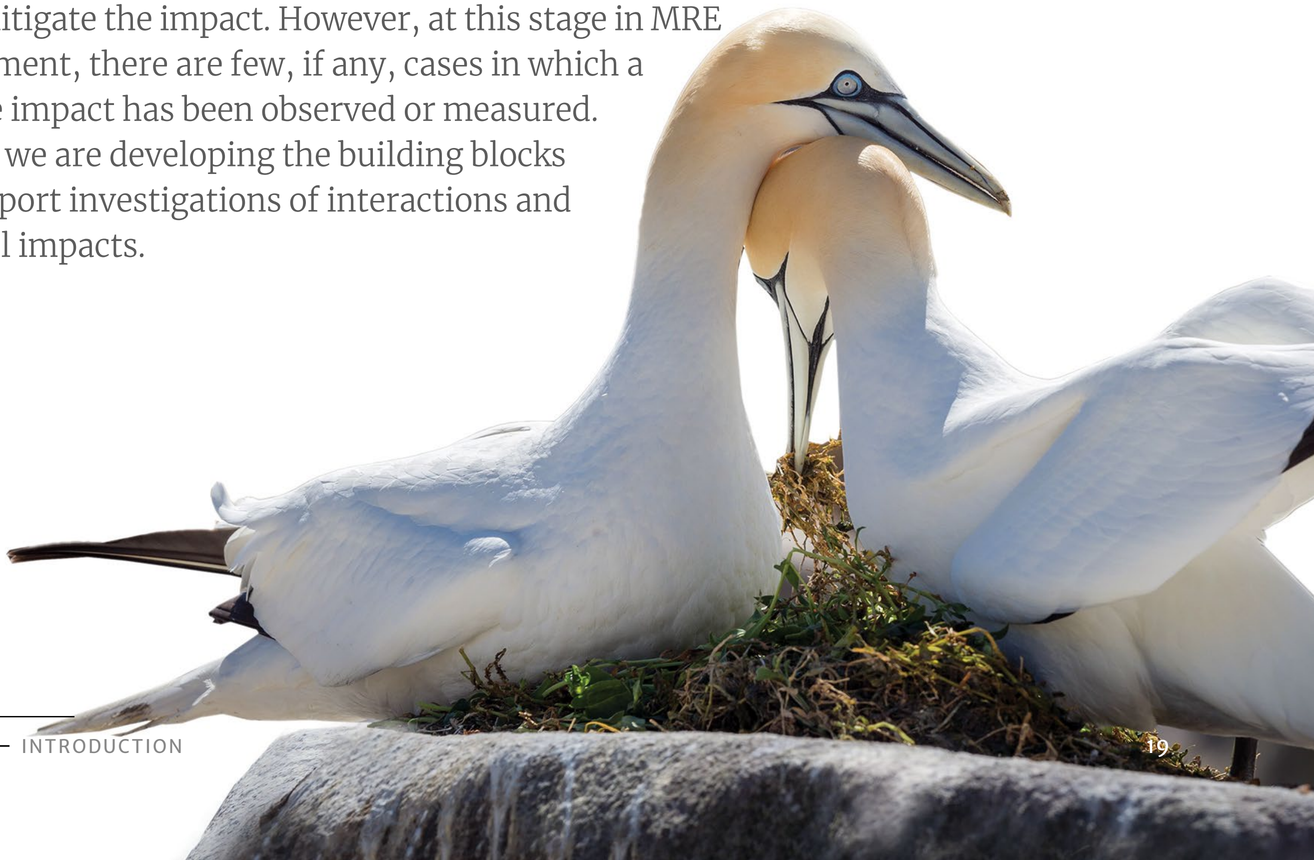
# 2.0

Chapter author: Andrea E. Copping
Contributor: Deborah J. Rose

# Marine Renewable Energy: Environmental Effects and Monitoring Strategies

As we learn more about interactions between marine renewable energy (MRE) devices, the animals and habitats near them, and the oceanographic processes with which they interact, we need to clarify the language used to discuss those interactions. For example, if an MRE device or system negatively affected a number of animals, we could say that the device or the system of foundations, anchors, and mooring lines had an impact on the population, and take steps to avoid the impact or, in some cases, mitigate the impact. However, at this stage in MRE development, there are few, if any, cases in which a negative impact has been observed or measured. Instead, we are developing the building blocks that support investigations of interactions and potential impacts.



