Marine Renewable Energy: An Introduction to Environmental Effects

OES ENVIRONMENTAL

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Overview

This brochure, developed by OES-Environmental, provides an overview of the environmental effects of marine renewable energy (MRE) development. It is intended to familiarize readers with the latest scientific information about the potential impacts of the installation and operation of MRE devices. The conclusions shared throughout the brochure are based on the findings from the OES-Environmental *2020 State of the Science Report*.

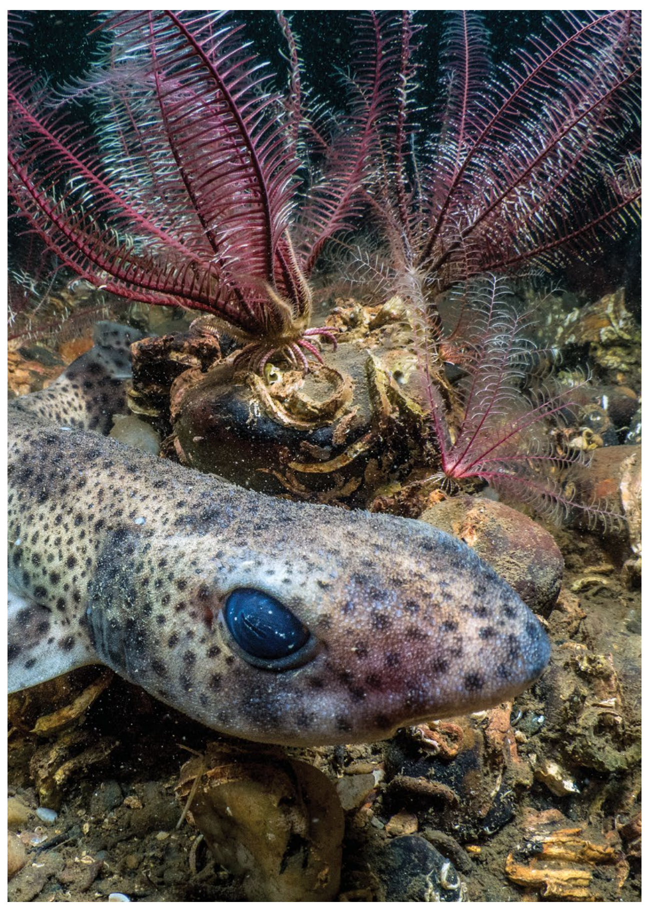
We begin by describing MRE and the way effects on the environment are defined, and then presenting individual sections about each environmental risk. Each section includes a description of the issue, the current status of the risk based on scientific data for small numbers of devices (1-4), recommendations for minimizing the risk, and a case study from a real-world project or research study. The brochure concludes by sharing the concepts of risk retirement and data transferability as developed by OES-Environmental.

To learn more about any of the content described in this brochure, check out the Additional Resources section where references for the case studies are listed as well as for links to the OES-Environmental *2020 State of the Science Report* and the *Tethys* website.

OES-Environmental

OES-Environmental is an international initiative tasked to study and synthesize the environmental effects of MRE development. OES-Environmental curates and distributes existing information about the environmental effects of MRE to help advance the industry in an environmentally responsible manner. By improving access to scientific data and information, the MRE industry can more effectively tackle the risks that may threaten marine species and habitats, address the remaining uncertainty about the potential effects of MRE devices, and enable faster deployment of safe, clean energy technologies.

The United States (U.S.) Department of Energy leads the task for the U.S., partnered with the U.S Bureau of Ocean Energy Management and the U.S. National Oceanic and Atmospheric Administration. 15 other countries are involved in OES-Environmental, which is implemented by Pacific Northwest National Laboratory. All work is facilitated by and hosted on *Tethys*.



Contents

What is Marine Renewable Energy?

MRE, also referred to as marine energy or marine and hydrokinetic energy, is energy harvested from the movement of water in the oceans or large rivers, and ocean gradients, but does not include hydroelectric dams.
This includes:

- tides
- waves
- temperature gradients
- currents
- river flows
- salinity gradients

Most MRE devices use rotating or moving parts to produce energy. The energy may be used at sea, exported to land via electric power cables, or used to generate stable fuels or products that can be transported for use. Many diverse designs of devices and strategies are used to harvest energy from the ocean.

Wave energy converters (WECs) are capable of transferring energy from ocean waves to electricity or other stored forms of energy. As shown in Figure 1, WECs include technologies such as point absorbers (A, D), surface attenuators (B), oscillating water columns (C), and oscillating surge converters (E).

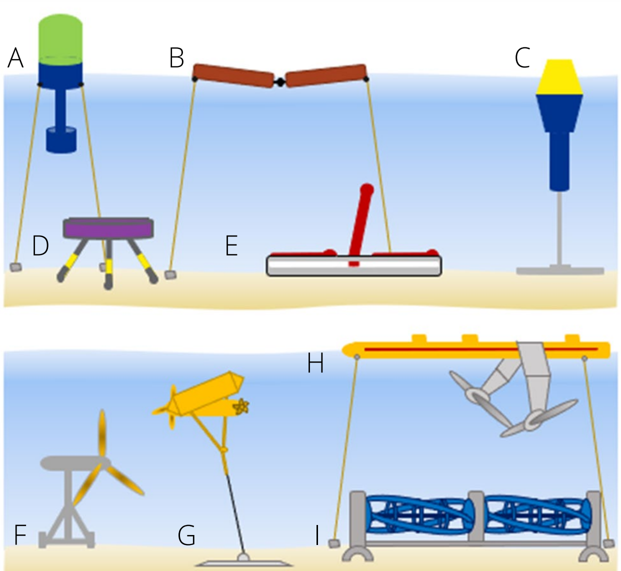


Figure 1. Wave (top) and tidal (bottom) energy technologies. Figure from Copping et al. 2021.

Tidal, river, and ocean current energy converters capture energy from flowing water to produce electric power. These include technologies such as axial flow turbines (Figure 1F, 1H), cross flow turbines (Figure 1I), and tidal kites (Figure 1G). Although not the focus of the work under OES-Environmental, tidal lagoons and tidal barrages extract potential energy by managing the flow of water with retaining walls and holding areas, and using controlled differences in water height to generate energy.

Energy can also be generated by the temperature gradients in tropical waters through ocean thermal energy conversion, and by salinity gradients between saltwater and freshwater.

