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Acoustic and Benthic Targeted Research Work Groups: Summary of Findings

Environmental Compliance Cost Assessment (ECCA) Project

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ABSTRACT -REQUIRED

Environmental compliance costs of Marine Energy (ME) projects collected through the Environmental Compliance Cost Assessment (ECCA) project show that acoustic and benthic studies are the most common and often most expensive environmental studies required for permitting and licensing an ME project in the U.S. The ECCA project team convened two inter-disciplinary Work Groups of subject matter experts, state and federal regulators, and ME industry members to discuss acoustic and benthic interactions with ME devices. These Work Groups participated in monthly calls and facilitated discussions to identify and prioritize critical research needs to increase the applicability of ME research funded by the federal, state, and local agencies; address the key information needs of regulatory agencies to improve the efficiency and effectiveness of the permitting process and compliance monitoring; and recommend best practices for licensing and permitting ME projects. The findings of the Work groups and the overlap of prioritized research projects with suggestions from the 2020 State of Science Report suggest that filling the technical scientific gaps is important to increase the efficiency and effectiveness of permitting ME projects in the U.S.

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ACRONYMS AND DEFINITIONS

Abbreviation	Definition
BOEM	Bureau of Ocean Energy Management
DOE	Department of Energy
ECCA	Environmental Compliance Cost Assessment project
EFH	Essential Fish Habitat
ESA	Endangered Species Act
HAPC	Habitat Areas of Particular Concern
ME	Marine Energy
MMPA	Marine Mammal Protection Act
MRE	Marine Renewable Energy
MSA	Marine Sanctuary Act
NMFS	National Marine Fisheries Service
SPI	Sediment Profile Imaging
USFWS	U.S. Fish and Wildlife Service

1.1. Background

1.2. Context and Project Background

The Marine Energy (ME) Environmental Compliance Cost Assessment (ECCA) project first began in 2017 and focused on collecting information from regulators and project developers related to permitting and licensing ME projects in the U.S. The work, funded by the Department of Energy (DOE) Water Power Technologies Office in association with Sandia National Laboratories, included collecting quantitative cost information for permitting and licensing ME projects from project developers, and qualitative information related to project developers and regulators experience in the permitting process, as well as research on permitting and licensing experiences of other industries (e.g., onshore wind and solar, offshore oil and gas, telecommunications cables)[1]. All of the information was synthesized to facilitate identification of strategies and actions that could increase the efficiency and effectiveness of permitting ME projects in the U.S.

The project team has already implemented one of the actions identified, "Targeted Research," by convening two Work Groups, each examining environmental interactions of ME devices; one between marine mammals and sound generated by ME projects (the Acoustics Work Group), and the other between benthic community response to the same ME projects, for example, tidal, river, or ocean current (the Benthic Work Group). These Work Groups identified and prioritized critical research needs to increase the applicability of ME research funded by federal, state, and local agencies; addressed the key information needs of regulatory agencies to improve the efficiency and effectiveness of the permitting process and compliance monitoring; and recommended best practices for licensing and permitting ME projects. The Acoustics and Benthic Work Groups used a similar process to guide discussion, as described below. This report explains the Acoustics and Benthic Work Groups discussions framework, summarizes discussions, and synthesizes key outcomes.

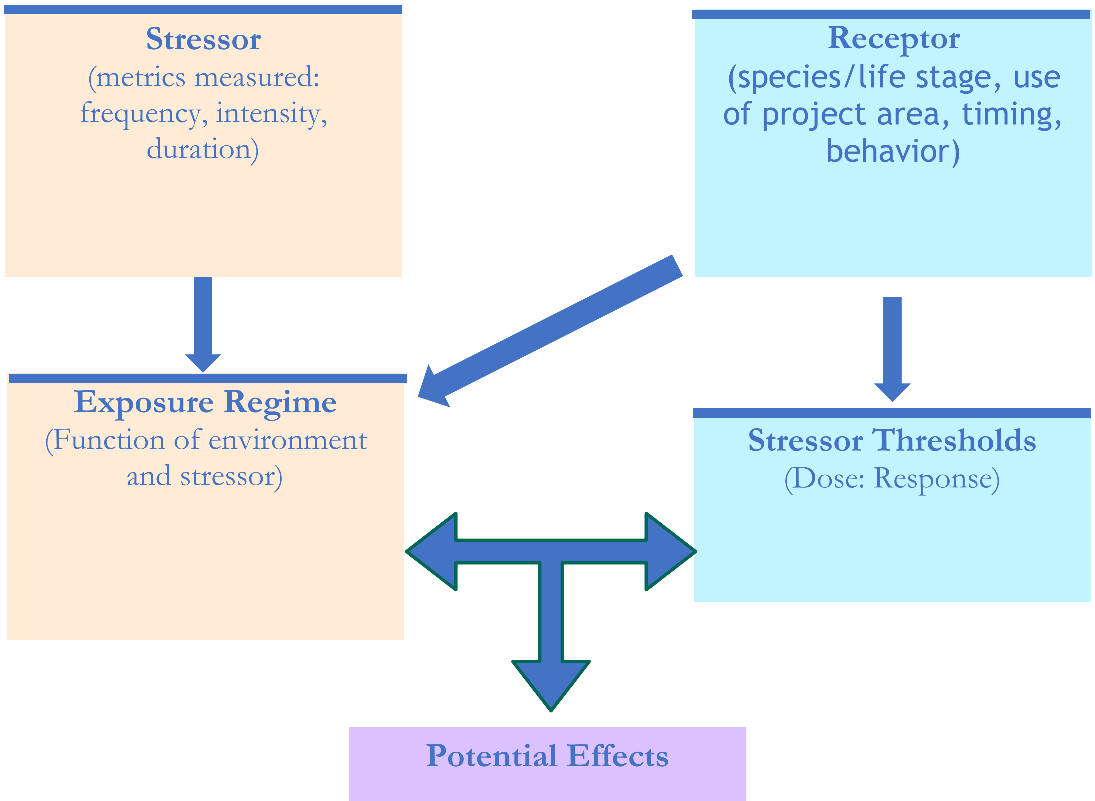
1.3. Conceptual Model Framework Approach

To guide both Work Group discussions, a conceptual model framework (Figure 1) and targeted questions were developed. Much of the information used for the framework and targeted questions was drawn from the *Annex IV 2016 State of the Science Report* (Copping et al., 2016). The framework examined interactions between stressors (e.g., acoustics, electromagnetic fields, static structures, and moving structures) and the receptors (e.g., marine mammals, fish, birds, benthos, sea turtles) to identify gaps in information that could be used later to prioritize research needs. These interactions depended on four distinct in-water project phases common to all ME projects, as described below:

Figure 1 Environmental Interaction Conceptual Model.

Boxes on the left (tan) describe information needs about stressors and stressor exposure regime (how the stressor interacts with the surrounding environment), boxes on the right (blue) describe information needs about receptors and thresholds of concern. The interaction between stressors and receptors (arrows) informs potential effects needed for assessing risk (purple box).