## 2.1. POTENTIAL EFFECTS OF MARINE RENEWABLE ENERGY

Key investigations to determine effects of MRE devices include determining the presence of animals close enough to devices/cables/lines that are potentially at risk, measuring device and cable outputs such as underwater noise and electromagnetic fields, measuring potential interactions of animals with these emissions or MRE devices, and modeling changes in water flow and sediment transport at large-scale MRE developments.

At this early stage of MRE development, few observations or data collection efforts point to devices or systems that are causing population-level impacts. The emphasis of research and monitoring studies has been on examining changes in or effects on individual organisms, particularly populations under stress or species of special concern. In most cases, it is difficult to determine whether such effects might be sufficiently deleterious to an animal (or a habitat) to have higher level impacts on populations or the marine ecosystem. Throughout this report, we refer to the effects or potential effects of MRE development and make the connection only to the population-level impacts if established methods or regulatory pathways require such examination.

## 2.2. STRESSORS AND RECEPTORS

Throughout this report, we examine interactions between MRE systems and the marine environment in terms of stressors and receptors (Boehlert and Gill 2010). Stressors are those parts of an MRE system that may cause harm or stress to a marine animal, a habitat, oceanographic processes, or ecosystem processes. These stressors include the moving blades on turbines, mooring lines, anchors or foundations, power export cables, and the emissions that can result from any of these parts. The receptors include the marine animals living in and traversing the vicinity of an MRE development; the habitats into which the devices are deployed; and oceanographic processes, such as the natural movement of waters, wave heights, sediment transport, and the concentrations of dissolved gases and nutrients that support marine life. It is the intersection of stressors and receptors that define the interactions that can be examined through observations, laboratory and field experiments, and modeling studies. Section 2 of this report (Chapters 3–8) describes the state of scientific understanding of these stressor-receptor interactions (Figure 2.1).