For more information on device types, see the *Tethys Glossary* and the *Tethys Engineering Photo Library*.

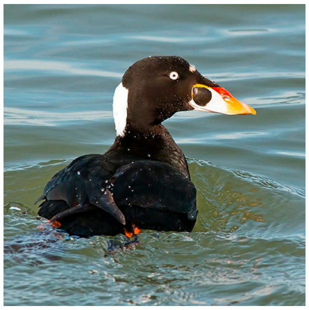
Stressors and Receptors

Interactions between MRE systems and the marine environment can be described in terms of stressors and receptors. Stressors are the parts of a device or system that may cause harm or stress to a marine animal or the environment. Moving blades on turbines, electromagnetic fields (EMFs) associated with power export cables, mooring lines in the water column, and underwater noise from operational devices are examples of some MRE stressors. Receptors include the marine animals living in and traversing the vicinity of an MRE development area, the habitats into which devices are deployed, and the oceanographic and ecosystem processes affected by a device. The complex relationships between stressors and receptors can be examined through observations, laboratory and field experiments, and modeling studies. For MRE, the key stressor-receptor interactions defined by OES-Environmental are collision risk, underwater noise, EMFs, changes in habitat, changes in oceanographic systems, entanglement, and displacement.

The human dimensions of MRE development are as equally important to consider as the environmental interactions. The social and economic impacts of an MRE project are similar to those involved in any development. They include job creation, impacts on communities, displacement of or competition with existing users of the space, and equity in the distribution of the costs and benefits of a project. An assessment of these types of impacts is often part of an environmental assessment.

Collision Risk

Description



The presence of MRE devices, in particular the rotating blades of tidal and river turbines, is thought to pose a risk to marine animals. Animals could come into close contact with turbine blades in the course of their natural movements because they are attracted to the device for purposes of feeding, shelter, or out of curiosity, or because they are not strong enough to avoid currents that might sweep them into the blades.

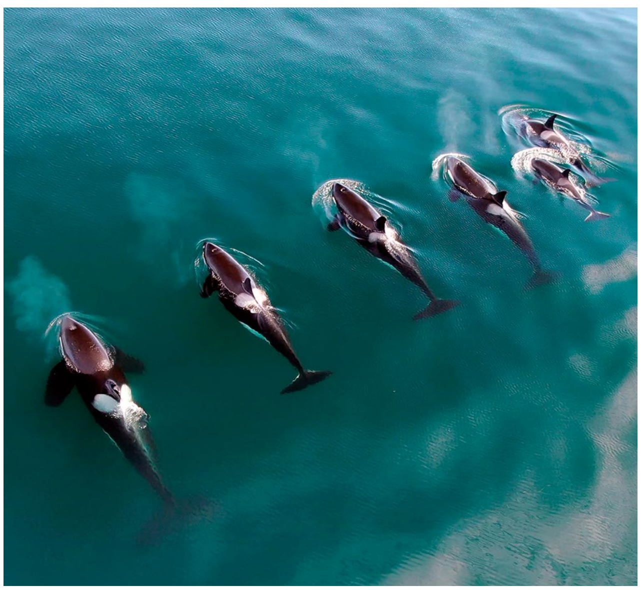
The concern is that a collision with moving device parts (e.g., turbine blades) or a moving device (e.g., tidal kite) could cause permanent injury or death. For animal populations that are already under stress for other reasons, such as historical overfishing, climate change, or other human activities, the loss of a few individuals due to collision might affect the survival of the population. The greatest concerns are for marine mammals, fish, seabirds, and sea turtles, including engendered species and commercially, culturally, and recreationally important species.

Level of knowledge/uncertainty

The current perceived risk of marine animals colliding with a tidal, river, or current device is considered to be relatively high because it is uncertain whether collisions will occur, and the consequences of a collision could be severe. However, the current data suggest that the probability of collision is low. There have been no observations of marine mammals, seabirds, or sea turtles colliding with turbine blades, and no evidence that fish collisions with operational turbines lead to injury or mortality. Furthermore, the sensory capabilities of these animals suggest that collisions with turbine blades will be rare. However, much remains unknown. Observing animals in the vicinity of tidal turbines is challenging, and we have few tools designed for this purpose. These waters are fast-moving and often murky, and the probability of observing a collision event under these conditions is low.

Guidance and recommendations

To better understand collision risk, we need additional information about animal presence and avoidance behavior around turbines, and on consequences of collisions (e.g., injury, mortality). We also need improved methods for monitoring around devices in high-energy conditions to better observe close interactions. These data can be used to develop, improve, and validate the accuracy of numerical models of collision risk to understand effects on individuals and populations of interest. Decreasing the uncertainty about collision risk will be particularly needed as the industry moves to arrays of devices. This is a topic of current research in the MRE community; subject matter experts and industry developers are working together to share knowledge and information as they become available to broadly advance understanding of this potential risk.



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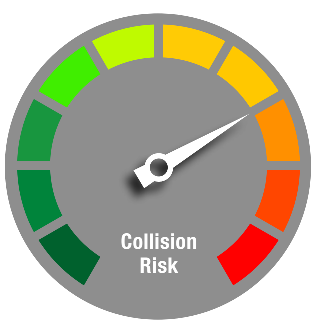


The dial summarizes the broadly understood level of risk from collision for marine animals and turbines for small numbers of MRE devices.

MRE case study: Collision risk monitoring at MeyGen

The MeyGen project team developed a monitoring plan to understand collision risk at their tidal energy project in the Pentland Firth, Scotland. The plan included two primary objectives: estimate avoidance and collision rates for harbor seals to verify and improve the accuracy of collision/encounter rate models, and provide sufficient monitoring data for impact assessment to allow each subsequent stage of the development to proceed. The monitoring plan included detecting avoidance behaviors and potential collisions of marine species, focusing on harbor seals using video cameras, passive and active acoustic monitoring, and tagging. Although harbor seals were the primary concern, the technologies deployed were capable of monitoring other marine animals.

The results showed no collisions or other detectable impacts caused by the presence of the tidal turbines. The study also found that harbor seals used the area less when the turbines were operational, suggesting that they were aware of and avoiding the turbine, or that they do not choose to swim when the tidal currents are strongest. A later study showed that harbor porpoises avoided the operational turbine.

