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OES OCEAN ENERGY SYSTEMS

ANNEX IV
Environmental Effects of
Marine Energy Development
around the World

THE STATE OF KNOWLEDGE FOR ENVIRONMENTAL EFFECTS

DRIVING CONSENTING/PERMITTING FOR THE MARINE RENEWABLE ENERGY INDUSTRY

Prepared for Ocean Energy Systems
by Andrea Copping, Pacific Northwest National Laboratory
On behalf of the Annex IV Member Nations

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The State of Knowledge for Environmental Effects Driving Consenting/Permitting for the Marine Renewable Energy Industry

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Preface and Acknowledgments

Annex IV was established as a task under the International Energy Agency Ocean Energy Systems Technology Collaboration Programme (OES) to examine the environmental effects of marine renewable energy (MRE) development. The examination is intended to help understand and facilitate the consenting/permitting of MRE devices to support the establishment and growth of the industry. Annex IV is led by the United States with the U.S. Department of Energy acting as the Operating Agent, in cooperation with the National Oceanic and Atmospheric Administration and the Bureau of Ocean Energy Management. The Annex IV task is implemented by Pacific Northwest National Laboratory (PNNL).

During the third phase of Annex IV (2016–2020), the OES Executive Committee requested that the Annex IV nations prepare a position paper to document the state of knowledge that drives, and in many cases, slows, consenting/permitting processes worldwide.

This paper was prepared by PNNL, under the guidance and direction of the Annex IV member nations, whose representatives are listed below. We express special thanks to Nikki Sather, Jonathan Whiting, Mikaela Freeman, Madelynn Whitney, and Susan Ennor of PNNL; to Hoyt Battey and Samantha Eaves of US Department of Energy; to Ana Brito e Melo and the OES Executive Committee for guidance on the document; to Patricia Cominskey of Sustainable Energy Authority of Ireland, and Yann-Hervé De Roeck and Morgane Lejart of France Energies Marines; and to the reviewers from several nations who provided useful comments.

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Abbreviations

AM	adaptive management
EIA	Environmental Impact Assessment
EMF	electromagnetic field
MRE	marine renewable energy
OES	Ocean Energy Systems Technology Collaboration Programme
ORPC	Ocean Renewable Power Company
PNNL	Pacific Northwest National Laboratory
WEC	wave energy converter

Introduction

The marine renewable energy (MRE) industry is young—most technology development and testing for tidal and wave devices has taken place over the past 10–15 years. As wave and tidal devices continue to be deployed for demonstration, testing, and pilot projects, and the earliest commercial arrays are being developed, regulators around the world are requiring that a significant amount of data be collected to determine the effects of devices and systems on marine animals, habitats, and ecosystems. The collection of pre- and post-installation monitoring data places substantial cost burdens on device and project developers, threatening the financial viability of this young industry.

This paper describes the state of knowledge that drives the consenting (permitting) processes for the MRE industry in most of the Ocean Energy Systems Technology Collaboration Programme (OES) nations, and how that level of knowledge is, or is not, driving the processes for consenting projects and moving the industry forward. There are of course many differences among the levels of acceptance and application of this knowledge. This paper attempts to summarize the current status and suggest pathways for moving the industry forward through efficient consenting processes.

Regulatory Requirements

Regulators are faced with significant uncertainty about the potential environmental effects of MRE devices on the quality of the environments they are charged to protect. Because of this uncertainty, regulators may take a precautionary approach, requesting extensive pre- and post-installation data to determine the significance and potential adverse effects of interactions of marine animals and habitats with all parts of MRE devices and systems.

In most nations, consenting (or permitting) processes for MRE development are driven by environmental legislation and regulation that require a significant level of evidence to support conclusions about whether potential impacts are acceptable (Aquatera Limited 2014). To date, regulators tasked with protecting the marine environment have interpreted these laws and regulations to require a high degree of certainty (Boehlert and Gill 2010). Collecting sufficient data to satisfy that level of certainty presents challenges for the emerging MRE sector. In some instances, data requested by regulators have not been proven to be useful in helping to further understand the most important questions about risks from MRE devices.

