Retiring environmental risks of marine renewable energy devices: the "habitat change" case

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Abstract— **The installation, presence, operation, and decommissioning of marine renewable energy (MRE) devices inevitably alters the surrounding ocean habitats. These changes may include direct effects on the benthos from the installation or removal of foundations and anchors, changes in community composition on and near devices, artificial reef effects, and indirect effects such as alteration of the food web or facilitation of non-native, invasive species dispersal. Although there is no expectation that MRE devices affect marine environments differently than other anthropogenic ocean uses, regulators and stakeholders continue to have questions about potential negative impacts to species and habitats from development. Research studies and survey reports that inform our understanding of habitat changes related to MRE devices and associated equipment were compiled into an evidence base, sorted into categories of effects, and evaluated by a group of international experts to assess potential risk to habitats and biota from small numbers of MRE devices, as well as to identify knowledge gaps. These gaps were organized by category and divided up by relevance to consenting, research, or project development and monitoring responsibilities. Identifying these "known unknowns" allows for study design and collaboration from various perspectives to fill the knowledge gaps. Distribution of the evidence base and remaining uncertainties and knowledge gaps to the MRE community, coupled with new research, will help advance the MRE industry while resolving concerns about the potential risks of habitat change for small numbers of devices.**

Keywords— **Evidence base, environmental effects, habitat change, knowledge gap, marine renewable energy, risk retirement, stressor-receptor interaction.**

I. Introduction

Marine renewable energy (MRE) devices are attached to the seafloor by means of anchors, gravity foundations, or pilings, require transmission cables running along the seafloor, and may include mooring lines and components in the water column. The presence of these devices and associated equipment inevitably changes the surrounding benthic and pelagic habitats at various spatiotemporal scales [1],[2]. These changes may include:

- alterations to species communities (e.g., abundance, composition, distribution) in and on the seafloor around devices, anchors, and cables;
- scouring of soft sediments around foundations and anchors;
- colonization of devices and associated structures by biofouling species; or
- attraction of mobile invertebrates and fish as these structures act as artificial reefs and fish aggregating devices.

In addition, some indirect effects may be seen, such as areas with MRE devices acting as marine reserves over time if fishing activities are excluded, with cascading effects throughout the entire food web [3].

Although there is no indication that MRE devices affect marine habitats differently than other structures currently and historically placed in the ocean (e.g., navigation buoys, oil and gas installations, offshore wind turbines), regulators and stakeholders continue to have concerns. Some of these concerns directly affect the ability for project developers to obtain consents and licenses in a timely manner for deploying their devices. Others are related to the long-term and large-scale effects that large arrays might cause, as well as effects from decommissioning activities. These concerns can be attributed to the novelty of MRE devices and the inherent uncertainty of effects that lead to perceived risks.

Applying a risk retirement approach to consenting and licensing processes may ease these concerns. Risk retirement is the process whereby each potential low risk

This work was supported in part by the US Department of Energy EERE-Water Power Technologies Office to PNNL under Contract DE-AC05-76RL01830.

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needs not be thoroughly examined for every small MRE project [4]. Instead, developers, regulators, and advisors may benefit from the knowledge generated by already consented projects, related research studies, or lessons learned from analogous offshore industries, to consent future MRE projects. Risk retirement does not replace any existing regulatory process, nor does it necessarily remove the need for data collection related to MRE deployment; data may still be needed to verify findings, validate numerical models, and increase overall understanding [4].

To advance toward risk retirement for potential habitat changes engendered by the installation, operation, and/or removal of MRE devices, OES-Environmental[1] collected an evidence base of documents that describe the current status of knowledge for this stressor-receptor interaction (as defined in [5]). The evidence base was then introduced to a group of subject matter experts during an online workshop, where attendees worked together to identify remaining uncertainties and knowledge gaps, and to highlight recommendations for resolution of these issues. This paper presents the evidence base and the outcome of the workshop, as well as a potential path forward to address the remaining uncertainties and knowledge gaps.