Underwater Noise

Description

Marine animals use sound underwater in the same way that humans and land animals use sight to communicate, navigate, interact, forage, and avoid predation. Marine animals are subject to many sources of anthropogenic noise in the ocean from shipping or other marine industries, to which the noise from MRE devices is added. Anthropogenic noise can cause stress, behavioral changes (e.g., avoidance), physical injuries, temporary or permanent reductions in hearing ability, and can also mask other important sound cues in the marine environment. The effects may vary by species based on noise detection and vocalization capabilities, which range across many frequencies and sound levels. Assessing the potential effects of underwater noise from MRE devices on marine animals requires that we understand the existing (or ambient) noise environment, measure the output from MRE devices and the distance it travels, and relate that noise to changes in animal behavior.

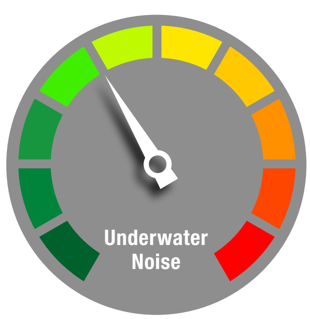
Level of knowledge/uncertainties

The risk to species due to underwater noise from small numbers of operational MRE devices is considered to be low. To date, measurements from single devices show that the level of MRE-generated underwater noise is considerably lower than levels expected to cause physical harm or affect the behavior of marine animals. Marine mammals and fish are the most likely marine animals to be affected, though there is also evidence that some sea turtles and invertebrates may also be affected. While sound detection and vocalization capabilities vary by species, any potential serious impacts on marine species can be avoided by managing and reducing the noise level of devices.

Guidance and recommendations

The International Electrotechnical Commission Technical Committee (TC) 114 published an international consensus Technical Specification for characterizing radiated noise near MRE devices. This international standard provides protocols for sound measurements to enable consistent data collection and allow for comparison across MRE developments. In addition, the U.S. has set regulatory thresholds for impacts from underwater noise on marine mammals, and some interim sound exposure guidelines are available for fish (see Additional Resources on the *Tethys* page). Noise measurements (i.e., operational noise profiles) provided by device developers can be compared to these noise thresholds to evaluate their potential impacts on species present at a planned project site.

While sound detection and vocalization capabilities vary by species, any potential serious impacts on marine species can be avoided by managing and reducing the noise level of deployed devices.



The dial summarizes the broadly understood level of risk from underwater noise to marine animals for small numbers of MRE devices.

MRE Case Study: Noise levels measured around Fred. Olsen Lifesaver

Underwater noise measurements were taken during two deployments of the Fred. Olsen Lifesaver WEC in Hawaii at the U.S. Navy Wave Energy Test Site. Noise associated with the device's generator and the mooring was detected with a monitoring platform fixed on the seabed 100 meters from the device and with drifting hydrophones at closer range. Operational noise levels were below U.S. regulatory thresholds for auditory harassment of marine mammals for all but 1% of the duration of the deployment. Higher-frequency noises were detected 1000 meters beyond the device, but were associated with a mooring chain at the test site, not the device operation itself.

Electromagnetic Fields

Description

EMFs occur naturally around the world, including in the marine environment. However, many anthropogenic activities and structures, such as subsea cables, ships, or bridges, may alter or increase EMFs. Power export or communication cables used in MRE projects emit EMFs. These cables are typically buried, laid on the seafloor, or draped in the water column.

Marine animals with specialized sensory capabilities, such as some species of sharks, skates, rays, sea turtles, fish, and crustaceans, may detect and react to EMFs. Artificial EMFs are thought to cause changes in the behavior and movement of susceptible animals and may potentially cause long-term changes in their growth or reproductive success. The animals most likely to be affected by EMFs from MRE systems are those that spend time close to a power cable over extended periods of time—mainly sedentary animals or benthic organisms with small home ranges.

Level of knowledge/uncertainties

Laboratory and field studies of biological and behavioral changes caused by EMFs have been carried out for a wide range of freshwater and marine species. Some studies have shown limited behavioral change for a few highly sensitive species, but overall the impacts due to the presence of EMFs from MRE cables or devices are unlikely to harm marine animals. In addition, the EMF levels from MRE cables are comparable to or lower than those from existing subsea power cables and lower than those used for offshore wind. For small numbers of MRE devices, the risk from EMF can be considered to be low.

Guidance and recommendations

The scientific community has determined that EMF impacts from cables associated with single devices are minimal. In addition, physical barriers (i.e., cable burial, shielding for electric fields) can help protect marine animals from high levels of EMF exposure. Exchange of information across the MRE sector and with other industries deploying cables will help continue to accumulate data about the effects of EMFs and improve understanding of the levels present in different cable types and configurations. This information will be useful as the MRE industry scales up to arrays of devices with increasingly complex cable deployments.

Though extensive monitoring may not be necessary for every new MRE project, it will be important to assess existing EMF sources, susceptible species, and local environmental conditions at an MRE deployment site. The cumulative effects of many cables in the ocean remain unknown and will need to be considered as larger arrays of MRE devices are deployed, especially in areas with existing sources of anthropogenic EMFs.

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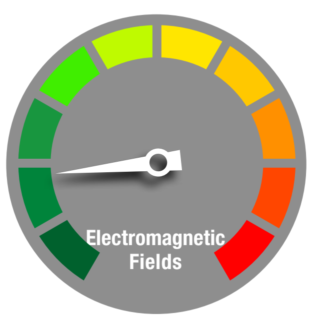
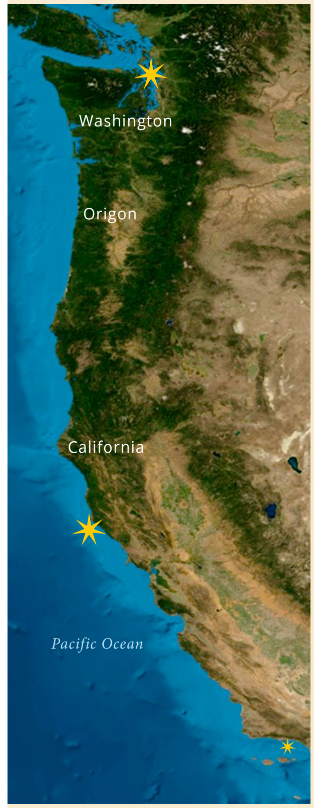
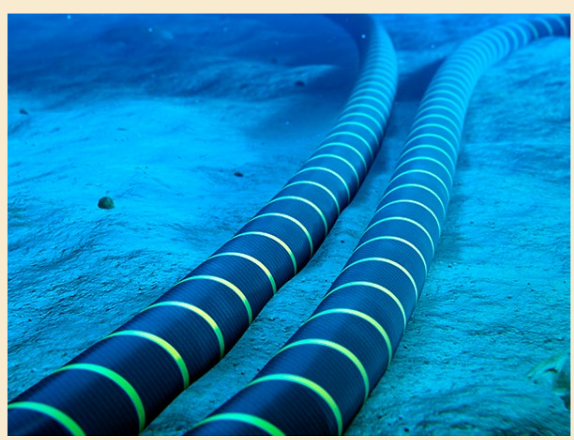


The dial summarizes the broadly understood level of risk from electromagnetic fields to marine animals for small numbers of MRE devices.