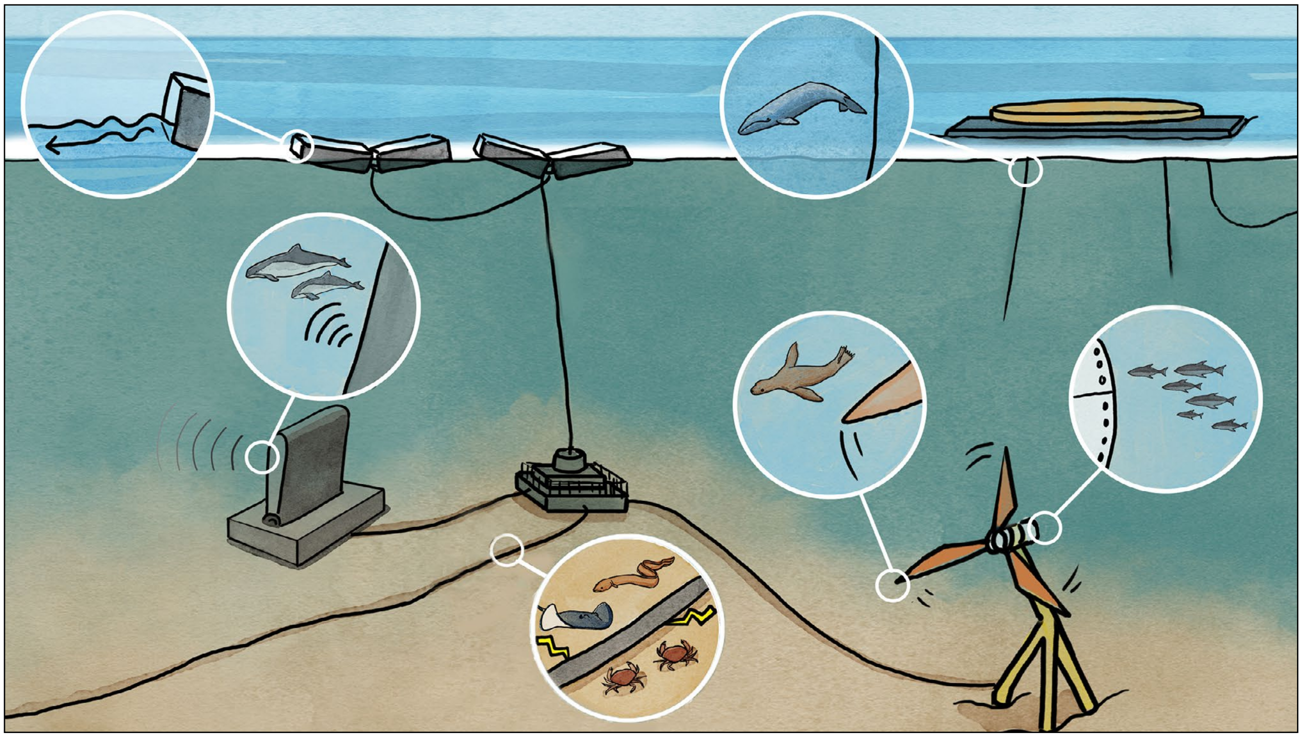


**Figure 2.1.** Stressor-receptor interactions potentially arising from various marine renewable energy devices. From top left to bottom right: changes in oceanographic systems, underwater noise, electromagnetic fields, mooring entanglement, collision risk, and changes in habitats. (Illustration by Rose Perry)

## 2.3. DEFINITIONS FOR MEASURING ENVIRONMENTAL EFFECTS

A number of common definitions are used in the measurement, analysis, and reporting of environmental monitoring results around MRE devices (Table 2.1). In addition, there are specific definitions that are used for measurements that describe certain stressor-receptor interactions; these definitions can be found in subsequent chapters.

## 2.4. MEASURING THE EFFECTS OF MRE DEVICES

Responsible and sustainable development of MRE as a renewable energy source requires that we understand the environments into which turbines or other devices such as kites (for harvesting power from tides, ocean currents, or river flows) and wave energy converters (WECs) will be deployed. Regulations often require that early deployments include extensive monitoring to collect sufficient data to understand the potential interactions of devices and systems with marine animals and habitats. The high-energy locations, and often turbid waters, into which MRE devices are placed add considerable challenges to deploying and operating the oceanographic gear and sensor platforms needed to characterize the stressor-receptor interactions that may be occurring. These challenging locations require that boat-based and human observations be kept to a minimum, in favor of *in situ* remote instrumentation. Collecting and interpreting useful information collected at MRE deployment sites poses significant difficulties, because of the challenges of operating instrumentation underwater, as well as the challenges of processing and transmitting data for analysis. Not all instrumentation and/or data collection efforts related to conducting this type of monitoring over the last decade have succeeded in meeting their monitoring goals. For future monitoring projects at MRE sites to be successful, lessons must be taken from previous efforts to assure that each subsequent effort builds on previous experience, thereby avoiding costly duplication and advancing the industry efficiently.

Details of the methods being used to monitor stressor-receptor interactions can be found in Chapters 3–8; extensive detail about the challenges of and solutions for measuring close interactions of animals and MRE devices can be found in Chapter 10 (Environmental Monitoring Technologies and Techniques for Detecting Interactions of Marine Animals with Turbines).

**Table 2.1.** Definitions associated with investigations for consenting of marine renewable energy projects and research studies. These definitions are used in multiple chapters in this report; certain chapters, notably Chapter 3 (Collision Risk) and Chapter 4 (Underwater Noise), will define additional terms specific to that interaction.

| Term | Definition |
|---|---|
| Baseline survey/site characterization | • Survey and fieldwork undertaken prior to marine renewable energy (MRE) device installation to gather data to better understand, quantify, and assess potential impacts.<br>• Generally required in support of license/consent applications. |
| Cumulative effects | • Changes to the environment caused by the combined effects of multiple human activities and natural processes. Cumulative effects may be realized as the effects of repeated actions that may have an effect greater than the sum of their individual effects. |
| Farfield | • The area of ocean or bay around an MRE device, generally defined as more than five device diameters from the device or array of devices. |
| Nearfield | • The localized area of sea occupied by and in very close proximity to an MRE device, generally considered to be within one to five device diameters. |
| Environmental monitoring associated with MRE projects | • Monitoring carried out to gather data before devices are deployed (post-consent monitoring) or monitoring of the environmental effects of deployed MRE devices (post-installation monitoring).<br>• Generally monitoring is required by regulators to validate predictions made in environmental assessments or to provide an evidence base for adaptive management of effects for which there is residual uncertainty. |
| Project environmental monitoring plan (may go by various names including PEMPs/EMPs/others) | • A document produced as a requirement of licensing/consenting processes for MRE projects setting out the objectives and methodologies of post-installation environmental monitoring. |

## 2.5.
## KEY MONITORING QUESTIONS

The most significant stressor-receptor interactions of concern, based on the accumulated knowledge to date (Copping et al. 2016; ICES 2019), and the primary factors that continue to generate interest and concern about these interactions among stakeholders with an interest in MRE development are summarized here.