[1] Kramer, S., Jones, C., Klise, G., Roberts, J., West, A., Barr, Z. "Environmental Permitting and Compliance Cost Reduction Strategies for the MHK Industry: Lessons Learned from Other Industries," *J. Mar. Sci. Eng.* 8, no. 554 (2020).



- Phase 1: Site Characterization/Assessment
  - The in-water duration of this phase is typically on the order of days to weeks, depending on project scale and purpose (i.e., a test or commercial installation).
  - Site characterization and assessment typically includes studies on:
    - Geophysics/geohazards
    - Benthic habitat
    - Metocean
    - Acoustics
    - Fish/fisheries
    - Marine mammals
    - Seabirds
    - Cultural/archeological

The information from this phase informs project design (e.g., cable routes, anchor types and footprint) and provides environmental information needed to assess potential environmental impacts for permitting and consultation. The information may also be used for identifying data gaps or limitations in this process.

- Phase 2: Construction

The in-water duration of this phase is typically months, depending on project scale and type (e.g., current energy convertor, wave energy convertor).

Construction activities typically include cable lay, pile driving, anchors/mooring, and device deployment. However, the duration and sequencing of specific activities also depends on permitting requirements and mitigation, and other environmental factors (e.g., work windows).

- Phase 3: Operations and Maintenance
  - The in-water duration of this phase is typically years, depending on project scale and type.
  - Operations and maintenance activities depend on the device technology, permitting requirements and mitigation, and other environmental factors.
- Phase 4: Decommissioning
  - The in-water duration of this phase is either months or years, depending on project scale and type.
  - Decommissioning typically includes removal of marine renewable energy (MRE) devices, anchors/mooring, and subsea transmission cables. Project decommissioning is typically addressed at a conceptual level during permitting and actual phasing, and activities depend on the type of project, permitting requirements and mitigation, and other environmental factors.

1.4. Regulatory Context

An important first step for the Work Groups was to discuss the regulatory setting and needs relevant to sound and benthic communities during the permitting and licensing of an ME project, as described below.

1.4.1. Acoustics

The primary federal statutes relevant to regulating noise impacts to marine mammals, fish, and sea turtles of an ME project are the Federal Power Act, and the Endangered Species Act (ESA). The Marine Mammal Protection Act (MMPA) is also relevant for noise impacts to marine mammals. ESA protects all listed species and their designated critical habitat from effects to individuals and populations that may jeopardize the continued existence of a species or adversely affect designated critical habitat. If a listed species under ESA could possibly be harmed or harassed, an incidental take permit will be required. MMPA protects marine mammals from harassment and also allows "take" of a species in small numbers with no more than a "negligible impact," and no "unmitigable adverse impact." The National Marine Fisheries Service (NMFS) has regulatory authority for most marine mammals and fish for both the ESA and MMPA, while the U.S. Fish and Wildlife Service (USFWS) has regulatory authority for other marine mammal species (i.e., walrus, manatees, sea otters, and polar bears) and some fish, with shared jurisdiction over sea turtles.

The Federal Energy Regulatory Commission is the lead federal agency that issues the license under the Federal Power Act, after consulting with NMFS, USFWS and other federal and state agencies. If the applying project is in federal waters (on the Outer Continental Shelf) then the Bureau of Ocean Energy Management (BOEM) has lease authority based on the Outer Continental Shelf Lands Act. The U.S. Army Corp of Engineers and U.S. Coast Guard also have permitting authorities, and tribal and state statutes also require certain actions, consultations, consistency determinations, or permits be acquired by an ME applicant. All state and federal actions have responsibilities under the

National Environmental Policy Act to disclose potential impacts to stakeholders according to significance criteria.

1.4.2. Benthic

The primary federal statutes that provide a nexus to regulating impacts to the benthic[2] community in both state and federal waters are the Federal Power Act, ESA, and the Magnuson-Stevens Fishery Conservation and Management Act (MSA). ESA protects listed species and their designated critical habitat from exposure to the action or its environmental consequences. MSA creates a regulatory nexus between the benthic environment and fisheries in the form of Essential Fish Habitat (EFH)[3]. Both laws can require consultation with the National Marine Fisheries Service (NMFS), and some protected species fall under the USFWS, to determine the level of impact on the benthic community.

The Federal Energy Regulatory Commission is the lead federal agency that issues a license for ME projects under the Federal Power Act, after consulting with NMFS, USFWS, and other state and federal agencies. If the applying project is in federal waters (on the Outer Continental Shelf) then the Bureau of Ocean Energy Management (BOEM) has benthic protections described in the Outer Continental Shelf Lands Act. The U.S. Army Corp of Engineers and U.S. Coast Guard also have permitting authorities that interact with the seafloor. Tribal and state statutes also require certain actions, consultations, consistency determinations, or permits be acquired by an ME applicant. All state and federal actions have responsibilities under the National Environmental Policy Act to disclose potential impacts to stakeholders according to significance criteria.

2.1. Work Group Discussion

Both Work Group discussions regarding targeted research needs were organized to correspond to the conceptual model framework (Figure 1): Stressors and Exposure Regime; Receptors and Thresholds of Concern; and Potential Effects and Risk Assessment. The Work Groups also shared a set of references (Appendix A) to form the basis for discussion. The discussions are summarized below, and the recommendations for priorities for future research reflect agreement among the Work Group participants.

2.2. Acoustics Work Group

2.2.1. Acoustic Stressors and Exposure Regime

Establishing an understanding of the stressors and potential exposure and tipping points for physiological and/or behavior response of the receptor is the foundation of developing an informed and probabilistic assessment of acoustic risk. Information on the ability of different marine mammal species or species groups to detect and respond to specific sound frequencies is necessary to put stressors and potential behavioral responses into context. Acoustic field measurements need to be interpreted by sound frequency, magnitude, duration, exposure scenario, and nature (impulsive or

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[2] Benthic is a term that is incorporating the sediment type and features as well as the algae, plants and animals that are primarily associated with the marine or estuarine seafloor.
[3] EFH "… refers to waters and substrate necessary for fish to spawn, breed, feed, or grow to maturity." (Federal Register: 16 U.S.C. §§ 1801 et seq.)

continuous) in order to understand effects to different species. The NMFS 2018 Revised Technical Guidance (Appendix A) uses species/species-group specific thresholds and exceedances to evaluate acoustic effects (e.g., onset of permanent or temporary threshold shifts in hearing) on marine mammals, but sound levels that cause behavioral effects (e.g., auditory masking, feeding impairment) are less well understood.

Generally, there is a need to collect pre-project ambient sound to provide baseline data for analysis of sound changes during the construction, and operations and maintenance phases but depending on project location (i.e., a busy shipping lane) it may be more difficult to characterize sound produced by an ME device. There is a need to develop an approach to use pre-project ambient sound data to help understand acoustic effects of ME projects, and to identify device sound compared to background noise during deployment. The approach should address methods, sound surveying and monitoring metrics, and instrumentation used to measure ambient and ME device sound.