MRE Case Study: Effect of EMF on crab from energized power cables on the U.S. West Coast



In Southern California and in Puget Sound in Washington State, field experiments were conducted to determine the effects of energized submarine power cables on two local crab species. They assessed whether cable presence would prevent crab from crossing the cable. Crabs were placed in baited traps connected by a wire tunnel over the cables and scuba divers observed whether crab would cross the cables. Results showed no evidence that EMFs prevented crabs from crossing the cables, and there was no difference in crab responses to unburied or lightly buried cables. This study used an energized submarine power cable as a proxy for underwater offshore wind array cables, which are likely to carry more power and produce higher EMF emissions than a single MRE device.



Changes in Habitat

Description

Introducing any new structure to the marine environment can change the physical habitat, and have the potential to alter where animals live and how common they are at a particular location. Changes in habitat can be caused by installation, operation, and/or decommissioning of MRE systems. Installation of MRE systems (including the device itself, foundations or anchors, mooring lines, and cables on the seafloor or in the water column) may lead to alteration, loss or creation of benthic and pelagic habitat, potential for introduction of non-native species, and possible changes in animal behavior or ecosystem function.

Level of knowledge/uncertainties

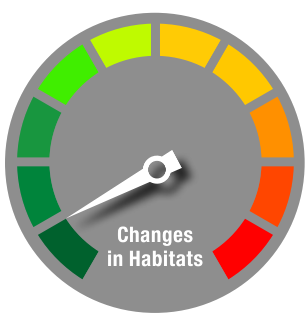
The effects of MRE on habitats are similar to those of structures involved in other well-studied marine industries, such as offshore wind turbines, navigation and observation buoys, platforms, docks, oil and gas rigs, and piers. Several studies at deployed MRE devices have shown rapid recovery from the disturbance caused by device installation. Based on existing information from analogous offshore industries and the relatively small footprint of MRE foundations, anchors, and mooring lines from small numbers of devices, this risk can be considered to be low.

Some uncertainty still exists regarding the spatial and temporal scales of changes in habitat, but this is mainly a question for long-term scientific researchers and not necessarily a concern to be addressed at individual MRE project sites.

Guidance and recommendations

The most critical aspect for minimizing harm to marine habitats is appropriately siting MRE projects to avoid rare or fragile habitat types. This will require baseline assessments and data collection to understand the surrounding habitat in an area of interest. As long as projects are appropriately sited, changes in habitat caused by MRE devices and arrays are likely to pose a low risk, and post-installation monitoring for changes in habitats may not be needed. Long-term research studies are recommended across industries from a scientific perspective to understand site recovery, colonization, and artificial reef effects on the ecosystem, especially to understand the cumulative effects of developed ocean space, but these studies are not needed as part of regular project permitting.

As long as projects are appropriately sited, changes in habitat caused by MRE devices and arrays are likely to pose a low risk.



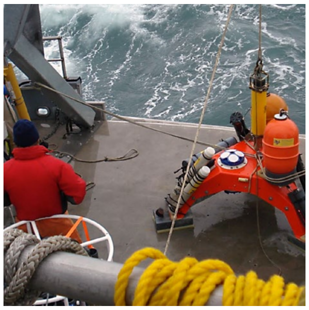
The dial summarizes the broadly understood level of risk from changes in habitats to marine animals for small numbers of MRE devices.

MRE Case Study: Artificial reef effect at Lysekil

The Lysekil test site off the west coast of Sweden was used to monitor the abundance and behavior of fish and invertebrates around WEC foundations. Visual surveys were conducted on and around the WEC foundations and at control locations periodically over a 12-year period. Species observed at the WEC foundations included brown crab, European lobster, cod, and several species of flatfish. The results of this long-term study clearly demonstrated an artificial reef effect—greater abundance and biodiversity of species on and near the foundations than at the control sites—but results varied over the years. Colonization of the foundations was perceived to be a beneficial effect of the Lysekil test site, because it created new hard-bottom habitat for existing native species within a soft-bottom area. While some concerns remain that the foundations would facilitate invasive species spread, no non-native species were recorded during the course of the study.