In many nations, regulators assume that at least some interactions could result in significant adverse impacts, or could be considered to be highly risky. MRE device and project developers may perceive regulators as being “too cautious.” In many cases, this perception of high risk appears to arise from

- a lack of understanding of the features and operation of MRE systems;
- the newness of the technologies, many of which bear little resemblance to other industrial uses; and

- pressure from other stakeholders who fear competition and degradation of the ocean space (Baring-Gould et al. 2016; Copping et al. 2016).

Studies to date have shown most perceptions of environmental impacts from MRE devices arise from uncertainty or lack of definitive data (Copping et al. 2016) about the real impacts. Nevertheless, regulators continue to perceive MRE interactions to be of high risk. Tidal devices have progressed more rapidly than wave devices probably perhaps because tidal devices more closely resemble developed technologies such as wind turbines and ship propellers, so that the technology and its impacts are more familiar to regulators; in addition, tidal devices are often not visible from the surface, which might reduce attention from stakeholders. Conversely, there has been no such design convergence for wave devices; instead, many radically different technologies that occupy different portions of the ocean are being developed to harness wave energy (Tethys 2017a). This leads to regulators' widespread misunderstanding of the potential effect of the technologies (Copping et al. 2017), and there are only a few MRE deployments that inform our global understanding of the likely impacts of future developments.

During the planning phases of an MRE project, stakeholder concerns can also influence regulators' perceptions of high risk. The most commonly voiced concerns are degradation of the marine environment and the organisms it supports, and competition for ocean space with ongoing activities, especially commercial fishing, shipping, and conservation. Working with stakeholders throughout development, deployment, and operation of MRE processes can promote better understanding and reduce stakeholder concerns. Marine Spatial Planning, a collaborative process of managing ocean space equitably, has been used around the world to manage ocean uses, decrease and mitigate conflicts, and address stakeholder concerns about overlapping marine uses (Ehler and Douvere 2009). Additionally, assessing stakeholders' perceptions of the benefits and risks of MRE development can lead to objective evaluations of the acceptability of MRE projects (Dreyer et al. 2017) and help stakeholders, regulators, and developers address concerns and mitigate any negative influence that stakeholders may have on regulators.

Data Needed to Meet Regulatory Requirements

Under most national and international regulatory regimes, sufficient data need to be provided by developers so regulators can analyze the potential effects of a proposed use of the ocean or other public resources. Such data and information are required to consent an MRE deployment, which commonly occurs through studies conducted to support required Environmental Impact Assessments (EIAs), sometimes called Environmental Impact Statements (European Commission 2016; Government of Canada 2016; UK 2000). Below are a few examples of data requirements linked to EIAs:

- In Portugal, the pre-consenting requirements for the Wave Roller project included a pre-application entailing detailed site characteristics and a comprehensive EIA that resulted in required monitoring plans to continue data collection and further understand the project's impacts on marine mammals and benthic communities (AW Energy 2012; Tethys 2017b).
- For consenting the SeaGen tidal turbine project in Northern Ireland, an EIA was required and sufficient data were collected to conclude that while some potential impacts were

uncertain, adverse impacts were unlikely. The combination of data collected and development of a comprehensive Environmental Monitoring Plan allowed this project to be permitted (Keenan et al. 2011).
- In Ireland, two draft environmental guidance documents were published to help developers and consultants conduct environmental assessments and to specifically outline data and monitoring requirements for deployments in Irish waters (Department of Communications, Climate Action & Environment 2017; Tethys 2017c).

While there must be sufficient data to analyze potential effects, it may not be possible to evaluate certain risks until significant numbers of devices are deployed. Environmental monitoring plans are necessary as a means of continuing data collection and monitoring before, during, and after installation (Copping et al. 2016).