II. Methods

A. Evidence base

The evidence base gathers documents such as peer-reviewed journal articles, conference papers, and field survey reports. References for documents were extracted from the 2016 and 2020 *State of the Science* reports ([6] and [2] respectively), keyword searches on the *Tethys* knowledge base (https://tethys.pnnl.gov; [7]) and Web of Science, and obtained from subject matter experts. Once reviewed and compiled into the evidence base, the documents were organized in five key categories: learning from surrogate industries (e.g., offshore wind, oil and gas extraction, power and communication cables); effects of installation and removal of MRE devices on benthos; changes in community composition on and near devices; artificial reef and fish aggregating effects; and indirect effects. This last category includes food web and trophic implications, as well as facilitation of the introduction and dispersal of non-native species.

B. Online workshop

Working with a selected group of international MRE developers, regulators, advisors, and subject matter experts including consultants and researchers, the evidence base was evaluated and gaps in knowledge were highlighted. The goal of the workshop was three-fold: 1) use the evidence base to determine data needs and monitoring requirements for working towards risk retirement of habitat change for consenting and licensing small (one to three devices) installations of MRE devices; 2) assess the status of risk retirement for habitat change overall as well as broken down in the five key categories; and 3) identify additional research needs that will increase the overall understanding of habitat change from MRE. The workshop included a presentation of the habitat change evidence base, followed by presentations of case studies from Oregon, United States (U.S.) and Scotland, United Kingdom (UK). Participants then discussed the evidence base to assess the ability to retire risk and highlight remaining uncertainties and knowledge gaps, aiming to reach consensus.

III. Results

A. Evidence base

The evidence base, available online on *Tethys* (https://tethys.pnnl.gov/habitat-change-evidence-base), provides results from field studies, modeling studies, and review discussions of the various potential habitat changes. As of March 2021, the evidence base comprises a total of 58 documents, of which 34 (≈ 59%) describe learning from surrogate industries, 13 (≈ 22%) describe effects of installation and removal on benthos, 38 (≈ 66%) describe changes in community composition on and near devices, 20 (≈ 34%) describe artificial reef effects, and 15 (≈ 26%) describe indirect effects (Fig. 1). Most of the documents in the evidence base refer to benthic and demersal organisms as they are more likely to see their habitats impacted by MRE devices than pelagic animals. However, several studies listed in the evidence base focus on pelagic organisms, especially when investigating artificial reef and fish aggregating effects, as well as food web and trophic implications.

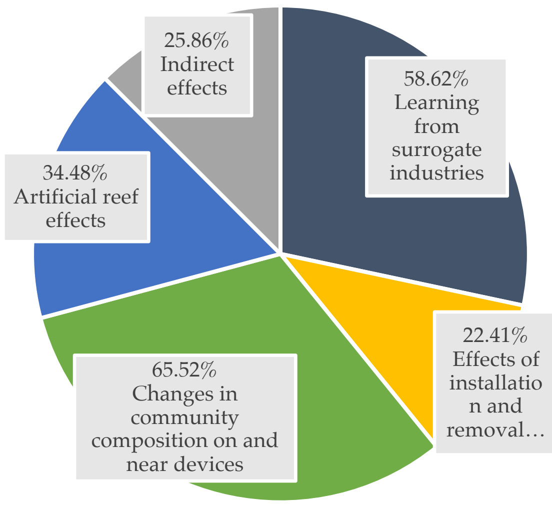

Fig. 1. Summary of the content of the habitat change evidence base. Note that the total percentage is greater than 100 percent since some documents cover multiple categories.

[1] OES-Environmental is a collaborative initiative of 16 nations under the International Energy Agency Oceans Energy Systems whose purpose is to understand MRE environmental effects that affect consenting.

Several documents are relevant to multiple categories, especially those related to surrogate industries (Fig. 2), and were counted in each category that they cover. The evidence base will be updated on an annual basis, adding all relevant articles and reports published since the previous update.