Changes in Oceanographic Systems

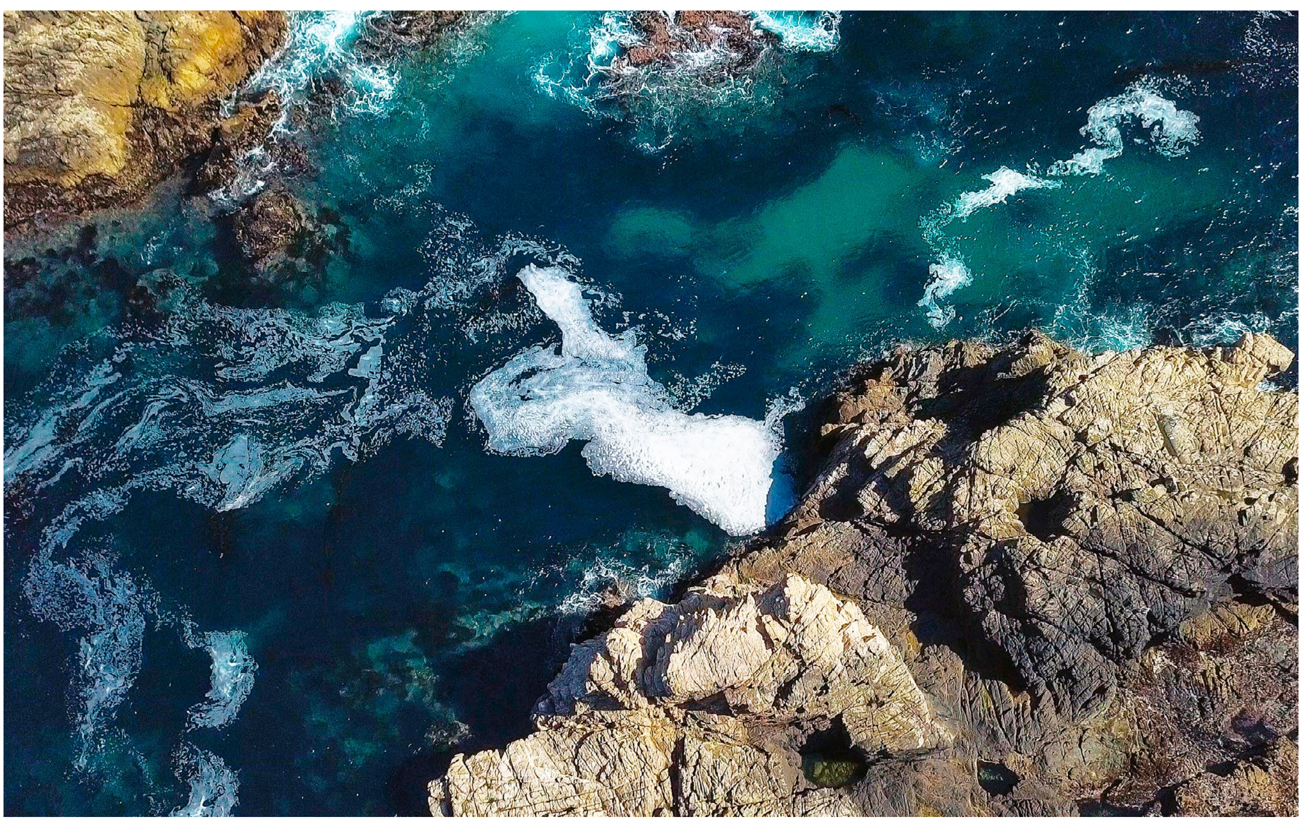
Description



Oceanographic systems include the physical processes related to the movement of ocean water, and the direct or indirect influences of these processes on marine ecosystems. The operation of large numbers of MRE devices could alter water circulation, wave heights, or current speeds, as well as remove energy from the system. These changes, in turn, could affect sediment transport, water quality, and/or marine food webs. Wave and tidal devices have the potential to affect oceanographic systems in unique ways, based on the way the devices are designed to harvest energy.

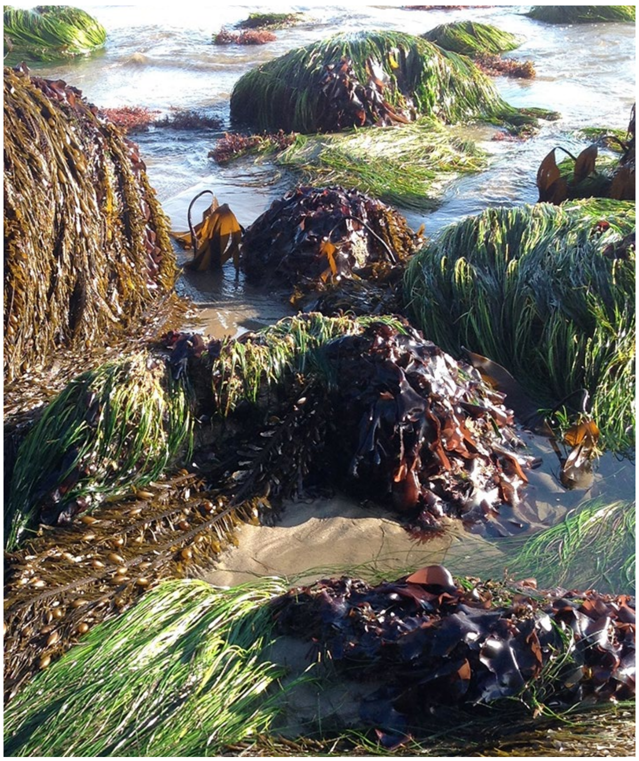
Level of knowledge/uncertainties

Our knowledge about potential changes in oceanographic systems caused by MRE devices is mainly derived from numerical model simulations. These models have been run most consistently with very large numbers of devices (tens to hundreds) at scales that have yet to be tested in the water. For these large numbers of devices, changes in circulation, wave heights, and secondary changes in water quality and sediment transport can be predicted by the models. However, for the small numbers of MRE devices now deployed (1–4 devices), any changes are too small to be measured relative to the natural variability of the ocean. Therefore, this risk can be considered low for small numbers of devices.



Guidance and recommendations

Working with researchers and developers to improve and validate models to understand effects on oceanographic systems will be important for addressing potential effects as the MRE industry moves toward larger arrays. In addition, assessing the cumulative effects across multiple MRE projects deployed in a region could become necessary as the industry develops. However, field data collection for the small numbers of devices at the scale of present operations will not benefit assessments of environmental effects.



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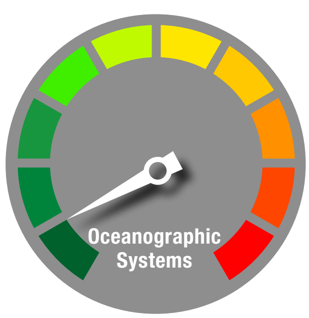


The dial summarizes the broadly understood level of risk from changes in oceanographic systems to marine animals for small numbers of MRE devices.

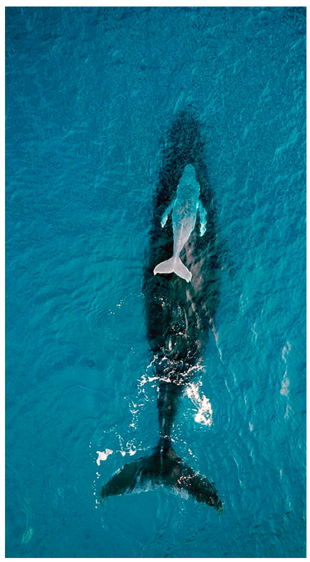
MRE Case Study: Oceanographic changes from tidal energy in Minas Basin

This modeling study focused on in-stream tidal turbines in the Minas Channel of the Bay of Fundy in eastern Canada. The goal was to explore the potential impacts of these devices on the physical environment, specifically sedimentation (mobilization and re-suspension) in ocean currents and tidal flats. Three-dimensional models compared natural variability (from tides, storm surges, winds, and waves) to a single device and several configurations of arrays to predict how the MRE devices could influence water quality and flow. The study showed that only the presence of multiple turbines reduced current speed for both upstream and downstream tides, and affected the rate of sediment transport within and outside an array due to changes in bypass flow.

