WHAT DO WE KNOW ABOUT ENVIRONMENTAL EFFECTS OF MARINE RENEWABLE ENERGY DEVICES? THE STATE OF THE SCIENCE IN 2016

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INTRODUCTION

The marine renewable energy (MRE) industry is no longer brand new, but is not yet established commercially. Researchers have been examining potential environmental risks of MRE development for about a decade now, but there are still limited data from monitoring around wave and in-stream tidal devices to definitively determine what interactions between devices and marine animals/habitats can be discounted, which continue to need further study, and which constitute actual risk to the environment.

Through a comprehensive review effort, we have investigated overall risks to the marine environment from single MRE devices, and the initiation of larger arrays. Annex IV, an initiative under the Ocean Energy Systems, is tasked with producing a report on the State of the Science for Environmental Effects of MRE development. The final report will be published in April 2016. The highlights and significant findings of that study are featured here, including a closer look at two interactions that continue to concern regulators and stakeholders: advances in our understanding of the potential for collision of marine animals with tidal turbines, and what level of risk is posed by EMF emissions from MRE power cables and moving machine parts.

METHODS

Information was gathered from published literature, MRE project monitoring reports, field studies, and ongoing research projects. With the assistance of prominent researchers in the field, and analysts representing the 13 nations engaged in the Annex IV initiative, all publically available information was evaluated to determine the extent of uncertainty associated with interactions between MRE devices and marine animals and their habitats. The synthesis of information incorporated findings from the 2013 Annex IV report [1] as well as more recently published research. It should be noted that a great deal of information has not yet found its way into the peer reviewed literature, but resides in monitoring reports and other “grey” literature. Following the overall analysis of status and risk, a path forward was suggested, based on interactions with a broad base of researchers in the field.

RISK TO THE MARINE ENVIRONMENT FROM MRE DEVELOPMENT

Concerns about potential negative effects of MRE devices on marine animals and habitats is often expressed as a level of risk - the likelihood of an adverse outcome from an action. Risk is evaluated as the probability of the occurrence of an event and its resulting consequence. Interactions with elevated risk are either unlikely to occur but result in serious consequence, or might occur regularly but may not result in non-significant consequences [2].

Levels of risk were summarized and ranked (high, medium, and low) for each priority environmental interaction examined, based on our current understanding of the scientific uncertainty for each (Table 1). Because the overall risk associated with each stressor (part of the device that could cause damage or stress to the environment) may change with the scale of a project, the risk for each stressor has been assessed for three project sizes: an individual MRE device (wave or tidal energy converter); a small-scale project (~10 devices); and a large-scale commercial array (~100 devices). Though most stressors pose similar risks for tidal and wave devices, the movement of tidal turbine blades presents a different risk to marine animals than that of a moving wave device, as reflected in the table.

TABLE 1. POTENTIAL RISK THAT MRE DEVICES MAY POSE TO THE MARINE ENVIRONMENT (LOW RISK , MEDIUM RISK , HIGH RISK).

Stressor	Single Device Deployment	Small Scale Commercial	Large Scale Commercial
Static Device			
Dynamic Device (Tidal)			
Dynamic Device (Wave)			
Acoustic			
Energy Removal			
EMF			
Chemical Leaching			

Due to the overall lack of data and detailed understanding of many of the potential environmental interactions associated with MRE developments, perceptions of environmental risks are typically considered to be driven by uncertainty. As seen in Table 1, the environmental interaction that is seen to be of highest risk (largely due to scientific uncertainty) is collision between marine animals and tidal turbine blades, followed by underwater noise generated by MRE devices, energy removal, and the potential effects of electromagnetic fields (EMFs).

To illustrate how an interaction might be considered to constitute an elevated risk: 1) collision of marine animals with turbine blades is unlikely, but the potential consequence of a blade strike could be fatal or cause serious injury, hence elevating the overall concern from regulators and stakeholders; 2) benthic organisms living near power cables may be chronically exposed to EMFs, but the potential for serious consequences is low; 3) numerical models have been used to evaluate effects of how energy removal by MRE devices, but the levels of potential change in the marine environment suggest that large commercial projects may remove enough energy to effect sediment transport processes and water quality; and 4) the addition of anthropogenic sound to the marine environment has the potential to affect marine animal behavior or cause injury, however sound from MRE devices adds to many other sound sources and no studies have yet been able to observe changes in animal behavior around devices.

To effectively advance the MRE industry, researchers must begin to alleviate concerns raised by regulators for the medium and high risk interactions. By addressing these risks and their associated uncertainty, researchers will assist the industry in navigating siting and environmental permitting/consenting processes.

The remainder of this paper focuses on two interactions associated with deploying MRE devices that are perceived to have relatively high levels risk: collision potential of marine animals with tidal turbines, and the exposure of marine animals to EMFs.