Sound propagation models can inform the anticipated sound exposure levels at various spatial scales from the source and identify uncertainties. However, there are numerous sound propagation models that vary with level of complexity and data requirements. The appropriateness of any specific model has not been examined using actual ME pre-project collected or monitoring data. Therefore, the Work Group suggested comparing results from the different available sound propagation models in a shallow water setting using actual ME data to evaluate model performance.

Additionally, there is a lack of long-term acoustic monitoring of tidal energy devices, in part because instruments to measure sound in a tidal setting would need to be stationery and flow noise could become problematic in certain areas such as river outlets; therefore, acoustic monitoring of tidal projects is typically conducted using short-term deployments of drifting hydrophones. Drifting systems are well developed but are not autonomous and must be deployed by personnel on boats so they do not provide long-term continuous monitoring of sound through a range of environmental conditions. Ideally, acoustic measurements can be taken continuously, recorded, and stored, with data downloaded periodically for analysis and reporting to the regulatory agencies responsible for the specific monitoring requirements, and thresholds developed during permitting and licensing. These data are needed to inform the permitting process by better understanding the impacts and thresholds before the permitting/licensing phase.

2.2.2. Marine Mammal Receptors and Thresholds

Understanding the environment and characteristics of sound propagation, the marine mammal species, timing and use of that area, and acoustic thresholds, are key to evaluating potential effects and developing monitoring plans for ME project acoustic effects on marine mammals. Monitoring protocols and tools have limitations or biases that need to be understood by stakeholders in the licensing process (regulators, developers, others) in order to manage expectations, as described above. An iterative and adaptive approach (Nowacek and Southall 2016) identifies areas of uncertainty or gaps in information, develops survey and monitoring plans to address information gaps, uses results to refine monitoring and develops mitigation strategies, and uses what has been learned to apply to future decision-making. An informed monitoring approach should provide data that reduces uncertainty for future ME developments.

The likely severity of impact (i.e., impulsive noise from impact pile driving is known to cause injury) needs to be considered during development of specific monitoring and surveying methods, and to identify thresholds of impact that need to be evaluated. It is unlikely that ME device noise will reach the level of injury for marine mammals. Thresholds are under development for behavioral response, which depends on several aspects such as spatial scale of project acoustic disturbance (e.g., exposure), proximity of animals to project sound, and use of the project area (e.g., temporary use of the project area [migration] versus residency). While information of acoustic effects on marine mammals is more robust, understanding acoustic effects on other species, such as fish, invertebrates, birds, and sea turtles has not been compiled in a meaningful way to develop a framework for considering acoustic effects.

2.2.3. Interactions and Assessing Risk

There is a need to understand how ME-generated sound may affect marine mammal behaviors, such as foraging, reproduction, and communication. There is still a great deal of uncertainty and variability about sound level thresholds and effects on behaviors, with most information based on intense human sound sources, such as impact pile driving and seismic. Using current thresholds based on impulsive vs. non-impulsive thresholds for evaluating effects on marine mammal hearing is not very meaningful when considering operational noise of ME projects. Yet, there are no data on acoustic levels from large ME arrays, so there is a need for sound propagation models to be applied and validated at the array-scale. Since specific acoustic thresholds for behavior change are unlikely to be identified in the immediate future, a more suitable approach will be to use a probability-based approach to assess risk. One approach to consider is the behavioral response data for different categories of sound (i.e., shipping, industrial, sonar, etc.) and developing probabilistic responses using the literature. The use of thresholds is a simplistic approach, as some animals are more tolerant of different types and levels of sound than others; therefore, an approach based on probability of response by different marine animals related to type of sound and aspects of exposure is warranted. Habituation may occur to continuous sounds, whereas infrequent sound may result in different behavioral responses. Project-specific monitoring can provide empirical data to inform and improve understanding of the finer scale aspects of spatial and temporal distribution of key species as well as behavioral responses and can also inform physiological measurements of stress levels in individual animals.

2.3. Benthic Work Group

2.3.1. Benthic Stressor and Exposure Regime

There is a need to understand the types of benthic resources, species or habitats that are likely to be affected at a specific location by an ME deployment through pre-project site assessment/characterization studies. These results may inform project layout and anchoring (e.g., that define the stressor) to minimize or avoid effects on specific resources such as soft corals or reef habitats. Studies can also inform post-installation monitoring programs.

Once the project footprint is developed and stressors are identified, models can be used to evaluate potential for effects of local scour and changes in flow dynamics that may affect the seabed. During permitting, clarifying what is important from the scientific perspective will inform a well-designed, scientifically based, cost-effective approach for site assessment that can be used to evaluate changes to benthos once the project is deployed. The spatial scale and extent of potential effects needs to be considered so that appropriate survey methods can be developed to detect impacts, and to develop appropriate mitigation measures for licenses and/or permits. Physical characteristics, habitats, and biotic communities will vary by site, therefore, aspects to consider when designing a survey protocol for a site are: 1) what level of change and resolution/scale is sufficient to detect change; 2) how will indirect impacts be assessed[4]; and 3) will the site be able to recover from the disturbance and, if so, how long might recovery take.

Studies have been conducted to better understand the spatial extent of benthic disturbance associated with ME project surrogates. For example, in a sensitive habitat off California, surveys were designed to quantify benthic impacts as far as 1,000 meters away from the disturbance. Another project conducted sampling at 500 meters and found impacts were only observed 20 meters from the disturbance site (Taylor et. al. 2014).

Recent studies on benthic disturbance from ME projects have concluded:

1. To capture variability and provide the appropriate level of monitoring, the project's location (e.g., depth, distance from shore), hydrography, type of sediment, and seasonality needs to be considered.
2. For cable installations, biological communities near the disturbance caused by cable laying were similar to the community in undisturbed areas of the benthos. In order to determine impacts, surveys occurred pre- and post-installation to assess potential changes in the benthic communities associated with the cable route.
3. Some animals can detect and respond to electromagnetic fields (EMF), but the impacts are localized and animals can become habituated to EMF.

2.3.2. Benthic Receptors and Thresholds of Concern

Important benthic receptors include a subset of Essential Fish Habitat designated as "Habitat Areas of Particular Concern (HAPCs)" that include rocky reefs, estuaries, kelp, and seagrasses. HAPCs provide important ecological functions or are especially vulnerable to degradation. Soft bottom substrates are assumed to be affected by ME structures (e.g., anchors), or transmission cables. There are many approaches, protocols and guidance for benthic monitoring at a project level for offshore wind energy (e.g., BOEM's offshore wind benthic survey guidance). Although the guidance can be helpful in developing survey designs, there are newer technologies that provide an integrated survey approach that can be used to evaluate benthic conditions and assemblages (both epibenthic and infauna)[5]. For example, the integrated Sediment Profile Imaging (SPI) instrumentation and plan view technology (Revelas et al. 2020) provides a large number of samples over a wide spatial scale in a short time; findings from the SPI survey can be supplemented with grab samples, which take longer to gather and analyze but have historic and global established metrics for measuring site condition. Survey design can be based on geophysical data from side-scan sonars or multibeam echosounders to ensure all habitat types are evaluated at a project site. Towed cameras or ROV surveys are more expensive and are done to estimate the percentage cover of species, or by types of substrate for epibenthic organisms. AUVs are starting to be used, especially in waters deeper than 200 meters and in areas with low relief. BOEM has guidance (BOEM 2019) for benthic site characterization for

[4] Indirect impacts include impacts to the mouth of an estuary if a project is upstream or impacts from the project area becoming de facto marine protected area because certain types of fishing will not be possible resulting in a change to community structure.