Entanglement

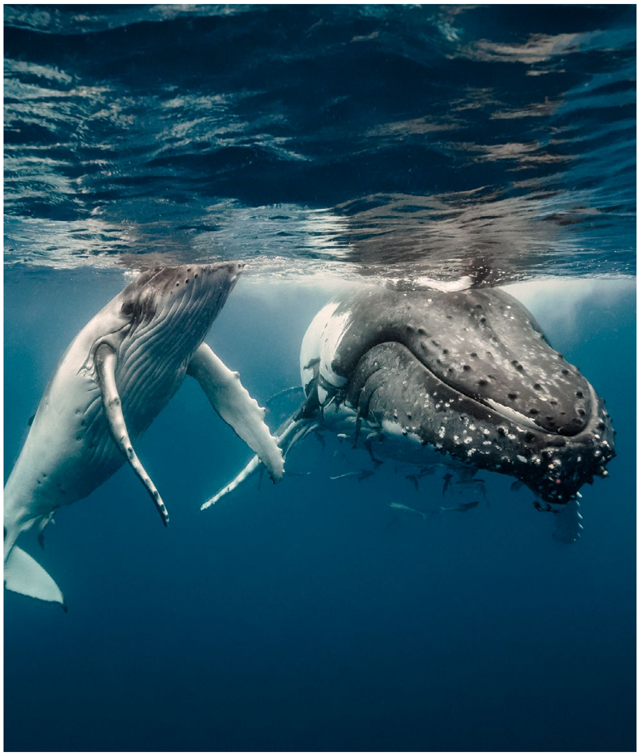
Description

Entanglement, or entrapment, is thought to occur when marine organisms (e.g., whales, sea turtles) become caught in a system without the possibility to escape, which can lead to injury or death. Typically, these unfortunate outcomes have resulted when marine animals encounter and become entangled in lost or abandoned fishing gear. MRE mooring lines, anchors, and cables are unlikely to be dangerous to marine animals because they have no loose ends or slack to create loops that cause entanglement. However, it is possible that entrapment may occur with large arrays of devices if an animal were to enter an array and become unable to navigate out due to the presence of multiple cables and devices.



Level of knowledge/uncertainties

Most of the current knowledge comes from observations of entanglement events involving the loose or slack lines from fishing gear or telecommunication cables, which are not comparable to the fixed or taut MRE lines and cables. As an early-stage industry, little field data is available from monitoring entanglement around MRE systems to aid in quantifying the risk, and no animals have been observed to be entangled in MRE devices or components. As more devices are deployed, we will continue to learn more about this risk. The potential impact is likely minimal for single MRE devices with few mooring lines and cables. However, the probability of, and associated risk for, large marine animals to encounter mooring lines and cables in large arrays and experience entrapment remains uncertain.



Guidance and recommendations

To assess the risk of entanglement for a particular MRE project, the swimming and diving behaviors of marine animals of concern, as well as their spatial distribution and migration patterns, should be identified and compared to features of the proposed project. Modeling of encounter potential could also improve the understanding of this risk, but empirical data are needed to test and validate existing models. Routine monitoring of the mooring systems and cables at MRE project sites will help detect any entanglement events or accumulation of derelict fishing gear. Prompt removal of debris will help reduce the risk of entanglement.

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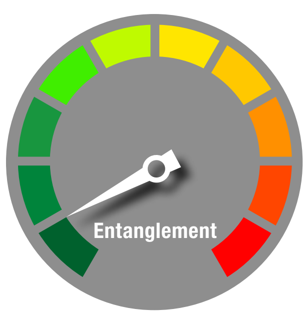

The dial summarizes the broadly understood level of risk of marine animal entanglement for small numbers of MRE devices.

MRE Case Study: Entanglement risk from a tidal kite at Minesto Holyhead Deep

The Deep Green Holyhead tidal project in Wales uses underwater kite devices that operate at specific depths in fast tidal currents. The devices are securely tethered to a foundation on the seafloor, which is designed to avoid drag and tangling. During project planning, there were initial concerns about entanglement and the interaction between animals, the mooring systems, and the tidal kite. While 20 cetacean species and two pinniped species were recorded in the area prior to device installation, only 7 of these species were observed regularly at the site. The results of the biological assessment performed during the pre-deployment suggested that no additional assessment was required for sea turtles, harbor seals, or basking sharks. However, concern remains for porpoises, dolphins, minke whales, and grey seals because of risks of secondary entanglement with derelict fishing gear caught in the mooring lines, which may need further consideration.

Displacement

Description

Displacement occurs when an individual or population changes its home range or movement patterns as a result of a change in their environment. Animal displacement is often due to their inability to access critical foraging, mating, rearing, or resting habitats. Marine animals with particular spatial habitat needs or migratory routes are the most likely to be affected. Large arrays of MRE devices could contribute to displacement of marine species, creating a barrier effect if animals are unable to navigate around a line of devices and associated cables, or if they encounter other obstacles while doing so. Displacement may temporarily or partially restrict movement, or it may completely bar an animal from accessing an area. These changes are more likely to happen across greater spatial and temporal scales (e.g., around large arrays of MRE devices) compared to evasion or avoidance that occurs on smaller scales (e.g., around single MRE devices).

Level of knowledge/uncertainties

The risk of displacement is very low for small numbers of devices because animals are expected to be able to navigate around single or small numbers of devices. To date, there have been no field studies that address displacement of marine animals around MRE arrays, and no large arrays are currently operating at which to measure this risk. To numerically model displacement, it would be necessary to differentiate the effects of multiple stressors on species distribution and due to this difficulty, no models exist at present. As the MRE industry moves toward larger arrays of devices, field observations will be required to understand the effects of displacement on marine species, specifically on barriers to seasonal migration routes.