Collision Risk of Marine Animals with Tidal Turbines

The presence of rotating tidal turbine blades in the ocean is thought to pose one of the greatest risks associated with development of the MRE industry. Marine animals may come into close contact or collide with turbine blades during the course of their natural movements, due to an inability to evade the device in strong currents, or because of attraction to the device for feeding, shelter, or curiosity. While the probability of colliding with a tidal turbine may be low (the chance of animals colliding with underwater structures is almost certain to be very rare), the potential consequence could be severe, perhaps resulting in irrecoverable injury or death to the animal. The risk of collision with tidal turbines has been much more of a concern for animal populations that are already stressed from external factors, such as climate change or other human activities, and where proposed projects overlap with the habitat of protected species where a loss of one or two individuals could affect the overall survivability of the population. High priority organisms include marine mammals, commercially and recreationally important fish species, and endangered seabirds.

Several key advancements have been made since the last Annex IV publication (Copping et al. 2013). A number of monitoring programs in the last three years have focused on collecting additional baseline data for marine animal densities and behavior in high energy areas where MRE deployments are planned, as understanding animal distributions and behavior prior to MRE deployments is an important predictor for collision risk [3], [4]. Studies have also focused on understanding movements of marine animals in tidal areas [5], [6], with the intent to track their reaction and behavior around installed tidal turbines.

Modeling studies have focused on potential collision rates of marine animals and seabirds with tidal blades, adapted from interactions of birds with wind turbines [7]. While these models provide a baseline understanding of collision rates, they generally do not consider behavior and biological attributes such as avoidance, attraction, evasion, life history, and feeding guild, which can be particularly important for apex predators such as large fish, which may lead to overestimates of collision rates. Other models have been used to estimate the potential consequences of a collision incident, in particular the potential blade strike on an endangered whale [8] and a harbor seal [9] with tidal energy converters.

No collision instances of marine mammals, fish, diving seabirds, or other marine animals have been observed to date. Scientists and researchers are in the process of developing instrumentation packages for improved monitoring around operating tidal energy devices; however, few of these systems have been adequately tested or deployed around operating devices. One of the primary challenges associated with these monitoring platforms and systems is gathering data with enough resolution to definitively identify a collision incident. Making observations with underwater cameras (optical or acoustic) in fast-moving tidal races is technically very difficult and results in large data sets that are costly to manage and process. Temporal factors should also be taken into consideration when deploying these monitoring packages, especially for migratory fish, where they may only be present during certain time periods and/or life stages. Evaluating the linkages between animal presence and tidal cycles could lead to better understanding of how many animals may be in proximity to tidal energy devices; for example, feeding seabirds may be more common during a slack tide even while schools of fish are present. Additionally, as more monitoring platforms and instruments are deployed, researchers should begin to consider the transferability of these datasets, and how these data may be applied or compared to other situations.

Electromagnetic Fields

EMFs are generated in the oceans as electricity is transmitted through cables or from moving parts of machines, such as MRE devices. The electrical field can be contained by a grounded metallic sheath and rapidly diminishes in the marine environment, but the magnetic field can persist over longer distances and induces a secondary electrical field. Although the Earth has a naturally occurring static geomagnetic field generated by earth and tidal motions, the addition of extra EMF signatures in the marine environment can affect certain organisms that use the Earth's magnetic field for orientation, navigation, and foraging. Marine organisms, such as certain species of elasmobranchs (cartilaginous fish), marine mammals, crustaceans, sea turtles, and other fish species, have electro- or magneto-receptors that allow them to detect electrical or magnetic fields [10]. The introduction of additional EMFs into the marine environment can potentially disrupt or alter these animals' abilities to detect or respond to natural magnetic signatures, potentially altering their survival, reproductive success, or migratory patterns [11].

Many subsea cables exist from analogous industries such as offshore wind and telecommunications; bridges, and tunnels have also been contributing EMFs to the marine environment for decades. Most interarray and export cables for MRE and offshore wind farms carry alternating current (AC) power, although future installations may also carry direct current (DC). Burial of subsea cables has the potential to shield animals living in proximity to MRE installations from EMF emissions. Field measurements around offshore wind farms have confirmed that the levels of EMF from interarray cables exceed those from turbines [12]. We know little about the level of EMF emissions from operating MRE devices.

To better understand how EMFs may affect marine animals, scientists have identified marine organisms that are known to be sensitive to magnetic and electrical signatures and seek to better understand the mechanisms by which these animals detect EMFs and may behave around specific levels of EMFs [13]. Scientists have also modeled potential EMF signatures for power cables and MRE devices, providing an estimate of how far electrical and magnetic signatures may persist from a cable, based on the level of EMF emitted from the cable [14]. To understand how certain animals may be affected by EMFs, laboratory studies have been designed to determine whether EMFs may affect behaviors of certain species of interest, and if so, to relate laboratory findings to a specific effect on the species in the wild. Mesocosm and field studies have been used to better understand how EMFs may affect animals in the marine environment, and whether the introduction of additional EMFs may affect their movement patterns and migrations [15].