[5] Animals and ecology of the sediments on the ocean floor or river or lake beds.

offshore wind project leasing and permitting, as well as for oil and gas development, which may provide a starting point[6] for developing an approach for some types of ME projects.

The ME industry has not used models often in permitting projects because projects to date have been small scale, where one or a few devices are deployed and changes to resources and the environment is anticipated to be small. However, impact models will be more pertinent as projects scale up to larger arrays. Regardless, physical models may be helpful in the regulatory context to understand the potential area of impact, the potential level of impact, and can be used to inform monitoring survey design. Models could also be used early in the regulatory process for determining impact levels and for scoping documents. Once potential effects on physical characteristics are modelled and predicted, habitat suitability models can be used to evaluate effects of physical change on receptors (e.g., species, assemblages, or communities) and evaluate risk, which can enable regulators and developers to make changes to project design or siting, and guide monitoring and adaptive management.

Models that evaluate physical changes to the environment from ME operations can be quite useful and are based on well-respected and verified algorithms where the influence of ME devices on the physical conditions are simulated. These models work as virtual laboratories and can be a cost-effective way to predict the cascading effects of site changes a priori (e.g., how changes in flow patterns affect the seabed) and potentially define the impact area. Linking models of physical changes to biological effects can directly address permitting questions. Physical models effectiveness will depend on information from baseline site characterization information.

Post deployment data can help verify the models' accuracies, but these data are as yet unavailable. There are different physical models that can be used to simulate changes in sediment transport and subsequent changes in benthic conditions, from within a meter of the device (near-field) to up to kilometers away (far-field). Models require information on depth, bathymetry, location of hard bottom vs. soft bottom substrate, grain size, and seasonal changes in boundary conditions (e.g., tidal, wave, river flow, wind). Model uncertainty and confidence need to be understood to properly apply the model and understand the context of the results especially with diverse audiences of technical experts, members of the public, and other stakeholders.

It is important to establish the specific metrics characterizing the benthic community of concern (e.g., diversity, specific classes of species) and which impacts should be mitigated. Habitat suitability models can be used to make assumptions about the distribution of benthic habitats and species, and the environmental variables driving this distribution. Habitat suitability models link specific habitat attributes (e.g., sediment grain size, oxygen level, depth, temperature, water clarity) to benthic species or assemblages. A habitat suitability model can then be used to predict changes to benthic species of concern based upon project-specific physical and habitat changes expected, modelled, or measured at a site. Habitat suitability models often report species occurrences, but potential changes in species relative abundance may be more important to regulators. Abundance might be particularly important for species of concern, or managed species, but accurately detecting a change from presence to absence may suffice at the species level to understand potential effects on tropic interactions food

[6] Offshore wind projects, particularly foundation mounted turbines, likely have greater seafloor disturbance than MHK projects. Oil and gas development, more heavily reliant on seafloor infrastructure, has to consider potential effects of drill muds and accidental spills. These other industries must address a wider range of risks to benthic habitats than MHK projects.

webs. In the future, biological and/or ecological investigations should consider trophic interactions; for example, if a predator species prefers one prey species over another, it may be important to study how changes (e.g., from a device or devices in the water) to those prey species might impact the food web of predatory species that are managed or of special concern. Habitat suitability models integrated with physical models should be tested in a real project setting to provide estimated levels of change to both the physical environment and biological communities, then validated to ensure their accuracy and predictive value. These models are widely applicable to different sites, habitats, and communities with appropriate testing and validation.

2.3.3. Interactions and Risk Assessment

Benthic macrofauna[7] have historically been monitored for a wide range of offshore projects and provides a foundation for understanding benthic community receptors; however, what is not clear is the consequence and translation of physical changes to measurable impact on EFH or ecosystem functions. For example, if a change in grain size does not affect the species assemblage, does it matter? In particular, small projects are unlikely to have much effect on benthic habitat or communities, but for larger commercial scale projects, project-specific monitoring of the sediment characteristics and the benthic fauna, both within a project area of potential effect and ideally farther away (e.g., as is standard practice using a reference site that can reflect natural variability), should be done to determine the magnitude of change, what the impact of that change is, and if that change or impact is ecologically significant. It is also important during study plan design to establish the level of change and what may be ecologically significant. For example, it could be that thresholds for change are statistically significant but does this translate to long-term or even permanent impacts to a species population trend or impacts to other species in the food web. While physical models can estimate the spatial and temporal changes expected from a project, those models need to be validated with data obtained by a project, particularly as arrays are developed. Regarding risks, regional location is an important factor. For instance, European experiences have shown that ME devices have not provided new habitat for non-native species while some oil and gas platforms in southern California were covered almost completely by a non-native bryozoan almost 40 years after construction (Viola et. al. 2017). Adaptive management approaches should be used to address impacts from ME devices, especially impacts on sensitive species or habitats.

The "triad approach," an EPA approach used for water quality/toxicity monitoring, involves local benthic monitoring to assess any change or response to a stressor, and compares the local average response and/or change to a regional average to evaluate effects to the benthic community. A challenge of the triad approach is that it has been historically used for determining change related to toxicity; however, understanding physical changes related to marine renewable energy is much more limited. Before this approach is carried out, a team needs to define how an approach centered around the release of chemicals and metals (pollution and toxicity) can be adjusted to evaluate sediment and nutrient changes. The issue is how to design a survey to detect meaningful and measurable change and design an adaptive management approach to mitigate for changes. The "triad approach," or a similar approach, should be considered for ME projects.

From a regulatory standpoint, there is a need to determine the acceptable extent of change and appropriate methods to measure that change. Additionally, cumulative effects are an important

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[7] Macrofauna are estuarine and marine organisms visible to the naked eye (> 0.5 mm) that commonly inhabit the benthos, where they can be found buried in sediment or attached to a fixed substrate (rocks, reefs, rhodolith, etc.) DOI: https://doi.org/10.1007/978-94-017-8801-4_261.

regulatory consideration for ME projects. If there are multiple disturbances to coastal or offshore habitats, it is possible that even a small ME project may lead to relatively large effects to benthos. The information needed for consultation under section 7 of the ESA, for EFH consultation, and other laws and/or regulations may also differ, which may affect the monitoring approach, the type of information to be collected, and make it difficult to use a standard suite of metrics. For example, NMFS is the agency responsible for approving the survey design to collect data used to determine if and when an EFH threshold is crossed. However, multiple agencies are responsible for managing fish habitat and may interpret the threshold for a reduction in quality or quantity of benthic habitat differently. This is a learning process for the regulators and as more projects are permitted, some of these questions will be answered, providing regulators with a basis for decision-making (e.g., if early project monitoring indicates that the biological community does not change significantly with changes to sediment grain size, there may be fewer project-specific concerns and needs for monitoring for future projects). The Work Group expressed uncertainty about the applicability of lessons learned and transferability of findings from East Coast projects to West Coast projects. Generally, the physical and ecological settings are very different between the East and West Coast sometimes requiring substantially different risk considerations. As such, the transferability of findings from any two disparate sites brings higher levels of uncertainty (even sites in the same region). The first step for any project should be to gather existing data and talk with the regulators to define what needs to be known before any metrics are defined.