As industries progress, data collected and lessons learned from earlier projects are used to predict the likely effects of development, indicate levels of risk, and design necessary mitigations. The MRE industry has not yet accumulated a sufficient track record to easily license (permit or consent) projects by relying largely on past project performance. However, regulators can inform their assessments by drawing from a considerable body of existing knowledge, including results of field research and monitoring, laboratory studies, numerical modeling simulations, as well as insights from other industries. This information is used to understand the science and to determine which impacts may be of low risk versus high risk, as summarized in the Annex IV State of the Science report (Copping et al. 2016). For example, field research and monitoring outcomes described in the Annex IV State of the Science report (Copping et al. 2016) included the following:

- Studies of fish populations near tidal devices deployed in the United States (Verdant Gen5) found there was no indication of different behavior during turbine operation (Bevelhimer et al. 2015).
- Studies of noise emitted from two operating wave energy converters (WECs) at high wave velocities demonstrated that many marine animals can detect the noise from the operating WECs, but the noise is not sufficient to alter their behavior or cause them physical harm. The noise from MRE devices is generally emitted below the frequency threshold at which most marine mammals hear (Haikonen et al. 2013).

Many laboratory studies and numerical models have also been used to better understand interactions with MRE devices (Copping et al. 2016). For example:

- A laboratory experiment using a small-scale turbine led to better understanding of hydrodynamics and geomorphology near tidal turbines, including erosion and sediment transport (Ramírez-Mendoza et al. 2015).
- Empirical data from field studies have been used to validate numerical modeling simulations, including probabilistic models for fish encounters with tidal turbines (Shen et al. 2015; Tomichek et al. 2015).
- A variety of collision risk models have also been used to identify potential collision risks for species of concern, especially marine mammals, using baseline information (Band 2014; Carlson et al. 2013; Wilson et al. 2007).

Based on field research, lab studies, and modeling simulations, underwater noise, energy removal, electromagnetic fields (EMFs), and chemical leaching can all be considered a low risk for single-device deployments (Copping et al. 2016). While additional research, studies, and modeling efforts can increase understanding of environmental risks, the current body of knowledge can inform MRE regulators' analyses.

Each proposed MRE development will require the collection of site-specific data to satisfy licensing requirements; however, rather than requiring extensive and complex data collection to inform the overall development of the industry, only data required to ensure that the chosen site meets necessary safeguards should be required as the industry moves forward. Regulators often request extensive baseline and post-installation data from developers, but these data may not represent the most effective or efficient use of resources aimed at understanding environmental risk (Copping et al. 2017). Strategically targeted research studies and monitoring results from early MRE deployments that address the environmental interactions most likely to slow consenting/permitting can provide information that will best reduce scientific uncertainty and help regulators support streamlined processes (Baring-Gould et al. 2016). The levels of uncertainty also need to be examined to move forward using a risk-based approach that allows uncertainty to be addressed in a transparent and consistent manner (Copping et al. 2015). Use of data sets collected in one location to determine likely effects in other locations, for instances in test sites, as well as flexibility in approaches to consenting/permitting single devices, will help move the industry forward with minimal risk to the marine environment. In addition, data collected from other known technology deployments, such as offshore wind foundations and floats, export cables, mooring lines should be used to complement knowledge on the potential effects of wave and tidal deployments for consenting.

Industry Analogs

The oceans have been used for industrial purposes for centuries and the interaction of vessels, navigation markers, piers, underwater installations, and other devices with marine life have been studied as these industries and uses have progressed. Some of these industrial uses and installations in the oceans are analogous to MRE and can inform our understanding of interactions between MRE devices and systems, and marine life, while others that may resemble MRE devices actually differ in important ways. Analog industries can serve as a scientific foundation for understanding particular environmental stressors, as long as these limitations are considered.

Structures such as buoys, platforms, piers, and docks have been deployed in the marine environment for centuries, creating hard substrates that can attract fouling communities made up largely of invertebrates and algae. These structures function as fish aggregating devices or artificial reefs, attracting fish and other mobile organisms to the biofouling organisms as a source of food and to the structures as sources of protection, refuge, and shade. Studies of fish, marine mammals, invertebrates, and seabirds interacting with these installations can help predict how marine life will react to the presence of MRE devices. For example, MRE devices function by introducing stationary hard surfaces, which can alter species distributions and abundance, habitat connectivity, and biodiversity (Langhamer et al. 2009; Kramer et al. 2015). Similarly, the presence of offshore oil and gas drilling rigs or offshore wind turbines can simulate and inform our understanding of these same interactions at a larger scale (Page et al. 1999; Wilhelmsson and Malm 2008) as species interact with mooring lines and electrical cables, changes in wave fields from surface-deployed devices, and changes in flow that can affect sediment transport and water quality (Copping et al. 2016).