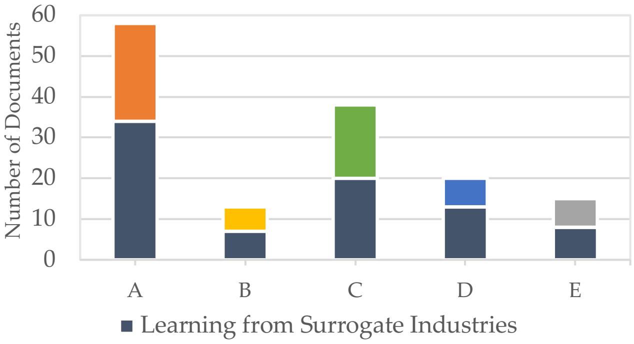

Fig. 2. Contribution of surrogate industries documents (proportions in dark blue) toward the different categories of habitat change in the evidence base (indicated by the other colors); A = total documents; B = effects of installation and removal on benthos; C = changes in community composition on and near devices; D = artificial reef effects; and E = indirect effects; colors correspond to those in Figure 1.

B. *Online workshop*

The online workshop was held on August 18th, 2020 and gathered 18 participants from eight countries (Canada, Chile, Denmark, France, Portugal, Sweden, UK, and U.S.).

In addition to sharing their point of view on the current status of the knowledge about habitat change and on the possibility for risk retirement, workshop participants also identified remaining uncertainties and knowledge gaps that would need to be addressed in order to move with confidence toward risk retirement for this stressor-receptor interaction. These gaps included: the absence of good surrogates for tidal environments, which are not well understood; the ideal timeframe for post-installation monitoring to understand long-term effects from installation and removal; the possibility that benthos recovery may be site-specific; and the need to evaluate large-scale impacts from artificial reefs on the ecosystem. These remaining uncertainties and knowledge gaps can be divided into two groups, based on whether they pertain to short-term efforts that will facilitate consenting and licensing (Table I), or long-term research that will help identify a future path toward deploying large arrays of devices and decommissioning (Table II).

TABLE I.
REMAINING UNCERTAINTIES AND KNOWLEDGE GAPS ABOUT HABITAT CHANGE, IDENTIFIED BY PARTICIPANTS DURING THE WORKSHOP, THAT WILL HELP WITH CONSENTING AND LICENSING OF MARINE RENEWABLE ENERGY DEVICES ONCE ADDRESSED.

Categories	Uncertainties & knowledge gaps
Learning from surrogate industries	Unlike for wave energy environments, good surrogates for tidal environments are still missing.
	Data transferability from surrogate industries is important, but transferred data need to be evaluated by experts to ensure relevance for a specific project.
Effects of installation and removal on benthos	Post-installation monitoring is typically not completed on long-enough timeframes to fully understand effects.
Community composition on or near devices	Identification of the appropriate level of site-specific study and monitoring is necessary.
	Established guidelines, standard mitigation, and frameworks for monitoring and characterizing risks are needed.
	Ongoing concerns about biofouling by non-native or invasive species remain.
Artificial reef effect	Remaining concerns about artificial reef effects may be better alleviated with post-installation monitoring.
	Uncertainties remain whether the artificial reef is representative of the existing surrounding community or an attraction of new species.
Habitat change overall	Wave and tidal environments need to be considered separately.
	Risks to habitats in tidal environments will be more difficult to retire due to current knowledge gaps and difficulties of monitoring.
	Lack of guidelines on appropriate timescales for studying effects, especially in anticipation of decommissioning.

TABLE II.
REMAINING UNCERTAINTIES AND KNOWLEDGE GAPS ABOUT HABITAT CHANGE, IDENTIFIED BY PARTICIPANTS DURING THE WORKSHOP, THAT WILL HELP WITH CONCERNS RELATED TO DEPLOYING LARGE ARRAYS OR DECOMMISSIONING, IF ADDRESSED THROUGH LONG-TERM RESEARCH.