3.1. Research Priorities

3.1.1. Research Topics

Based on the Work Groups discussions, the Project Team developed a Prioritization Matrix that outlined research topics and recommendations developed through the Work Group process and research topics recommended in the corresponding *2020 State of the Science Report* chapter (Hemery 2020; Polagye and Bassett 2020). Each Work Group member ranked each set of research topics (0-3, 0 = does not satisfy, 1 = minimally satisfies, 2 = somewhat satisfies, 3= fully satisfies) on the following criteria and sub-criteria:

- Stressor Information
    - Identifies information needs for site assessment
    - Helps develop survey objectives and methods
    - Defines potential exposure level (spatial, temporal)
- Receptor Information
    - Identifies appropriate receptor metrics (+/- abundance communities, specific taxa, life stage, timing, variability)
    - Helps develop survey objectives and methods
    - Identifies thresholds of change
- Interaction Significance
    - Probability/risk of interaction resulting in an effect
    - Identifies thresholds of significance

Members were also encouraged to add and rank additional topics not included by the Project Team. Work Group member responses are provided in Appendix B. The Work Group members then discussed the regional applicability, potential funders (private and public entities), and challenges to implement the research priorities. Each topic was subdivided into three categories that focused on;

a) stressor information, b) receptor information, and c) interaction significance. Within the stressor and receptor categories there were three key criteria questions, while the interaction category had two key criteria questions.

3.1.2. Acoustics Work Group

The topic rankings are based on scoring by the Acoustic Work Group members (Table 1). The scores in the table below represent the overall average score for a given topic (average of the answer to all eight key criteria questions). Therefore, the maximum and minimum scores remain 3 and 0 respectively. It is important to note that research topics are ordered by the priority score established by the Work Group and do not necessarily represent the sequence for implementing research topics.

Table 1 Summary Ranking for Acoustic Work Group Priorities

Priorities sorted in descending order of priority score for Work Group recommended topics and for *2020 State of the Science Report* recommended topics.

Work Group Recommended Topics	
Topic	Score
General acoustic interaction framework for marine mammals	2.94
Develop framework or approach for other species, e.g., fish, invertebrates, birds, and sea turtles	2.23
Approach for using ambient monitoring information to inform acoustic effects	2.19
Instrumentation for long term (24/7) tidal turbine stationary monitoring (addresses flow noise)	2.19
Application and testing/validation of sound spreading models, especially in regard to understanding array effects	1.60
Model comparison with real ME data model validation for arrays	1.58
2020 State of the Science Recommended Topics	
Establish a framework for evaluating animal behavior consequences of ME noise	2.29
Approaches to differentiate between ambient and device noise	1.85

The Acoustic Work Group participants identified potential funding agencies and challenges to implement each of the priorities. Generally, the research topics could be funded by the relevant regulatory agencies or other agencies that have existing programs funding similar research. The Project Team estimated the potential cost to fund the research priority and anticipated deliverables, with input from the Work Group. The *2020 State of the Science Report* recommendations, "Approaches to differentiate between ambient and device noise," and "Establish a framework for evaluating animal behavior consequences of ME noise," were closely aligned with the Work Group recommendations, "General acoustic interaction framework,'" and "Instrumentation for long-term

(24/7) tidal turbine stationary monitoring (addresses flow noise)" are combined in the prioritizations shared below.

3.1.2.1. Research Topic #1: Probabilistic Risk Assessment Framework for Evaluating Marine Animal Behavior Consequences of ME Noise

The Work Group discussed that the effects of MRE development on the marine acoustical environment, in particular for marine mammals, is understood with respect to thresholds for injury, but far less understood with respect to severity of acoustic effects on behavior, which was also identified in the *2020 State of the Science Report*. The regulatory setting for acoustic effects includes 1) ESA, 2) MMPA, 3) Magnuson-Stevens Fishery Conservation and Management Act, 4) MSA, 5) Marine Protected Areas, and other state regulations in territorial seas. As data are becoming available, sound levels from ME devices appear to be below levels of marine mammal injury, although they may be at levels where harassment or behavioral effects may occur. Methodologies have been developed to ensure consistency and accuracy in the measurement and analysis of acoustical emissions from marine energy converters (IEC TC-114 2019). However, the context with respect to evaluating acoustic effects (stressors) on marine mammals (receptors) is less well-defined for some cases: levels of acoustic injury are well-defined for marine mammals (NOAA 2018), but levels for behavioral effects specific thresholds, and potential level of behavioral affect, are less well-defined particularly in terms of relevant ecological and spatio-temporal contexts beyond simply received sound levels.

A probabilistic risk assessment framework should be developed to provide a clear path for determining needs for ambient pre-project acoustic monitoring, compliance sound monitoring, and for any additional marine mammal surveys. The framework should put project-level acoustic effects and concerns into context, including cumulative effects for migratory species.

The framework should:

- Identify for a site and/or project the ecological concerns, in particular the species of concern and the species site-specific uses of the project area, including spatial, temporal, and spectral (frequency) aspects of interaction with development and operations, and separately taking into account relevant biological, life-history, and population parameters of key species.
- Develop a science-based, cost-effective approach for identifying risks and developing studies and adaptive management.
- Provide developers and regulators with an understanding and increased certainty about the process for determining monitoring needs for a project.

Regional Applicability: Nationally applicable with additional details on the interaction provided on a regional basis

Anticipated Deliverable and Estimated Cost:

- Framework Approach: $500,000
- Use case for developed Framework: $300,000
- Modified Framework published: $200,000
- **Total:** $1,000,000

Challenges to Implement: For the framework to be effective and nationally applicable, there is a need to develop metrics for understanding consequences of ME noise and behavioral effects. Some effects, such as masking, would be nationally applicable, but other behavioral effects may be species- and site- or region- specific and the framework needs to accommodate those nuances. An effective framework would require coordination with multiple agencies at the federal and state levels to understand regulatory needs.

3.1.2.2. Research Topic #2: Develop Analytical Approach to Differentiate Between Background and Device Noise and Instrumentation for long-term (24/7) tidal turbine stationary monitoring (to address flow noise).