Export cables for MRE installations will generate EMF emissions that may affect the orientation, navigation, or hunting ability of electro- or magneto-sensitive species. Yet EMF signatures are not new to the marine environment; many subsea cables for power and telecommunications, bridges, tunnels, and offshore wind farms have been deployed and emit measurable electromagnetic signatures in the ocean (EPRI 2013; Meißner et al. 2006). Understanding of the potential exposure of marine animals to EMFs from MRE export cables can be informed by the presence of these power and telecom cables that line the seafloor.

Anthropogenic noise has been shown to affect marine animal communication, navigation, and hunting (Kastelein et al. 2013). Underwater sound from installing MRE devices, particularly if pile driving is needed, is equivalent to in-water work done for installation of bridges, piers, and other marine infrastructure. Underwater sound for MRE developments includes sound associated with vessel traffic and device installation and decommissioning, all of which are typically of weeks to months in duration. Pile driving associated with device installation will produce the loudest and most disruptive noise, and mitigation measures and effects have been developed for other industrial purposes like the installation of bridges, piers, offshore wind turbines (Dubusschere et al. 2014), and other marine infrastructure. The sounds from operational MRE devices differ somewhat from sound from other industries, but they have been shown to be of lower amplitude than other industrial uses such as commercial shipping (Lossent et al., 2017).

Not all industry analogs are appropriate for determining potential MRE effects. Most notably, the risks to aquatic life from conventional hydropower turbines and rotating ship propellers are not generally equivalent to risks from tidal turbines. If these key differences are not understood, the perception of risk from MRE devices can appear greater than they are.

Tidal turbines are generally larger than conventional hydropower turbines (1−16 m and 1.5 – 9 m, respectively), and have slower rotational speeds (5–70 rpm and 50–100 rpm, respectively) and blade tip velocities (18–32 m/s and several hundred meters per second, respectively) (ABPmer 2010). These differences mean tidal turbines produce smaller changes in shear stress, turbulence, and water pressure, than those associated with ship propellers or conventional hydropower turbines. These lower forces suggest that if collisions between animals and MRE devices occur, they would be much less damaging and provide a greater likelihood of the animals surviving (EPRI 2011). In addition, marine animals have ample room to avoid and evade tidal turbines placed in open channels in the ocean, while conventional hydropower in rivers and streams force fish through the turbines mounted in dams (Sparling et al. 2017).

Ship propellers are also poor analogs because they have significantly higher rotational speeds than tidal turbines and can be moving laterally at faster speeds than marine animals can swim and evade (Silber et al. 2010).

MRE Environmental Risks

Wave and Tidal Installations

Wave and tidal energy devices may cause similar effects on marine animals and the environment through certain interactions, but there are also substantial differences in the potential risks from turbines and WECs.

Concerns about changing the behavior of animals moving past MRE arrays, potential effects of EMFs from cables and energized devices on animal welfare, and disruption of animal behavior by underwater sound from generators or other moving parts may be of equal concern for wave and tidal devices.

Tidal turbines may constitute a risk of collisions with marine animals that does not apply to WECs (Sparling et al. 2017). There is a perception that collision risks from rotating turbine blades might cause serious injury or death to marine animals, while the flapping or bobbing of WECs does not raise the same level of concern (ABPmer 2010). The placement of tidal turbines and WECs in ocean waters will have differing potential effects on those waterbodies. Tidal turbines capture kinetic energy from the movement of water from tidal currents, causing potential changes in water flow as energy is captured, and potentially resulting in changes in sediment transport and basin flushing (Wang et al. 2015). On the other hand, WECs capture energy from wave propagation that may affect shoreline erosion (Roberts et al. 2015).

