information on environmental effects, to assess risk retirement, or to analyze appropriate levels of mitigation or monitoring requirements. Bringing together the evidence bases, risk retirement for key stressors, and country-specific regulations provides a process and resource for regulators, advisors, and developers to use when consenting MRE projects.

OES-Environmental continues to develop the remaining guidance documents, outlined in Fig. 2., in collaboration with international partners and content experts. This large-scale cooperation, coupled with the commitment to environmentally, socially, and economically sustainable development, will enable success for the MRE industry. As the industry achieves success in deploying small numbers of devices, and transitions toward deployments of arrays, these guidance documents should provide a foundation for assessing risks and prioritizing knowledge gaps.

ACKNOWLEDGEMENT

We would like to thank our collaborators at Aquatera Ltd. for help in developing the guidance documents and providing feedback on the risk retirement approach. We would also like to thank the representatives of the other 15 OES-Environmental nations and the US Department of Energy EERE-Water Power Technologies Office for their guidance and insight. We also much thank members of the MRE community for attending our workshops and webinars and providing useful feedback as we refine our approach. We would also like to thank the rest of the OES-Environmental team at Pacific Northwest National Laboratory for their contributions to this work.

REFERENCES

[1] G. W. Boehlert and A. B. Gill, "Environmental and Ecological Effects of Ocean Renewable Energy Development: A Current Synthesis," *Oceanography*, vol. 23, no. 2, pp. 68-81, 2010. DOI: 10.5670/oceanog.2010.46, [Online].

[2] 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), 2020. DOI: 10.2172/1632878, [Online].

[3] A. E. Copping, M. C. Freeman, A. M. Gorton, L. G. Hemery, "Risk Retirement—Decreasing Uncertainty and Informing Consenting Processes for Marine Renewable Energy Development," *Journal of Marine Science and Engineering*, vol. 8, no. 3, pp. 172, 2020. DOI: 10.3390/jmse8030172, [Online].

[4] A. E. Copping, L. G. Hemery, D. M. Overhus, L. Garavelli, M. C. Freeman, J. M. Whiting, A. M. Gorton, H. K. Farr, D. J. Rose, L. Tugade, "Potential Environmental Effects of Marine Renewable Energy Development—The State of the Science," *Journal of Marine Science and Engineering*, vol. 8, no. 11, pp. 18, 2020. DOI: 10.3390/jmse8110879, [Online].

[5] A. E. Copping, M. C. Freeman, A. M Gorton, and L. G. Hemery, "Risk Retirement and Data Transferability for Marine Renewable Energy," in A.E. Copping and L.G. Hemery (Eds.), *OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World*. Report for Ocean Energy Systems (OES). pp. 263-279, 2020. DOI: 10.2172/1633208, [Online].

[6] A. E. Copping, M. C. Freeman, A. M. Gorton, and L. G. Hemery, "A Risk Retirement Pathway for Potential Effects of Underwater Noise and Electromagnetic Fields for Marine Renewable Energy Development," paper presented at OCEANS 2019, Seattle, WA, USA, 2020. DOI: 10.23919/OCEANS40490.2019.8962841, [Online].

[7] A. E. Copping, A. M. Gorton, and M. C. Freeman, "Data Transferability and Collection Consistency in Marine Renewable Energy," Pacific Northwest National Laboratory, Report No. PNNL-27995, 2018.

[8] A. E. Copping, A. M. Gorton, M. C. Freeman, D. J. Rose, H. K. Farr, "Data Transferability and Collection Consistency in Marine Renewable Energy: An Update to the 2018 Report," Pacific Northwest National Laboratory, Report No. PNNL-27995 Rev. 1, 2020.

[9] National Marine Fisheries Service, "2018 Revisions to: Technical guidance for assessing the effects of anthropogenic sound on marine mammal hearing (Version 2.0): Underwater thresholds for onset of permanent and temporary threshold shifts," pp. 167, 2018.

[10] Tetra Tech, "Underwater Acoustic Modeling Report - Virginia Offshore Wind Technology Advancement Project (VOWTAP)," 2013.

[11] K. Haikonen, J. Sundberg, and M. Leijon, "Characteristics of the Operational Noise from Full Scale Wave Energy Converters in the Lysekil Project: Estimation of Potential Environmental Impacts," *Energies,* vol. 6, no. 5., pp. 2562-2582, 2013. DOI: 10.3390/en6052562, [Online].

[12] International Electrotechnical Commission (IEC), "Marine energy - Wave, tidal and other water current converters - Part 40: Acoustic characterization of marine energy converters (IEC TS 62600- 40:2019)," 2019.

[13] G. Keenan, C. Sparling, H. Williams, and F. Fortune, "SeaGen Environmental Monitoring Programme: Final Report," Royal Haskoning. The Netherlands. 2011.

[14] Z. Hutchison, P. Sigray, H. He, A. B. Gill, J. King, C. Gibson, "Electromagnetic Field (EMF) Impacts on Elasmobranch (Shark, Rays, and Skates) and American Lobster Movement and Migration from Direct Current Cables," U.S. Department of the Interior, Bureau of Ocean Energy Management. Sterling, VA, USA. OCS Study BOEM 2018-003, 2018.

[15] S. Kramer, C. Hamilton, G. Spencer, and H. Ogston, "Evaluating the Potential for Marine and Hydrokinetic Devices to Act as Artificial Reefs or Fish Aggregating Devices, Based on Analysis of Surrogates in Tropical, Subtropical, and Temperate U.S. West Coast and Hawaiian Coastal Waters," H.T. Harvey & Associates, Report No. OCS Study BOEM 2015-021, 2015.