The Work Group discussed that the sound produced by tidal turbines is best monitored with drifting hydrophones to minimize flow noise; however, drifting hydrophones have to be deployed by vessel with limited windows of time monitoring can take place. This method does not allow for continuous acoustic monitoring over a range of environmental conditions. To better characterize the sound produced by tidal devices, sound data needs to be recorded for a longer duration, spanning day/night, tidal and seasonal periods to capture ambient noise variation. This would include modifications to acoustic instrumentation to decrease flow noise, as well as analytical approaches to filter flow noise to improve differentiation between background and device noise. This was also identified as a research need in the *2020 State of the Science Report.*

Regional Applicability: Nationally

Anticipated Deliverables and Estimated Cost:

- Develop analysis approach to differentiate background from device noise framework: $500,000
- Field test analysis approach and modify: $500,000
- **Total:** $1,000,000

Challenges to Implement: Early stages to develop the approaches will require verifying information collected in a controlled environment to pinpoint sound source. Methods such as wave tanks contain ambient noise that create difficulties in pinpointing the sound source.

3.1.2.3. Research Topic #3: Developing A Risk Assessment Framework or Approach for Other Species (e.g. fish, invertebrates, birds, and sea turtles)

Similar to Priority 1, the Work Group recognized that the effects of MRE development on the marine acoustical environment is synthesized and better understood for marine mammals than it is for fish, invertebrates, birds and sea turtles, especially with respect to thresholds for injury and harassment. The regulatory setting for acoustic effects includes 1) ESA, 2) MSA, and 3) state regulations. As data are becoming available, sound pressure levels from ME devices appear to be below levels of marine mammal injury, although they may be at levels where harassment or behavioral effects may occur; for fish, invertebrates, birds and sea turtles, it is often assumed that levels affecting them are higher than levels affecting marine mammals. The context with respect to evaluating acoustic effects, stressors including particle motion on fish, invertebrates, birds and sea turtles, (receptors)[8] is far less well-defined than for marine mammals.

Similar to Priority 1, a probabilistic risk assessment framework should be developed to provide a clear path for determining needs for ambient pre-project acoustic monitoring, compliance sound monitoring, and for any additional surveys for receptors. The framework should put project-level acoustic effects and concerns into context, including cumulative effects for migratory species.

The framework should:

- Identify for a site and/or project the ecological concerns, in particular the species of concern and the species site-specific uses of the project area.
- Develop a science-based, cost-effective approach for identifying risks and developing studies and adaptive management.
- Provide developers and regulators with an understanding and increased certainty about the process for determining monitoring needs for a project.

Regional Applicability: Uncertain due to lack of existing information.

Anticipated Deliverables and Estimated Cost:

- Synthesis of literature to develop thresholds and metrics, and identify gaps: $400,000
- Using approach developed for marine mammals (Research Topic #1) to develop framework: $400,000
- Publish framework: $200,000
- **Total:** $1,000,000

Challenges to Implement: There is a considerable lack of information on the potential effects and importance of acoustics on injury or behavioral functions for many species other than marine mammals. Available information would need to be collected through extensive literature synthesis, and data gap analysis would need to be performed to inform the framework or approach, as well as which studies could be conducted to address data gaps.

3.1.2.4. Research Topic #4: Procedure for Using Ambient Pre-Project Acoustic Monitoring Information to Inform Acoustic Effects

The Work Group discussed that most ME projects have been required to collect ambient noise pre- and during project deployment. However, there is no guidance for collecting this data, as well as no standardized process or approach for how to use the pre-project acoustic information to inform project effects. Because acoustic data collection and analysis is costly and requires a high level of expertise, the information should be collected and made useful for informing the regulatory process. Building on IEC TC 114[9], guidance on how to collect this data, and an approach for using ambient pre-project acoustic data as context for project permitting and post-project sound monitoring needs to be developed. This will provide certainty to developers on the acoustic monitoring design and

[8] While particle motion has been identified as a relevant stressor for fish and invertebrates, there is no framework developed for making measurements or regulatory threshold criteria.

[9] [IEC] International Electrotechnical Commission. 2019. Marine Energy: Wave, Tidal and Other Water Current Converters: Part 40: Acoustic Characterization of Marine Energy Converters. Edition 1.0. IEC TS 62600-40.

value of ambient pre-project acoustic data collection during the permitting and licensing process and make those data useful for characterizing the acoustic characteristics of ME projects.

Regional Applicability: Nationally

Anticipated Deliverables and Estimated Cost:

- Approach for taking and using pre-project acoustic information in permitting decisions - $400,000
- Test and evaluate approach in a regulatory setting: $200,000
- Publish approach: $150,000

- **Total:** $750,000

Challenges to Implement: An effective procedure would require coordination with multiple agencies at the federal and state levels to understand regulatory needs.

3.1.2.5. Research Topic #5): Sound Propagation Model Comparison with Real ME Data to Evaluate Arrays

The Work Group discussed that numerous sound propagation models relevant to anticipating exposure levels and spatial extent and identifying uncertainties have not been compared or validated using actual ME data. This comparison can help clarify which models are most useful for permitting and determine the models best suited to evaluate the cumulative acoustic effects of an ME array.

Regional Applicability: Nationally

Anticipated Deliverables and Estimated Cost: $250,000

Challenges to Implement: The availability of actual ME data may be dependent on the number of current projects deployed and their ability or regulatory requirement to collect the relevant information for the comparison. Understanding the variability of sounds produced by different ME devices would be valuable in this type of study, but this information isn't currently available.

3.1.2.6. Additional Research Topic Considerations

In addition to the Research Topics above, some Work Group members provided additional topics to be considered. These topics, listed below, were not discussed or ranked by the Work Group.

1) Variability of sound produced by various ME designs.

There are multiple ME device designs for wave or tidal environments[10]. Different device design types may produce different sound profiles, and measurements from one device design may not be representative of other device design types. Understanding the nuance in sound profile of device design may help inform permitting of ME devices.

[10] Examples of wave device designs: http://www.emec.org.uk/marine-energy/wave-devices/; examples of tidal device designs: http://www.emec.org.uk/marine-energy/tidal-devices/

2) Comparing a few devices and full commercial arrays to background ambient sound levels

There may be different considerations needed between a few devices and a full commercial array for both the sound source itself and/or how receptors perceive the source(s).

3.2. Benthic Work Group

The topic rankings are based on scoring by the Benthic Work Group members (Table 2). The scores in the table below represent the overall average score for a given topic (average of the answer to all eight key criteria questions). Therefore, the maximum and minimum scores remain 3 and 0 respectively. It is important to note that research topics are ordered by the priority score established by the Work Group, and do not necessarily represent the sequence for implementing research topics.

Table 2 Summary Ranking for Benthic Work Group Priorities.
Priorities sorted in descending order of priority score for Work Group recommended topics and for *2020 State of the Science Report* recommended topics.