WECs and floating tidal devices could introduce the risk of animals interacting with mooring lines and draped cables in the water column. Many WECs and floating tidal devices are tethered to the seabed by mooring lines, and could have electrical cables draped between platforms to centralize electricity export to shore. There is a perceived risk of large marine mammals becoming entangled in mooring lines and cables, but mooring lines and export cables are under tension and have no loose ends, making entanglement less likely than encounters with lost fishing gear or other ropes and nets in the marine environment (Johnson et al. 2005) that can lead to whale drownings (Cassoff et al. 2011). Several cases of whale entanglement with submarine cables indicate that sperm whales have become entangled around their jaws (an encounter known as "bridling") while feeding from bottom sediments (Heezen 1953). Fishing gear can create drag on entangled marine mammals, potentially increasing predation pressure, impairing foraging behavior, or increasing energetic costs (van der Hoop et al. 2015). Direct entanglement with MRE cables is not analogous to entanglement with fishing gear. In addition, concerns have been raised that lost or derelict fishing gear could become hung up on MRE lines and devices, causing harm to marine life, but there is no evidence that MRE lines and cables are more likely to catch derelict fishing gear than any other fixed structure in the marine environment.

Single Devices and Arrays

To date, commercial-scale MRE development has been slow and data collected about the environmental effects of MRE deployments are generally limited to small-scale or single devices (Copping et al. 2016). While uncertainties remain about how marine animals and habitats will be affected by and interact with single devices in the ocean, there is a reasonable understanding of likely effects. No sizable arrays of wave or tidal devices are currently in the water anywhere in the world, so there have been no opportunities to collect environmental effects data or to validate numerical models that simulate the effect of multiple devices operating in the ocean over long periods of time. As development ramps up from single devices to small-scale projects and to large-scale commercial arrays, the magnitude of environmental effects may vary (Polagye et al. 2011; Copping et al. 2016), and understanding environmental effects becomes increasingly important as the number of devices and the size of arrays increase.

Modeling studies indicate that the ability for a marine animal to traverse an array without becoming entrapped or entangled is more a function of the number and density of devices than the type of device (ABPmer 2010). The potential effects of EMFs from cables will differ based on whether the EMF emissions are generated by alternating current or direct current; most single devices are designed to use alternating current cables but future large arrays are more likely to move electricity to shore as direct current (Thomsen et al. 2015). EMF effects may also differ based on the level of power carried by a cable; larger arrays will burden lines with higher voltages and levels of power (Thomsen et al. 2015). Underwater noise from generators, moving parts, and pile driving will differ slightly between device designs, but will be at similar scales for wave and tidal devices, and larger potential noise fields will be associated with larger arrays (Lepper and Robinson 2016). Additionally, underwater noise from a single MRE device can be measured and appears to remain below levels likely to harm marine mammals or fish, but the interaction with, and increase in sound from, multiple devices remains unknown (Copping et al. 2016; DOE 2009; Thomsen et al. 2015). There are no monitoring data for underwater sound from commercial-scale arrays; as MRE installations expand, additional monitoring will be needed to ensure that such emissions are not harmful. Changes in flow and energy removal from a single device will be unmeasurable compared to the natural variability in waterbodies; at the array scale this interaction must be examined again. As MRE developments are scaled up to arrays, there may be a trade-off between environmental risks and performance of devices, which can only be resolved through additional studies, simulations, and collection of array deployment data (Polagye et al. 2011). Information from single-device studies can help determine risks, but the full effects of array-scale projects can only be understood once commercial arrays come online (Copping et al. 2016) and additional studies, monitoring data, and numerical simulations help determine their effects.

Interactions and Risks

Researchers responsible for collecting much of the data about MRE environmental effects to date believe, with reasonable confidence, that certain interactions between single devices and the environment are not likely to cause harm, particularly at the single-device scale. These interactions, which can perhaps be “retired” or removed from further consideration for single devices, include EMF exposure from export cables, entanglement of marine animals with mooring lines and cables in the water column, changes in water flow, and decreases in wave energy (Copping et al. 2016).