Guidance and recommendations

Identification of species potentially at risk of displacement at a potential MRE site is important during project planning to minimize the potential risk. Siting arrays of MRE devices outside of migration corridors is especially important to avoid large-scale displacement. Additionally, when siting MRE devices the cumulative effects of all potential

barriers or space-use conflicts in an area (e.g., other marine industries, shipping channels, etc.) should be considered to fully assess displacement risk for a particular marine animal.

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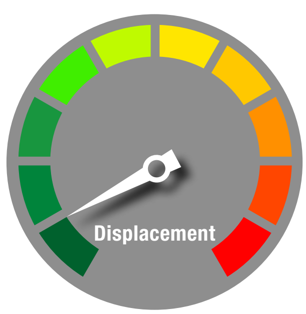
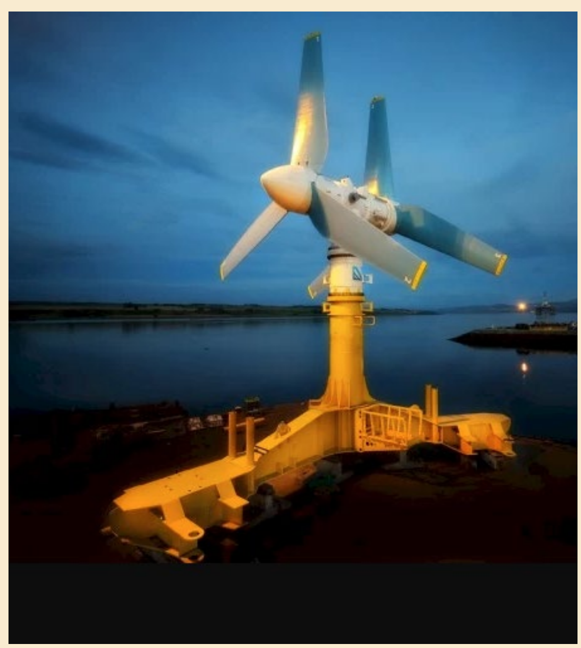


The dial shows that the level of risk from displacement for small numbers of MRE devices is low. As larger arrays of devices are deployed we will continue to learn about this risk.

MRE Case Study Monitoring displacement from wave and tidal devices at the European Marine Energy Centre (EMEC)

At their wave and tidal energy test sites, EMEC created an observation program to detect marine animals visible at the water's surface, including seabirds and marine mammals. Animal presence near devices was analyzed for patterns and variability related to device operation. Observations of surface-visible species (such as basking shark, European otter, seabirds, and marine mammals like seals and harbor porpoise) around devices were relatively consistent across the study areas. Displacement of animals was noted during the installation of MRE devices, likely due to boat activity, but was only temporary, and normal sightings resumed after the work phase was over and devices were operational. The results over the 10-year study (2005–2015) show little indication that seabirds and marine mammals were displaced from either of EMEC's two grid-connected sites.



Socioeconomics

Description

Social and economic effects include the benefits or adverse effects on human systems such as employment, local infrastructure, services, health or well-being, and community dynamics. While social and economic effects are often grouped together, they carry their own distinguishing characteristics and should be assessed separately when considering the impacts of an MRE development. Social effects are mostly described qualitatively, while economic effects are often described quantitatively. Both differ in assessment method, data type, and temporal and spatial scales.

The socioeconomic effects of MRE developments may include impacts on coastal development or infrastructure, valuation of property within an area, local energy security, export of products and services, population, services, cultures, and overall well-being. Some aspects of MRE development may have impacts on local areas, such as by creating job opportunities or spurring infrastructure development in the local community, while other aspects may have larger-scale impacts, such as on the regional or national supply chain, economy, or gross domestic product.

Level of knowledge/uncertainties

Current understanding of the socioeconomic effects of MRE is limited because the MRE industry is relatively new. In addition, regulatory requirements for collecting social and economic data are minimal, poorly defined, or highly variable across jurisdictions—if they exist at all. Studies at a few key sites have found that the MRE industry can benefit rural and coastal communities by providing jobs and revenue alongside clean renewable power. While knowledge from similar industries can be used to inform our understanding of the expected socioeconomic impacts of MRE, the potential benefits or adverse effects of each MRE development are likely to differ depending on the extent of the project, the community involved, and other place-based factors.

As the industry advances, it will become increasingly important to collect data consistently and comparably, specific to a location, over long periods of time to allow for long-term assessments and analysis of the socioeconomic effects of the MRE industry.

Guidance and recommendations

Understanding the tradeoffs between socioeconomic costs and benefits is necessary for equitable strategic planning. Baseline assessments during the planning phase of an MRE project are important to understand the current social and economic systems present in a community or region and to enable measures to be applied to avoid negative effects and enhance benefits. A well-planned and transparent process for stakeholder outreach and engagement should also be incorporated into project planning and development. Working with communities can help build trust and support with local stakeholders and identify relevant concerns and how best to address or mitigate them.

As the industry advances, it will become increasingly important to collect data consistently and comparably, specific to a location, over long periods of time to allow for long-term assessments and analysis of the socioeconomic effects of the MRE industry. Two levels of assessment and data collection for social and economic data are needed:
(1) strategic-level activities and measures that meet objectives of local, national, and regional policy, which generally fall to governments; and
(2) project-level activities and measures that meet objectives on a local scale, such as within a municipality or community, that should be carried out by MRE project developers.

MRE Case Study: Social and economic effects from the Fundy Ocean Research Centre for Energy (FORCE)

After the construction of the FORCE test site in Nova Scotia, Canada, a socioeconomic scoping study was completed. The study showed that the development of tidal energy in the region could create 22,000 new full-time equivalent jobs and generate $1.5 billion in value from new goods and services. The construction, installation, operation, and maintenance workforce was locally sourced and involved more than 300 local companies in the supply chain. The study also highlighted the need for stakeholder consultation and incorporation of socioeconomic impacts in environmental impact assessments, and identified socioeconomic research gaps and priorities moving forward with the operation of the site.

Risk Retirement and Data Transferability

Risk Retirement

Risk retirement describes a means of simplifying consenting/permitting processes for single or small numbers of devices by focusing on key issues of concern. Based on available evidence, risk retirement helps define risks that are unlikely to cause harm to marine animals or habitats and can be "retired" so that extensive investigations at every new MRE project are not needed. Instead, MRE developers and regulators can rely on what is known from already consented/permitted projects, from related research studies, or from analogous offshore industries. Risk retirement does not take the place of any existing regulatory processes, or replace the need for all data collection before and after MRE device deployment. When larger arrays of MRE devices are planned, or when new information comes to light, these "retired" risks may need to be reconsidered and new decisions made.