Work Group Recommended Topics	
Topic	Total Score
Development of species probability maps (Habitat Suitability models) linkages to physical models	2.21
General benthic interactions decision framework	2.14
Evaluate and validate physical models as a tool for informing potential physical effects to habitat (important for moving from single devices to commercial arrays)	1.89
2020 State of the Science Report Recommended Topics	
Identified justified and acceptable thresholds for changes in benthic environments	2.22
Use modeling approaches to define habitat suitability and connectedness during the siting process	2.16
Define relevant spatial and temporal scales for permitting and monitoring surveys	2.13
Identify the cumulative effects of MRE devices and other activities occurring in the same area, especially relative to the artificial reef, reserve, and steppingstone effects	1.87

The Benthic Work Group participants identified potential funding agencies and challenges to implement each of the priorities. Generally, the research topics could be funded by the relevant regulatory agencies or other agencies that have existing programs funding similar research. The Project Team estimated the potential cost range to fund the research priority for anticipated deliverables, with input from the Work Group. The *2020 State of the Science Report* recommendations "Identified justified and acceptable thresholds for changes in benthic environments," "Define relevant spatial and temporal scales for permitting and monitoring surveys," and "Identify the cumulative effects of MRE devices and other activities occurring in the same area, especially relative to the artificial reef, reserve, and steppingstone effects," research topics are included in the "General benthic interactions decision framework," as described in the prioritization section below.

Additionally, the "Use modeling approaches to define habitat suitability and connectedness during the siting process," and "Development of species probability maps (habitat suitability models) linkages to physical models," research topics closely aligned and are combined in the prioritization section below.

3.2.1.1. Research Topic #1: Linking Species Habitat Suitability Models to Physical Oceanographic Models to Inform Project Effects, Monitoring Needs, and Permitting

The Work Group discussed linking species probability models with physical oceanographic models that predict project effects to habitat in order to help inform analysis of potential interactions and enhance collaboration between project developers and regulators during the permitting process. This research topic was also identified in the *2020 State of the Science Report*. The information obtained by these models helps link the physical factors that most affect species presence/absence, especially for species of concern and sensitive habitats, to the physical effects of the project. While regulators may only need to know if a species is present or absent, this information is important for developers to help design site-specific surveys, inform short-term construction effects, and long-term operation and maintenance phases of a project. The linkage of the physical oceanographic and habitat suitability models is inherently related to the validation of the physical oceanographic modeling outlined in Research Topic #3.

Regional Applicability: Nationally, but where regional habitat suitability models already exist

Anticipated Deliverables and Estimated Cost:

- Linkage of appropriate species model and numerical oceanographic model (e.g., Regional Ocean Modeling System; ROMS) for a test region $250,000
- Application of linked species and numerical model, revision, and publication $450,000
- **Total:** $700,000

Challenges to Implement: This would not fund new research but instead use existing information on habitat suitability and existing oceanographic modeling. The challenges to implement are 1) identification of specific regions where existing data can be synthesized to develop habitat suitability model case studies, such as in coastal waters of the Pacific off northern California, Oregon, and Washington, 2) habitat suitability models may be too spatially coarse for regulatory needs, depending on habitat types, 3) limited confidence in model results without validation alongside an ME deployment, and 4) needs agency participation to make sure the information is useful to the permitting process. While all of these challenges do not need to be addressed simultaneously to achieve project success, they present challenges that potential researchers would face.

3.2.1.2. Research Topic #2: Benthic Interactions Risk Assessment Framework

The Benthic Work Group discussed that the effects of MRE stressors on benthos are generally understood; however, effects are likely to be highly site-specific, lack specific metrics and thresholds, and have uncertainty with respect to the scale, level, and ability of receptors to recover from effects. The regulatory setting for benthic effects includes EFH and ESA, which provide guidance on certain types of habitats or species of concern, with input from multiple federal, state, and tribal entities. However, species, habitats, and regulatory jurisdictions vary with water depth, distance offshore, and regionally, with no national framework for guiding decisions on what organisms need to be monitored, the methods and instrumentation needed to monitor for effects, the duration, frequency, and spatial intensity of surveys, or thresholds of concern for project effects. A framework should be developed to help guide regulators through the decision-making process for evaluating effects to benthic species and habitats in the permitting and licensing process.

The framework should be a structured, decision-making collaborative process with regulators to satisfy their diverse needs and be implementable across a broad variety of sites and ME project scales and types, by:

- Identifying the ecological concerns, objectives, and metrics of concern for a site
- Developing science-based, cost-effective survey designs that satisfy regulatory needs for evaluating effects at a range of scales
- Referencing and connecting to regulations in order to provide developers and regulators with an understanding and increased certainty about the regulatory process

This framework should also address the following recommendations from the *2020 State of the Science Report*:

1) Define relevant spatial and temporal scales for permitting and monitoring surveys
2) Identify and justify acceptable thresholds for changes in benthic environments
3) Identify the cumulative effects of MRE devices and other activities occurring in the same area, especially relative to the artificial reef, reserve, and steppingstone effects.

This effort would include establishing the framework and applying it to a handful of case studies.

Regional Applicability: Nationally, with additional details provided on a project-level basis

Anticipated Deliverables and Estimated Cost:

- Framework approach $500,000
- Use case for framework $300,000
- Modify and publish framework $200,000
- **Total:** $1,000,000

Challenges to Implement: The framework would need to be developed using case studies and tested on actual ME projects, therefore, development of the framework would be iterative and improved as it gets used.

3.2.1.3. Research Topic #3: Evaluate and Validate Physical Oceanographic Models as a Tool for Informing Potential Physical Effects to Habitat

Oceanographic models are useful for evaluating changes in the physical environment; however, the usefulness and uncertainty in applying those models to predict the processes important to habitat change must be defined for regulators. Results of the models should be validated with site monitoring of the processes and habitats of interest. This includes collection of a series of key physical oceanographic parameters where and when possible, in the absence and presence of ME devices. The first step is to validate the predictive capabilities of the baseline physical oceanographic model. However, since full size deployments of ME devices have been limited, there is little to no field and/or site monitoring data to validate the incorporation of ME devices into the physical oceanographic models. When and where possible, monitoring data around field deployed devices should be targeted. In the absence of site data, ME-friendly models have been validated against controlled tests in tanks and flumes. With validation, baseline physical oceanographic models can be used to predict, a priori, the anticipated changes an ME project has on the processes that may affect the local habitat.

Regional Applicability: Nationally, with additional details provided on a project-level basis. A physical oceanographic modeling framework that is successfully validated at a site would provide a guide for application at any site where applicable data are available.

Anticipated Deliverables and Estimated Cost:

- Assessment of model performance in evaluating baseline spatial and temporal changes $200,000
- Development of model validation and uncertainty assessment guidance and publication $200,000
- **Total:** $400,000

Challenges to Implement: Models require adequate regional data in order to be reliably developed and validated, which may be a limitation for some regions depending on data availability. Physical oceanographic models can be useful to regulators and developers, but standardized data evaluated in a consistent manner are needed to effectively utilize the physical models.

3.2.1.4. Additional Research Topic Considerations

In addition to the Research Topics above, some Work Group members provided additional topics to be considered. These topics, listed below, were not discussed or ranked by the Work Group.