Regulators and stakeholders continue to raise concerns about animals interacting with EMFs. Additional exposure to EMFs emitted by device cables or moving machine parts is thought to possibly affect marine animals, particularly those that rely on the Earth's natural magnetic field (EPRI 2013). Scrutiny is primarily driven by potential changes in behavior in animals' feeding habits and barrier-induced patterns of movement (Tricas and Sisneros 2004). Threshold values for EMF effects are only available for a few species (mainly elasmobranchs), leaving major uncertainties in several important taxonomic groups (cetaceans, pinnipeds, fish, crustaceans, etc.). Although EMF effects are not well understood, studies indicate that EMF levels emitted from devices are not strong enough to cause substantial harm to animals (Baring-Gould et al. 2016). If MRE devices emitted higher levels of EMFs there would be cause for concern, but, based on current knowledge, EMF emissions from cables and energized devices are likely to pose little environmental risk (Copping et al. 2016).

Entrapment (also known as entanglement) is the hypothetical trapping of large animals such as whales in mooring lines or draped power cables associated with MRE devices, potentially causing confusion or drowning (Benjamins et al. 2014). This risk is thought to increase with larger numbers of devices in the water (Copping et al. 2016). Concerns about entanglement are derived from reported injuries and mortality due to entanglement with derelict fishing gear (Benjamins et al. 2014). However, MRE mooring lines are unlikely to have loose ends or sufficient slack to create loops in which animals can become entangled (Baring-Gould et al. 2016).

MRE devices are hypothesized to affect waterbodies over time due to changes in water flow and removal of energy. The concerns are that these changes could affect water quality, circulation or flow, and sediment transport, particularly for tidal devices. Removal of wave energy by WECs could decrease wave heights. The consensus among researchers and regulators is that there is minimal risk to the environment from the removal of energy from single devices (Baring-Gould et al. 2016). Numerical models have determined that only the addition of hundreds to thousands of tidal or wave devices are likely to have a negative effect on the stability of the ecosystem (Wang et al. 2015; Yang and Wang 2015).

Certain interactions may be more difficult to consider retiring and will continue to require investigation into the future, particularly collision risk and the effect of underwater noise from MRE devices on marine mammals (Copping et al. 2016). Most notably, the risk of collision of marine mammals, fish, diving seabirds, and sea turtles with tidal turbine blades will continue to be a concern and may result in consenting/permitting delays, unless concentrated effort is exerted to resolve the issue and decrease the scientific uncertainty (Hutchison and Copping 2016). The greatest concerns are associated with endangered animals for which the loss of a single animal could affect population stability (Carlson et al. 2013). To date, no observations of marine mammal collision or strike injury from tidal turbines have been recorded (Copping et al. 2016), and fish interacting with turbines appear to be unharmed. Research indicates that the occurrence of collision injury and mortality are likely to be rare, although there are significant challenges to observing these events under water (Baring-Gould et al. 2016).

Similarly, uncertainty about the effects of underwater sound from turbines and WECs that may cause behavioral changes in animals, particularly marine mammals and certain species of fish, will continue to be a concern raised by regulators and stakeholders. Many marine animals rely on sound for predation, evasion, and social interactions, much the same as most terrestrial animals rely on light for vision. Understanding marine animals' reactions to sources of underwater sound such as MRE devices is inadequate and more research is needed to determine the ability of marine animals to detect and evade tidal turbines and WECs (Copping et al. 2016). The noise from several single device turbine and WEC designs have been measured, and it appears that operational noise from MRE devices is unlikely to cause harm (Baring-Gould et al. 2016, Lossent et al., 2017), and likely falls below existing regulatory thresholds. Although considerable research is still needed to determine the behavior of marine animals in response to sounds emitted by turbines and WECs, regulatory thresholds for allowable underwater sound exist in some countries, such as the United States (National Marine Fishery Service 2016).

Recommendations to Advance the Industry

To advance understanding of environmental risks and the extent to which they should influence precautionary-focused decision-making in consenting/permitting MRE devices and arrays, and to help advance the MRE industry the following strategies that seek to decrease scientific uncertainty and expedite regulatory processes are recommended.