Based on the evidence to date there is no demonstrable impact (negative or positive) of EMF related to MRE devices for any marine species that has been examined. Fish and invertebrates living on or near the seabed (i.e., benthic or demersal species) are more likely to be exposed to EMF emissions from MRE devices, while mobile species have the opportunity to move out of the vicinity. While laboratory and field data have helped advance our understanding of the potential effects of EMF signatures, and models of EMF emissions can help estimate the levels of exposure, collection of additional data around MRE devices is needed to better understand this interaction and how it may affect marine animals. New data collection devices are needed as no instruments currently available measure EMF at the levels needed.

RETIRING RISK

Interactions of MRE devices with marine animals and habitats that continue to concern regulators are those surrounded by the greatest uncertainty. In order to reduce the perception of these risks, there is a need to begin to retire risk for those interactions that are not causing harm to the marine environment; this will also allow the MRE community to focus efforts on mitigating the real risks in an effective manner. The collection of additional data may help to lower uncertainty around interactions, and thereby lower risk. The perception of risk for many interactions is currently driving regulators to request large amounts of data collection pre- and post-installation, saddling MRE developers with burdensome and costly monitoring programs. The path forward for the industry involves retiring risks by increasing scientific understating, identifying risks that require mitigation, and optimizing data collection efforts by monitoring interactions where more certainty is still needed (Figure 1). The risk categories can be considered as low or discountable risk (in green), medium risk (in yellow), and identified risks (in orange) for which mitigation strategies are needed. Moving from the present situation (left hand figure) to the preferred future condition (right hand figure) will help accelerate the MRE industry.

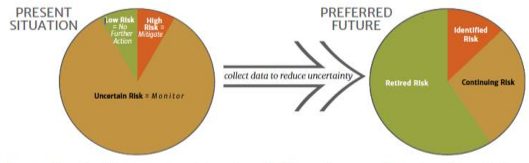

FIGURE 1. CATEGORIES OF RISK AND UNCERTAINTY REDUCTION PATHWAYS. THE RISK CATEGORIES CAN BE CONSIDERED AS LOW OR DISCOUNTABLE RISK (GREEN); MEDIUM RISK (YELLOW); AND IDENTIFIED RISKS (ORANGE) FOR WHICH MITIGATION STRATEGIES ARE NEEDED. MOVING FROM THE PRESENT SITUATION (LEFT) TO THE PREFERRED FUTURE CONDITION (RIGHT), THROUGH INCREASED DATA COLLECTION, WILL HELP ACCELERATE THE MRE INDUSTRY. (FIGURE COURTESY OF BRIAN POLAGYE AND ANDREA COPPING)

A CONSTRUCT FOR MOVING FORWARD IN THE FACE OF UNCERTAINTY

Reducing uncertainty around animal/device interactions is a critical step to ensuring that the MRE industry continues to grow. The path forward must continue to decrease uncertainty for priority interactions, while maintaining momentum with early deployments, pilot projects, and commercial arrays. Parsing the priority interactions for data collection to decrease uncertainty can be approached through three strategies (Table 2): those for which we already have techniques for monitoring; those that would benefit from strategic research investments; and those for which there are currently no adequate monitoring techniques and for which progress requires strategic research investments.

CONCLUSIONS

The MRE community must seek to better understand the potential outcomes of animal encounters with turbines, animal reactions to noise and EMF, and other possible deleterious outcomes, through data collection around single MRE devices and commercial arrays. Drawing from these data collection and research efforts, the development of a set of best practices will optimize the quantity of data to be collected around devices, provide insights into potential risks, and inform future mitigation strategies. The research community must continue to come together, along with regulators and developers, to share information, collaborate on strategic research projects, and define best practices, in order to accelerate the siting and permitting of

MRE devices and arrays. International efforts such as Annex IV, the 2016 State of the Science report, and the collaborations they spark, are important steps in this direction.

TABLE 2. EXAMPLES OF INTERACTIONS BETWEEN MARINE ANIMALS AND MARINE ENERGY DEVICES THAT CAN BE ADDRESSED THROUGH MONITORING AND STRATEGIC RESEARCH INVESTMENTS.

Strategies for Moving Forward	Example of Each Strategy
Monitor now - Interactions can be monitored now with existing instruments, platforms, technologies; significant measurement and data acquisition challenges remain.	Seals changing their swimming patterns around tidal arrays can be monitored using boat-based and aerial observations, and tags on seals, although there is a need for better tags and more automated observations.
Benefit from research -Interactions would benefit from targeted strategic research efforts in the near term, to reduce costs and the duration of monitoring.	Interactions of marine animals with tidal turbine blades; key research and development efforts are needed to improve instruments for observation and the ability to observe rare events in high flow environments.
Requires research - Interactions require upfront strategic research investments; no viable path for monitoring at this time.	Potential for large marine mammals to become entrapped in mooring lines from wave and floating tidal arrays; there are currently no appropriate models or data collection procedures available for monitoring around floating structures to determine if this interaction is a risk to the populations.

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