Gaps in our knowledge and understanding of the potential effects of interactions between MRE stressors and marine receptors span multiple spatial and temporal scales, such that a large range of monitoring efforts would be needed to fully understand and track these effects. The significant increase in our understanding of potential effects across multiple scales over the past decade has come about largely as the result of focusing on two general categories of monitoring questions: direct interactions of stressors and receptors, and the context and environment in which MRE devices are placed.

### 2.5.1.
### DIRECT EFFECTS OF STRESSOR-RECEPTOR INTERACTIONS

Scientific questions that inform our understanding of the direct effects of MRE devices focus on the actions and interactions of organisms as they encounter devices in their natural habitat. Topics that inform those questions include the following:

- rates of encounter and effects (injury/mortality rates) of collision with turbine blades (e.g., Bevelheimer et al. 2019; Copping and Grear 2018; Copping et al. 2017; Joy et al. 2018; Onoufriou et al. 2019; Schmitt et al. 2017)
- avoidance of moving parts or acoustic fields generated by the device (e.g., Grippo et al. 2017; Hastie et al. 2018; Robertson et al. 2018)
- avoidance of or attraction to magnetic and induced electrical fields (e.g., Gill et al. 2014; Westerberg and Lagenfelt 2008)
- attraction to or aggregation around bottom-mounted or floating structures (e.g., Fraser et al. 2018; Kramer et al. 2015; Williamson et al. 2019)
- displacement or permanent alteration of behavior patterns due to novel device presence (e.g., Long 2017; Sparling et al. 2018)
- probability and effects of entrapment or entanglement of large marine animals because of the presence of mooring lines, anchors, and export cables (e.g., Benjamins et al. 2014; Copping et al. 2018).

Studies have been designed to observe specific marine animal behaviors in response to the presence of MRE devices or their acoustic or electrical signatures; these potential effects occur at known or expected locations and/or at times that can be targeted for observation. Many of these interactions can be examined through modeling and other techniques that do not require the in-water study of the physical/biological setting of a specific device. For example, our understanding of the mechanisms for blade strike or collision assume an animal is encountering a device; for electromagnetic field (EMF) effects we assume a receptive organism is located near the cable/component; and when investigating acoustic effects we assume the animal can detect the emitted sound and is within range, etc.

### 2.5.2.
### MONITORING WITHIN THE CONTEXT OR ENVIRONMENT OF MRE DEVICES

The second set of questions on which we focus deals with the context or vicinity of the device(s). While necessarily site-specific, answers to these questions will build our understanding of the biological and physical components of (and their linkages with) the highly energetic environments targeted for wave or tidal power development. It is necessary to understand the background processes at work at a site before designing a monitoring program that will reliably separate effects from the background natural variability as well as from effects of other anthropogenic activities. Topics that inform those questions include the following:

- inventories of organisms that naturally occur in the area and examinations of their normal distribution in space and time, as well as their movement patterns (e.g., Cox et al. 2017; Holdman et al. 2019; Lagerquist et al. 2019; Viehman et al. 2018; Yoshida et al. 2017)
- examinations of the amplitude and other characteristics of the MRE stressors, including underwater noise and EMF (e.g., Dhanak et al. 2015; Nedwell and Brooker 2008; Pine et al. 2019)
- modeling and validation of hydrodynamic and sedimentation patterns, and their associated variability in space and time (e.g., Ashall et al. 2016; Fairley et al. 2017; Haverson et al. 2018; Khaled et al. 2019)

- modeling of potential effects of MRE systems on ecosystems; although relatively little modeling has been carried out to date, agent-based models and ecosystem models will become useful as the industry moves toward large commercial arrays.

This information enables us to predict device effects, with some degree of confidence, and can be used to design effective mitigation measures, if needed. For example, animal distribution and movement patterns at a site will largely determine how likely the animals are to encounter a device or be affected by acoustic or electrical signatures. This contextual information can also indicate patterns of device encounter probability, thereby assisting with the siting of MRE developments to avoid or minimize the most likely adverse environmental effects. Combined with information about what occurs when an animal interacts with a device, such as rates of injury or mortality from blade strike, these results may inform regulatory needs to determine likely population-level impacts. A prime example of this approach can be seen in the outputs from several stages of the SeaGen turbine development and operation in Strangford Lough, Northern Ireland (Savidge et al. 2014) that informed adaptive management programs. These adaptive management programs helped MRE projects like TideGen in Cobscook Bay, Maine, United States (U.S.) develop effective monitoring and mitigation plans (ORPC 2013, 2014, 2017).