Categories	Uncertainties & knowledge gaps
Effects of installation and removal on benthos	Effects from decommissioning or removal are less understood due to the nascent status of the industry, and will need to be carefully studied.
	Monitoring is still needed to support modeling and validation for impacts of arrays.
Community composition on or near devices	1-2 devices are not expected to have effects on the seabed, but it depends on how long they are in the water and the colonizing species.
	Monitoring is still needed to support modeling and validation for impacts of arrays.
	Lack of information whether effects on functional diversity are similar to those observed on taxonomic diversity.
	The mechanisms of colonization by non-native species are not sufficiently well understood, though some data exist. Examples in a variety of geographic regions are missing.
	Ongoing concerns about biofouling by non-native or invasive species remain.
Artificial reef effect	Uncertainties remain whether the artificial reef is representative of the existing surrounding community or an attraction of new species.
	The potential effects on fish stocks and aquaculture need to be evaluated over the long-term.
	Apprehending local flow conditions is necessary for understanding the artificial reef effect.
Habitat change overall	There is a lack of guidelines on appropriate timescales for studying effects, especially in anticipation of decommissioning.

Additionally, the workshop participants highlighted a series of recommendations that may help resolve some of these uncertainties and knowledge gaps at short- and long-term timescales. Recommendations that will help with consenting and licensing included:

- Rely on offshore wind as the most relevant surrogate industry for habitat change.
- Consider processes used by the oil and gas industry for consenting challenges and solutions, recognizing how different the scale and type of activities are from MRE.
- Categorize known effects as positive or negative, based on technologies and habitats.
- Concerns about artificial reef effects (e.g., displacement of fish from nearby natural reeds, or installation of non-native species) should not prevent device installation and may be alleviated with post-installation monitoring.
- A certain level of site-specific survey and monitoring may remain necessary, especially to localize rare or critical habitats.

Recommendations related to research on a longer timeframe included:

- Monitoring at small development scales can help improve knowledge on a greater diversity of habitats and prepare for understanding potential effects at the array scale.
- Studying potential effects on proper timescales is important, especially in anticipation of decommissioning.
- Supporting strategic research and monitoring for the deployment of arrays and decommissioning without putting the burden on developers.

IV. DISCUSSION

Examination of the documents in the evidence base, along with workshop discussions with the subject matter experts, confirmed that several environmental effects identified in [1], [2], and [6] related to the habitat change stressor-receptor interaction are well understood for small numbers of MRE devices, and could benefit from risk retirement to ease consenting and licensing requirements. These effects include changes in community composition on and near devices, direct effects from the installation of devices and associated equipment on the benthos, and the artificial reef and fish aggregating effects. With the acknowledgement of some caveats (see below), based on the experts' opinion, there is enough evidence gathered around MRE devices and/or surrogate industries to favor retiring these risks for new projects involving small numbers of devices. Rather than carrying out new, long, and costly surveys to investigate these risks ahead of consenting and licensing new MRE projects for small installations, regulators, advisors, and developers may benefit from referring to the documents compiled in the evidence base on *Tethys*. They may also rely upon information from other MRE projects and other relevant studies that may not be listed in the evidence base yet, and transfer the data and knowledge to their project. The monitoring datasets discoverability matrix, available on *Tethys* (https://tethys.pnnl.gov/monitoring-datasets-discoverability-matrix; [8]), is a complementary tool to the evidence base for finding such relevant studies.