The risk retirement pathway (Figure 2), developed by OES-Environmental, includes the following steps:

1. Determine if a likely/plausible risk exists for a particular project.
2. Determine whether sufficient data exist to demonstrate if a risk is significant.
3. Collect additional data, as needed, to determine whether a risk is significant.
4. Apply existing mitigation measures to determine whether a risk can be mitigated.
5. Test novel mitigation measures to determine whether the risk can be mitigated.

Each step provides an opportunity for a potential risk to be retired.

For key stressor-receptor interactions, OES-Environmental has developed evidence bases (made up of essential research papers and monitoring reports) that support risk retirement for small numbers of devices (1–4 devices).

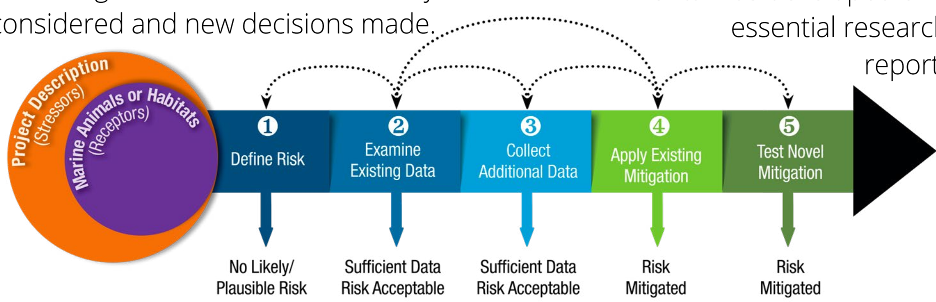


Figure 2. Risk retirement pathway. Additional information available at https://tethys.pnnl.gov/risk-retirement.

Both the evidence bases and feedback from OES-Environmental international workshops on risk retirement have led to the following readiness levels for risk retirement:

Interaction	Readiness for risk retirement
Collision Risk	Need more information.
Underwater noise	Retired for small numbers of devices. May need to revisit as the industry scales up to arrays.
EMF	Retired for small numbers of devices. May need to revisit as the industry scales up to arrays.
Habitat change	Retired for small numbers of devices. May need to revisit as the industry scales up to arrays.
Oceanographic systems	Retired for small numbers of devices. May need to revisit as the industry scales up to arrays.
Entanglement	Need more information as the industry scales up to arrays.
Displacement	Need more information as the industry scales up to arrays.

Data Transferability

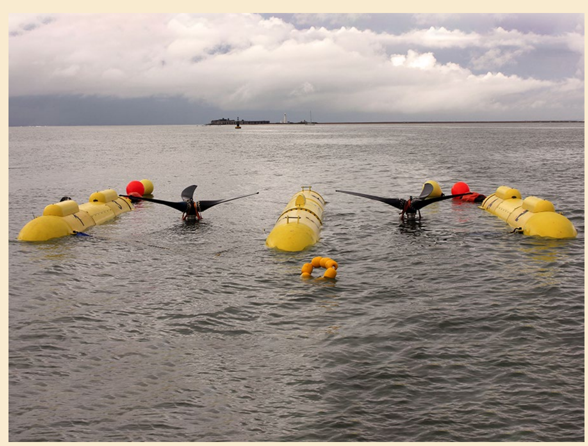
An important component of risk retirement is the process of applying information and knowledge from already consented/permitted MRE projects, research studies, and analogous industries to inform consenting/permitting of new MRE projects—called data transferability. OES-Environmental has developed a data transferability process that comprises four components to help discover and compare existing datasets: a data transferability framework, a data collection consistency table, a monitoring datasets discoverability matrix, and best management practices. Applying this process can help project developers meet regulatory requirements and lower the costs of data collection by identifying available data for each stressor-receptor interaction.

MRE Case Study: Risk retirement from fish monitoring at the RITE Project

Verdant Power's TriFrame + 3 Turbines were installed at the Roosevelt Island Tidal Energy (RITE) project in New York, U.S., and several fish species were documented nearby, leading to concerns about potential collision risk. Atlantic sturgeon and striped bass were surveyed using acoustic telemetry to track individual fish movement. Data related to water flow and fish response to moving blade parts were collected extensively over two weeks. The fish responded differently depending on the species, location, environmental conditions, and device operation. Interaction models were developed to simulate the probability of encounter with the tidal devices. Based on the modeling and field results, the study concluded that there was little evidence of potential harm to fish species. These data allowed the RITE project to be approved for the deployment of devices with a limited suite of targeted environmental monitoring protocols. Following successful deployment and operation, the risk of potential harm to fish was retired for this project.

MRE Case Study: Data transferability for SME Plat-O #1 at EMEC

Sustainable Marine Energy (SME) deployed a tidal device in Yarmouth, England, where acoustic monitoring was used to assess the possible effects of anchor installation on marine mammals and basking sharks. SME used the information derived from this monitoring program to develop the environmental management plan for a tidal energy device deployment at EMEC's Fall of Warness grid-connected tidal test site in Orkney, Scotland. The data collected in Yarmouth informed the EMEC deployment, alleviating the need for marine mammal observers or acoustic monitoring during system installation at EMEC. This significantly decreased the need for offshore personnel on site and reduced costs.



Additional Resources

MRE Brochure *Tethys* page

https://tethys.pnnl.gov/mre-brochure

Relevant *Tethys* pages

- Home page: *https://tethys.pnnl.gov/*
- About OES-Environmental: *https://tethys.pnnl.gov/about-oes-environmental*
- Risk retirement: *https://tethys.pnnl.gov/risk-retirement*

Information in this brochure was compiled from the following sources

- OES-Environmental 2020 State of the Science report: *https://tethys.pnnl.gov/publications/state-of-the-science-2020*
- Monitoring datasets discoverability matrix: *https://tethys.pnnl.gov/monitoring-datasets-discoverability-matrix*
- Knowledge base: *https://tethys.pnnl.gov/knowledge-base-marine-energy*

Additional references for each section can be found on the MRE Brochure *Tethys* page.