## 2.6. MONITORING STRATEGIES

Answering these wide-ranging questions at the highly energetic sites targeted for power production is a significant challenge. The need to understand environmental consequences has driven innovation in developing environmental monitoring gear. A number of different methods and technologies have been used to describe the close interactions of marine animals with devices at wave and tidal sites around the world, some of which are discussed in Chapter 10 (Environmental Monitoring Technologies and Techniques for Detecting Interactions of Marine Animals with Turbines). As with other stressor-receptor interactions, the myriad and complex questions that need to be answered suggest that no one instrument or method can provide all the answers; rather, a suite of methods, instruments, and study designs must be employed to capture the full picture of how MRE devices interact with their environment.

## 2.7. REFERENCES


Ashall, L. M., Mulligan, R. P., and Law, B. A. 2016. Variability in suspended sediment concentration in the Minas Basin, Bay of Fundy, and implications for changes due to tidal power extraction. *Coastal Engineering*, 107, 102-115. doi:10.1016/j.coastaleng.2015.10.003 *https://tethys.pnnl.gov/publications/variability-suspended-sediment-concentration-minas-basin-bay-fundy-and-implications*

Benjamins, S., Harnois, V., Smith, H., Johanning, L., Greenhill, L., Carter, C., and Wilson, B. 2014. Understanding the Potential for Marine Megafauna Entanglement Risk from Marine Renewable Energy Developments. Paper presented at the 2nd International Conference on Environmental Interactions of Marine Renewable Energy Technologies, Stornoway, Scotland. *https://tethys.pnnl.gov/publications/understanding-potential-marine-megafauna-entanglement-risk-marine-renewable-energy*

Bevelhimer, M. S., Pracheil, B. M., Fortner, A. M., Saylor, R., and Deck, K. L. 2019. Mortality and injury assessment for three species of fish exposed to simulated turbine blade strike. *Canadian Journal of Fisheries and Aquatic Sciences*, 76(12), 2350-2363. doi:10.1139/cjfas-2018-0386 *https://tethys.pnnl.gov/publications/mortality-and-injury-assessment-three-species-fish-exposed-simulated-turbine-blade*

Boehlert, G. W., and Gill, A. B. 2010. Environmental and Ecological Effects of Ocean Renewable Energy Development: A Current Synthesis. *Oceanography*, 23(2), 68-81. *https://tethys.pnnl.gov/publications/environmental-and-ecological-effects-ocean-renewable-energy-development-current*

Copping, A., and Grear, M. 2018. Applying a simple model for estimating the likelihood of collision of marine mammals with tidal turbines. *International Marine Energy Journal*, 1(1), 27-33. doi:10.36688/imej.1.27-33. *https://tethys.pnnl.gov/publications/applying-simple-model-estimating-likelihood-collision-marine-mammals-tidal-turbines*

Copping, A., Grear, M., Jepsen, R., Chartrand, C., and Gorton, A. 2017. Understanding the potential risk to marine mammals from collision with tidal turbines. *International Journal of Marine Energy*, 19, 110-123. doi:10.1016/j.ijome.2017.07.004 *https://tethys.pnnl.gov/publications/understanding-potential-risk-marine-mammals-collision-tidal-turbines*

Copping, A., Grear, M., and Sanders, G. 2018. Risk of whale encounters with offshore renewable energy mooring lines and electrical cables. Paper presented at the Environmental Interactions of Marine Renewables Conference, Kirkwall, Orkney, Scotland. *https://tethys.pnnl.gov/publications/risk-whale-encounters-offshore-renewable-energy-mooring-lines-and-electrical-cables*

Copping, A., Sather, N., Hanna, L., Whiting, J., Zydlewski, G., Staines, G., Gill, A., Hutchison, I., O'Hagan, A., Simas, T., Bald, J., Sparling, C., Wood, J., and Masden, E. 2016. Annex IV 2016 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report by Pacific Northwest National Laboratory for Ocean Energy Systems. *https://tethys.pnnl.gov/publications/state-of-the-science-2016*