Despite the near complete consensus from the subject matter experts on the conclusions above, they also agreed that significant knowledge gaps persist within each category of habitat change, that may prevent from fully retiring the risks when scaling up to arrays of MRE devices. Tables I and II list uncertainties identified by the workshop participants, and additional gaps and uncertainties can be found in [1], [2], [6], and [9]. Many of these uncertainties and knowledge gaps can be defined as "known unknowns" [1], which would allow for specific studies to be designed in order to collect the necessary data. This is especially the case for issues that can be studied with targeted and/or long-term surveys and monitoring (e.g., knowledge gaps related to durable effects from installation and/or removal). On the other hand, several uncertainties fall under the denomination of "unknown unknowns" [1]. Understanding how MRE devices may affect ecological processes, food webs, and functional diversity will require recognizing as yet unidentified relationships and cascading effects. Modeling studies may help in this process, yet modelers often lack the necessary field data for parameterization and validation of their models [10]. However, such ecosystem-wide effects are not expected at the scale of a single device or small array deployments (e.g., [3]). To tackle these knowledge gaps, long-term research projects under government funding would be more efficient than monitoring surveys by consultants and developers, as they would be able to investigate a variety of research questions rather than fulfilling licensing requirements.

There was also agreement that a certain level of data collection remains to resolve the lingering uncertainties and to better understand potential effects of habitat change. Some of this data collection may not be required for regulatory or consenting purposes and therefore would be captured under the umbrella of academic or governmental scientific research (Table II). However, one should not collect new data for the sole purpose of increasing the data coverage, running the risk of a "data-rich, information-poor" (DRIP, [11]) situation that will do little in answering the uncertainties and moving the industry forward. Identifying whether each uncertainty and knowledge gap in Table I and Table II would help with consenting and licensing requirements, or fall under long-term research will help the MRE community design surveys and studies that could effectively bring answers while staying away from DRIP situations. A key aspect in achieving this goal is to encourage and improve transparent dialogue between all relevant parties when new MRE projects are still in their infancy and throughout the life of a project [9].

One of the greatest remaining uncertainties is the appropriate timescale for identifying effects (Tables I and II). Benthic habitats and artificial reefs are dynamic systems where communities of sessile and motile organisms change over time until reaching a state of persistence, a certain level of equilibrium that allows for temporal variation [12], [13]. How long after installation or removal of MRE devices the persistence is reached may be site-specific, therefore requiring long-term, multiyear research studies to shed light on this aspect [2], [13]. At the Lysekil wave energy research site on the west coast of Sweden, a 12-year study showed the community dynamics on and around the foundations of wave energy converters over time [14], providing a much better picture than surveys carried out only a couple of years after device deployment [15], [16]. However, it would be unrealistic, and economically unbearable, to require 12 years of post-installation monitoring for each and every MRE project. Transparent dialog between regulators, advisors, developers, and scientists, and the transfer of data and knowledge from relevant studies, projects, and analogous industries [8] would help assess risk retirement at a project-level, identify site-specific necessities, and share the burden of data collection.

A possible path forward to address the knowledge gaps and uncertainties identified here would be to widely share this list (Tables I and II) with the MRE community members with interests in understanding and minimizing environmental effects related to habitat change. Regulators and their advisors would need to identify (and potentially rank) which of these uncertainties, especially those identified in Table I, are of greatest concern for their area(s) of jurisdiction, and share the information with developers, consultants, and researchers. Researchers then would be tasked to collaboratively collect, analyze, and publicly share data and results, ideally with financial support from governments.

V. Conclusion

Working with a group of subject matter experts from various backgrounds (developers, regulators, advisors, consultants, and researchers) allowed the identification of uncertainties and knowledge gaps that still stand in the way of understanding the impact of habitat change associated with the deployment of MRE devices.

Dissemination of the evidence base and knowledge gaps to the broader MRE community will help ease concerns related to the potential risks of habitat change and progress toward retirement of this stressor-receptor interaction for consenting small numbers of MRE devices.

Acknowledgement

We would like to thank all the participants of the online workshop, along with Dr. Sarah Henkel and Jennifer Fox who presented the Oregon and Scotland case studies, respectively. This research was possible due to the generous support of the U. S. Department of Energy EERE Water Power Technologies Office to Pacific Northwest National Laboratory under Contract DE-AC05-76RL01830, and the support of Ocean Energy Systems.

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