1. Trophic Level impacts to soft bottom disturbance and alteration

   The effects of ME projects on benthic species focused on metrics including presence and/or absence of benthic species and changes to abundance. However, abundance of certain benthic invertebrate groups might be very important in the food web for higher trophic levels. Therefore, trophic interactions should be considered, particularly if predator species prefer one prey species over the other or if those species perform different ecological roles, and changes in those prey species (from an ME project) might impact the food web of managed fish species or species of concern, such as ESA-listed species.

2. Invasive Species Potential

The potential for novel hard structure in the ocean to serve as habitat for non-native invasive species and to facilitate their spread is an information gap. Therefore, more information is needed to understand the species composition of biofouling assemblages, and their distributions and potential to spread, in order to develop mitigation measures, if needed.

3.3. Project-level Recommendations

3.3.1. Acoustic Work Group

Minimizing the cost of technology readiness levels advancement through sea trials is paramount to the ME industry. Given the stage of development and the scarcity of private capital required to complete that process, use of national ME test centers such as PacWave South and WETS is essential. Collaborative research synergies should be an effective means of sharing costs and value amongst those who conduct their research in tandem with a deployment. To the extent that research on environmental baseline and response and ME device survival and performance can be conducted in parallel, and budgets segregated, test centers would seem to provide a venue and value that should help to optimize information for addressing data gaps. Test centers provide finite location, known listed species, and practical controls, all likely helpful in advancing the scientific basis in understanding behavioral baselines. Test centers also offer multiple small-scale experimental opportunities across a range of technological topologies, with limited risk (given the required envelope defined in the biological assessment) that should be helpful in the investigation of behavioral response.

It is important, early in the permitting process, to identify the likely characteristics of new sound sources, as well as the array design so that the type and level of monitoring can be developed (e.g., single device installations may not have much sound greater than ambient noise, a larger array may depending on the device). However, depending on the site and device characteristics, it may be difficult to differentiate or measure ME device generated sound levels as, for example, a device is relatively quiet, and the ambient environment is noisy. Additionally, collecting data on pre-project ambient noise can be expensive for the level of information it provides and how regulators use it during the permitting and licensing process. Developers should consult with regulators to confirm their information needs and develop a study to collect pre-project data and a monitoring plan to follow construction/installation.

The ESA status and acoustic sensitivity of species and type of habitat affected by the sound generated from the project are important considerations for developing surveying and monitoring approaches. Key questions and survey objectives should be identified for the species of concern and should consider multiple and integrated surveying methods. Developing a specific question or objective to address is critical to determine appropriate surveying methods, and to identify the levels of change that trigger the need for mitigation. Additionally, having as good of information as possible of endangered species with the highest spatial and temporal resolution of habitat use is critical to development and operations of ME projects.

3.3.2. Benthic Work Group

State and federal agencies have different concerns and perspectives; therefore, feedback from all agencies involved is important. Pre-consultation to determine what an agency wants or needs may provide a cost savings for ME developers since clarifying information needs for all agencies up front enables a more efficient information/data gathering effort. During pre-consultation, the triggers for adaptive management should be determined, as well as how decisions are to be made, and the mitigation steps if thresholds are exceeded. Additionally, developers should understand what data, if any, are available in the region to develop habitat suitability models and confirm their relevance and use in the permitting process with regulators. Reference site(s) should be selected to determine what typical variability in benthic communities exist in the region and help compare benthic effects in the project area.

4.1. Conclusion

The focus of this effort was to identify targeted research that could assist with environmental permitting needs and concerns based on input from subject matter experts participating in the Work Groups. The prioritized targeted research needs identified several topic areas, including decision/risk assessment approaches, to help regulators with characterizing the magnitude and extent of the potential impacts of ME projects on marine resources. To this end, our goals were different than the *2020 State of the Science Report*, which focused specifically on technical scientific gaps and research recommendations, rather than on permitting needs. However, the overlap between the *2020 State of the Science Report* and the prioritized research topics identified in this report demonstrates that filling technical scientific gaps is important for permitting and licensing. The identified targeted research priorities will facilitate collaboration between regulators and developers by providing pathways for decision-making, improving confidence in modeling approaches, and providing a common understanding on expectations, methods and thresholds of concern.

The Work Group approach was an effective and efficient means to engage a broad range of expertise, from scientists to regulators, to develop useful outcomes and recommendations with modest time commitments from Work Group participants. However, because all meetings were held virtually, the benefits of face-to-face interaction were not possible, and some Work Group participants may have benefited from a stipend or other funding to help with the time commitments. Additional challenges included uncertainties derived from low numbers of permitted ME projects in the U.S., as well as lesser-known cumulative effects due to the lack of deployed ME arrays to learn from.

The discussion and findings summarized in this report were shared and discussed with a larger group of ME regulators, developers, and subject matter experts during the ECCA Final Webinar in September 2020. Via online polling, participants provided their perspectives on research priorities for both acoustic and benthic research topics and additional research topics to be considered for future work group efforts. Finally, webinar participants indicated that Acoustic Research Topics #2, Develop Analytical Approach to Differentiate Between Background and Device Noise and Instrumentation for long-term (24/7) tidal turbine stationary monitoring (to address flow noise) and #4, Procedure for Using Ambient Pre-Project Acoustic Monitoring Information to Inform Acoustic Effects as the highest priorities from the Acoustic Research Topics; and Benthic Research Topics #2, Benthic Interactions Risk Assessment Framework and Research, and #3, Evaluate and Validate Physical Oceanographic Models as a Tool for Informing Potential Physical Effects to Habitat (important for moving from single devices to commercial arrays) as the highest priority benthic research topics. One participant recommended including a case study of the application of IEC/TS 62600-40 standards as a deliverable for Acoustic Research Topic #2, Develop Analytical Approach to Differentiate Between Background and Device Noise and Instrumentation for long-term (24/7) tidal turbine stationary monitoring to address flow noise[11]. Additionally, one participant advocated for including the collection of information under the IEC/TS 62600-40 standards as an Acoustic research priority. Entanglement of marine mammals, including secondary entanglement in lost fishing gear, and collision of marine animals with tidal or marine current turbines were ranked as the top two topics for future consideration of future work group efforts.

Possible next steps to advance work in this area includes:

1. convene Work Groups for addressing other key interactions, such as EMF, entanglement/collision;
2. coordinate with entities that may be able to fund targeted research to make these priorities known;
3. cross-walk with other MRE project types where applicable (e.g., offshore wind for acoustics/marine mammal interactions); and
4. coordinate with other efforts (e.g., State of the Science, Synthesis of Environmental Effects Research Project, Triton Initiative, etc.) to ensure that the findings are available and considered during the development and implementation of new marine renewable energy initiatives.

[11] While the IEC TC 62600-40 standards were used as a reference during Work Group discussion, the inclusion of a case study application of the IEC TC 62600-40 standards would increase expected costs and expand scope beyond the original intent of the Work Group's recommendation.

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APPENDIX A. ACOUSTIC AND BENTHIC WORK GROUP SHARED REFERENCES

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APPENDIX B. REFERENCES FOR THE BENTHIC WORK GROUP

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