Cox, S. L., Witt, M. J., Embling, C. B., Godley, B. J., Hosegood, P. J., Miller, P. I., Votier, S. C., and Ingram, S. N. 2017. Temporal patterns in habitat use by small cetaceans at an oceanographically dynamic marine renewable energy test site in the Celtic Sea. *Deep Sea Research Part II: Topical Studies in Oceanography*, 141, 178-190. doi:10.1016/j.dsr2.2016.07.001 *https://tethys.pnnl.gov/publications/temporal-patterns-habitat-use-small-cetaceans-oceanographically-dynamic-marine*

Dhanak, M., Kilfoyle, A., Ravenna, S., Coulson, R., Frankenfield, J., Jermain, R., Valdes, G., and Spieler, R. 2015. Characterization of EMF Emissions from Submarine Cables and Monitoring for Potential Responses of Marine Species. Paper presented at the 11th European Wave and Tidal Energy Conference, Nantes, France. *https://tethys.pnnl.gov/publications/characterization-emf-emissions-submarine-cables-and-monitoring-potential-responses*

Fairley, I., Karunarathna, H., and Chatzirodou, A. 2017. Modelling the Effects of Marine Energy Extraction on Non-Cohesive Sediment Transport and Morphological Change in the Pentland Firth and Orkney Waters. Report by Swansea University for Marine Scotland Science. doi:10.7489/1913-1 *https://tethys.pnnl.gov/publications/modelling-effects-marine-energy-extraction-non-cohesive-sediment-transport*

Fraser, S., Williamson, B. J., Nikora, V., and Scott, B. E. 2018. Fish distributions in a tidal channel indicate the behavioural impact of a marine renewable energy installation. *Energy Reports*, 4, 65-69. doi:10.1016/j.egyr.2018.01.008 *https://tethys.pnnl.gov/publications/fish-distributions-tidal-channel-indicate-behavioural-impact-marine-renewable-energy*

Gill, A. B., Gloyne-Philips, I., Kimber, J., and Sigray, P. 2014. Marine Renewable Energy, Electromagnetic (EM) Fields and EM-Sensitive Animals. In M. A. Shields and A. I. L. Payne (Eds.), *Marine Renewable Energy Technology and Environmental Interactions* (pp. 61-79). Dordrecht: Springer Netherlands. *https://tethys.pnnl.gov/publications/marine-renewable-energy-electromagnetic-em-fields-em-sensitive-animals*

Grippo, M., Shen, H., Zydlewski, G., Rao, S., and Goodwin, A. 2017. Behavioral Responses of Fish to a Current-Based Hydrokinetic Turbine Under Multiple Operational Conditions: Final Report (ANL/EVS-17/6). Report by Argone National Laboratory for U.S. Department of Energy; Argonne, Illinois. *https://tethys.pnnl.gov/publications/behavioral-responses-fish-current-based-hydrokinetic-turbine-under-multiple*

Hastie, G. D., Russell, D. J. F., Lepper, P., Elliott, J., Wilson, B., Benjamins, S., and Thompson, D. 2018. Harbour seals avoid tidal turbine noise: Implications for collision risk. *Journal of Applied Ecology*, 55(2), 684-693. doi:10.1111/1365-2664.12981 *https://tethys.pnnl.gov/publications/harbour-seals-avoid-tidal-turbine-noise-implications-collision-risk*

Haverson, D., Bacon, J., Smith, H. C. M., Venugopal, V., and Xiao, Q. 2018. Modelling the hydrodynamic and morphological impacts of a tidal stream development in Ramsey Sound. *Renewable Energy*, 126, 876-887. doi:10.1016/j.renene.2018.03.084 *https://tethys.pnnl.gov/publications/modelling-hydrodynamic-morphological-impacts-tidal-stream-development-ramsey-sound*

Holdman, A. K., Haxel, J. H., Klinck, H., and Torres, L. G. 2019. Acoustic monitoring reveals the times and tides of harbor porpoise (*Phocoena phocoena*) distribution off central Oregon, U.S.A. *Marine Mammal Science*, 35(1), 164-186. doi:10.1111/mms.12537 *https://tethys.pnnl.gov/publications/acoustic-monitoring-reveals-times-tides-harbor-porpoise-phocoena-phocoena-distribution*

International Council for the Exploration of the Sea (ICES). 2019. Working Group on Marine Benthal Renewable Developments (WGMBRED; Report No. 550297). ICES Scientific Reports, 1:6. doi:10.17895/ices.pub.4914 *https://tethys.pnnl.gov/publications/working-group-marine-benthal-renewable-developments*