Information Sharing

Increased sharing of existing information among researchers, regulators, stakeholders, and developers provides an important pathway to more efficient consenting. The online knowledge management system *Tethys*, https://tethys.pnnl.gov, is an important part of this effort to collect, curate, and disseminate all known information about environmental risks (Copping et al. 2013). Solving many of the remaining risks will require the involvement of all parties to further the industry around the world. Clear, efficient, and accessible delivery of information to regulators at all levels of government—national, regional, and local—is needed (Baring-Gould et al. 2016). In addition, international coordination and cooperation can efficiently and effectively target key risks that are still shrouded in uncertainty by bringing together the most experienced and brightest researchers with developers and stakeholders who have intimate knowledge of the proposed project sites, devices, and the marine environment (Copping et al. 2013).

It is recommended that all existing information about what is known about the potential adverse effects of marine environmental interactions with all parts of MRE devices and systems be broadly shared. Pertinent information should be directly delivered to regulators at all levels of government, and ongoing interactions should be planned to ensure regulators understand the implications of the underlying research results. Similarly, it is important that the same information be readily available and understandable to stakeholders. This international collaboration to encourage the exchange of ideas can occur through efforts such as OES (https://www.ocean-energy-systems.org/) and Annex IV (https://tethys.pnnl.gov/about-annex-iv).

Transferability of Data

To date, most MRE deployments have been of single devices, at few locations, for limited periods of time, and with a constrained amount of environmental data collection. Regulatory and stakeholder concerns have dictated that many early projects collect extensive baseline and post-installation data, constituting an effort that is beyond what is a sustainable for MRE companies. Progress on understanding and retiring environmental risks will be most effective if data are analyzed to extrapolate findings to additional locations where devices might be deployed in the future (Polagye et al. 2014; Norris et al. 2014). Concentrated research efforts are essential for determining what interactions can be resolved and the information used to inform future projects.

It is recommended that monitoring data collected from one location be used to the maximum extent possible to clarify and explain interactions around devices at other locations. A process for encouraging and evaluating the extent to which environmental effects data can be transferred from project to project is needed. Test sites around the world can play a key role by collecting appropriate data around deployed devices, acting as centers for testing data collection and analysis methods, and focusing strategic research programs on device testing programs.

Numerical Models

Numerical models will increasingly form the backbone of future MRE project site assessments, but each model must be validated and calibrated to ensure its realism and accuracy. For example, environmental stressors such as changes in water flow and energy removal will not be measurable with the operation of a single MRE device, but numerical models can be used to predict the number of installed devices that is likely to cause ecosystem-level changes, clarify risks that are difficult to observe, and direct future monitoring programs (Willsteed et al. 2017).

It is recommended that numerical models continue to be developed and refined to inform the larger picture of MRE interactions around the world. Monitoring data are needed, particularly from early MRE projects and test centers, to inform the development and validation of these models, although acquisition of these data may be beyond the collection efforts that a single MRE project can sustain. Field data collected around commercial arrays will further help to validate these models.

Strategic Research and Monitoring

Strategic research and targeted monitoring data can determine whether there is a need for mitigation of certain MRE-environment interactions, and ensure that the mitigation measures are appropriate, targeted, and effective (Copping et al. 2014; Hutchison and Copping 2016; Copping et al. 2017).

It is recommended that targeted strategic research studies be designed and implemented to address lingering questions about single devices and to focus on array effects as MRE commercialization ramps up. Key questions should include issues related to the risk of marine animal collision with turbines and behavior of marine animals in response to underwater noise of projects that involve multiple MRE devices. These strategic research studies will be most effective and efficient if they are pursued through international coordination and collaboration.

Adaptive Management

If effective management measures are identified before all potentially damaging interactions are completely understood, these measures, working in an adaptive management mode, could be applied to allow the operation of tidal and wave farms, even in the face of ongoing uncertainty. Adaptive management (AM) is a learning-based management approach that allows renewable energy projects to adapt monitoring and mitigation practices over time, leading to improved decision-making (Hanna et al. 2016). Not a new concept, AM has been used by many industries (to date mostly in the United States) to reduce scientific uncertainty (Baring-Gould et al. 2016; Hanna et al. 2016). AM has been used for several MRE projects in the United States, including the following:

- The Admiralty Inlet Pilot Tidal Project (Washington State) included an AM framework as part of an application for a pilot project license (Snohomish County Public Utility District No. 1 2012). While the two tidal devices were never deployed because of financial shortfalls, the framework directed the development of specific monitoring plans for potential environmental risks through a collaborative approach, including meetings with regulators and local stakeholders (Snohomish County Public Utility District No. 1 2012).
- Ocean Power Technologies developed an AM process for their Reedsport Wave Park (Oregon State) development (Ocean Power Technologies 2010). The goal in applying AM was to reduce negative environmental and socioeconomic effects, to alter management and monitoring practices as new data were collected, and to inform the potential for a larger project (Ocean Power Technologies 2010).
- Ocean Renewable Power Company (ORPC) developed an AM Plan for their (State of Maine) Cobscook Bay Tidal Energy Project (ORPC Maine LLC 2016). This plan provided a strategy for evaluating monitoring data and making informed, science-based decisions that would modify monitoring as necessary, and also acknowledged that elements such as environmental uncertainties may evolve over time (ORPC Maine LLC 2016; Copping et al. 2016). Through data collection, analysis, and transparent communication, ORPC removed seasonal restrictions for pile driving (based on mitigation methods and measured acoustic levels) and were able to reduce the frequency of or eliminate specific monitoring surveys, based on increased knowledge of species presence and environmental effects (ORPC Maine LLC 2016; Baring-Gould et al. 2016).

Consideration of AM programs is recommended for all MRE projects. If AM is determined to be a useful strategy, all monitoring data should be examined periodically and changes made to monitoring schemes to target scarce monitoring funds effectively and to identify cost-effective research projects. Implementing AM strategies may face significant challenges, including a lack of legislation and regulations requiring AM in most countries, and potential increased costs to the project for AM implementation (Hanna et al. 2016). However, this approach has the potential to help MRE projects move forward in the face of uncertainty and learn from previous developments (Hanna et al. 2016).

Government Funding Assistance

Some risks from MRE devices are likely to continue to be of concern and will require focused strategic research. Similarly, mitigation for existing risks may be needed. Experience from early deployments and operational tidal and wave farms will provide insights into mitigation measures that are effective and do not place excessive financial burdens on developers. Identifying a range of measures to manage potential harm from devices can ensure that optimal measures are tested and applied. These measures must follow the life cycle of MRE projects, beginning with the design phase of devices and systems, and continuing through their installation, operation, and maintenance, and decommissioning. These measures can proactively protect the marine environment and ensure the health of MRE projects, for example by ensuring that marine debris is cleared from operational MRE areas. However, identification, development, and testing of management measures, as well as solving common environmental challenges (such as the mechanics and behavioral aspects of collision risk) are beyond the scope of what an individual project or technology developer can or should perform. Research studies that address these challenges should be carefully planned and implemented, allowing for objective and publicly available results. Studies that are international in scope and strategically planned by the research and regulatory community are likely to provide the most useful and cost-effective solutions to benefit the MRE industry.

It is recommended that international and national government assistances be sought for the collection of monitoring data and funding of strategic research projects that will answer questions about specific interactions of MRE devices and the marine environment, including the development and testing of effective management measures, as well potential effects that cross national boundaries. This will decrease uncertainty about scientific understanding and allow regulators to implement a risk-based approach to consenting/permitting requiremen ts, in place of more precautionary approaches.

Conclusions

Based on the current level of understanding of the interactions of wave or tidal devices with the marine environment, the risks for deployment and operation of single devices appear to be very low. Very small arrays of wave devices may also present low risks. However, the remaining uncertainties associated with commercial arrays will require investigation as the larger arrays come online. The risks from wave and tidal devices differ somewhat and need to be addressed separately. Regulatory requirements are currently high and may not always target the most useful information.

As the MRE industry moves toward deployment and operation of larger arrays at the commercial scale, assuring that this emerging low-carbon energy source can expand add to global energy sources without causing unacceptable harm to the marine environment will require:

- sharing of all the collected information;
- application of data collected from one location to another;
- additional monitoring and validation of numerical models;

- development of strategic research programs at regional, national, and international levels;
- AM strategies; and
- the ongoing need for international and national government assistance.

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