Joy, R., Wood, J. D., Sparling, C. E., Tollit, D. J., Copping, A. E., and McConnell, B. J. 2018. Empirical measures of harbor seal behavior and avoidance of an operational tidal turbine. *Marine Pollution Bulletin*, 136, 92-106. doi:10.1016/j.marpolbul.2018.08.052 *https://tethys.pnnl.gov/publications/empirical-measures-harbor-seal-behavior-avoidance-operational-tidal-turbine*

Khaled, F., Guillou, S., Hadri, F., and Méar, Y. 2019. Numerical modelling of the effect of the hydro-kinetic turbines on the transport of sediments - Application to the Rhone site. *MATEC Web Conference*, 261, 05003. doi:10.1051/matecconf /201926105003 *https://tethys.pnnl.gov/publications/numerical-modelling-effect-hydro-kinetic-turbines-transport-sediments-application*

Kramer, S. H., Hamilton, C. D., Spencer, G. C., and Ogston, H. O. 2015. Evaluating the Potential for Marine and Hydrokinetic Devices to Act as Artificial Reefs or Fish Aggregating Devices. Based on Analysis of Surrogates in Tropical, Subtropical, and Temperate U.S. West Coast and Hawaiian Coastal Waters. OCS Study BOEM 2015-021. Report by H. T. Harvey & Associates for U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Golden, Colorado. *https://tethys.pnnl.gov/publications/evaluating-potential-marine-hydrokinetic-devices-act-artificial-reefs-or-fish*

Lagerquist, B. A., Palacios, D. M., Winsor, M. H., Irvine, L. M., Follett, T. M., and Mate, B. R. 2019. Feeding home ranges of Pacific Coast Feeding Group gray whales. *The Journal of Wildlife Management*, 83(4), 925-937. doi:10.1002/jwmg.21642 *https://tethys.pnnl.gov/publications/feeding-home-ranges-pacific-coast-feeding-group-gray-whales*

Long, C. 2017. Analysis of the Possible Displacement of Bird and Marine Mammal Species Related to the Installation and Operation of Marine Energy Conversion Systems. Report No. 947. Report for Scottish Natural Heritage; Redgorton, Scotland. *https://tethys.pnnl.gov/publications/analysis-possible-displacement-bird-marine-mammal-species-related-installation*

Nedwell, J., and Brooker, A. 2008. Measurement and Assessment of Background Underwater Noise and its Comparison with Noise from Pin Pile Drilling Operations During Installation of the SeaGen Tidal Turbine Device, Strangford Lough. Report No. 724R0120. Report by Subacoustech Ltd. for Collaborative Offshore Wind Research into the Environment (COWRIE). *https://tethys.pnnl.gov/publications/measurement-assessment-background-underwater-noise-its-comparison-noise-pin-pile*

Ocean Renewable Power Company (ORPC). 2013. Cobscook Bay Tidal Energy Project: 2012 Environmental Monitoring Report. Report by Ocean Renewable Power Company; Portland, Maine. *https://tethys.pnnl.gov/publications/cobscook-bay-tidal-energy-project-2012-environmental-monitoring-report*

Ocean Renewable Power Company (ORPC). 2014a. Cobscook Bay Tidal Energy Project: 2013 Environmental Monitoring Report. Report by Ocean Renewable Power Company; Portland, Maine. *https://tethys.pnnl.gov/publications/cobscook-bay-tidal-energy-project-2013-environmental-monitoring-report*

Ocean Renewable Power Company (ORPC). 2014b. Cobscook Bay Tidal Energy Project: 2013 Environmental Monitoring Report. Report by Ocean Renewable Power Company; Portland, Maine. *https://tethys.pnnl.gov/publications/cobscook-bay-tidal-energy-project-2016-environmental-monitoring-report*

Onoufriou, J., Brownlow, A., Moss, S., Hastie, G., and Thompson, D. 2019. Empirical determination of severe trauma in seals from collisions with tidal turbine blades. *Journal of Applied Ecology*, 56(7), 1712-1724. doi:10.1111/1365-2664.13388 *https://tethys.pnnl.gov/publications/empirical-determination-severe-trauma-seals-collisions-tidal-turbine-blade*

Pine, M. K., Schmitt, P., Culloch, R. M., Lieber, L., and Kregting, L. T. 2019. Providing ecological context to anthropogenic subsea noise: Assessing listening space reductions of marine mammals from tidal energy devices. *Renewable and Sustainable Energy Reviews*, 103, 49-57. doi:10.1016/j.rser.2018.12.024 *https://tethys.pnnl.gov/publications/providing-ecological-context-anthropogenic-subsea-noise-assessing-listening-space*

Robertson, F., Wood, J., Joslin, J., Joy, R., and Polagye, B. 2018. Marine Mammal Behavioral Response to Tidal Turbine Sound (DOE-UW-06385). Report by University of Washington for U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, Washington D.C. *https://tethys.pnnl.gov/publications/marine-mammal-behavioral-response-tidal-turbine-sound*

Savidge, G., Ainsworth, D., Bearhop, S., Christen, N., Elsaesser, B., Fortune, F., Inger, R., Kennedy, R., McRobert, A., Plummer, K. E., Pritchard, D. W., Sparling, C. E., and Whittaker, T. J. T. 2014. Strangford Lough and the SeaGen Tidal Turbine. In M. A. Shields and A. I. L. Payne (Eds.), *Marine Renewable Energy Technology and Environmental Interactions* (pp. 153-172). Dordrecht: Springer Netherlands. *https://tethys.pnnl.gov/publications/strangford-lough-seagen-tidal-turbine*

Schmitt, P., Culloch, R., Lieber, L., Molander, S., Hammar, L., and Kregting, L. 2017. A tool for simulating collision probabilities of animals with marine renewable energy devices. *PLoS ONE*, 12(11), e0188780. doi:10.1371/journal.pone.0188780 *https://tethys.pnnl.gov/publications/tool-simulating-collision-probabilities-animals-marine-renewable-energy-devices*

Sparling, C., Lonergan, M., and McConnell, B. 2018. Harbour seals (*Phoca vitulina*) around an operational tidal turbine in Strangford Narrows: No barrier effect but small changes in transit behaviour. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 28(1), 194-204. doi:10.1002/aqc.2790 *https://tethys.pnnl.gov/publications/harbour-seals-phoca-vitulina-around-operational-tidal-turbine-strangford-narrows-no*

Viehman, H., Boucher, T., and Redden, A. 2018. Winter and summer differences in probability of fish encounter (spatial overlap) with MHK devices. *International Marine Energy Journal*, 1(1). doi:10.36688/imej.1.9-18 *https://tethys.pnnl.gov/publications/winter-summer-differences-probability-fish-encounter-spatial-overlap-mhk-devices*

Westerberg, H., and Lagenfelt, I. 2008. Sub-sea power cables and the migration behaviour of the European eel. *Fisheries Management and Ecology*, 15(5-6), 369-375. doi:10.1111/j.1365-2400.2008.00630.x *https://tethys.pnnl.gov/publications/sub-sea-power-cables-migration-behaviour-european-eel*

Williamson, B., Fraser, S., Williamson, L., Nikora, V., and Scott, B. 2019. Predictable changes in fish school characteristics due to a tidal turbine support structure. *Renewable Energy*, 141, 1092-1102. doi:10.1016/j.renene.2019.04.065 *https://tethys.pnnl.gov/publications/predictable-changes-fish-school-characteristics-due-tidal-turbine-support-structure*

Yoshida, T., Kitazawa, D., and Mizukami, Y. 2017. Observing Fish Using Underwater Camera at the Test Site Before Installing Ocean Power Generation. Paper presented at the 36th International Conference on Ocean, Offshore and Arctic Engineering, Trondheim, Norway. *https://tethys.pnnl.gov/publications/observing-fish-using-underwater-camera-test-site-installing-ocean-power-generation*

**Marine Renewable Energy: Environmental Effects and Monitoring Strategies**

Copping, A.E 2020. Marine Renewable Energy: Environmental Effects and Monitoring Strategies. In A.E. Copping and L.G. Hemery (Eds.), OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). (pp. 18-26). doi:10.2172/1632880

**REPORT AND MORE INFORMATION**

*OES-Environmental 2020 State of the Science* full report and executive summary available at:
*https://tethys.pnnl.gov/publications/state-of-the-science-2020*

**CONTACT**

Andrea Copping
Pacific Northwest National Laboratory
*andrea.copping@pnnl.gov*
+1 206.528.3049

Go to *https://tethys.pnnl.gov* for a comprehensive collection of papers, reports, archived presentations, and other media about environmental effects of marine renewable energy development.

OES OCEAN ENERGY SYSTEMS An IEA Technology Initiative

OES ENVIRONMENTAL

Pacific Northwest NATIONAL LABORATORY