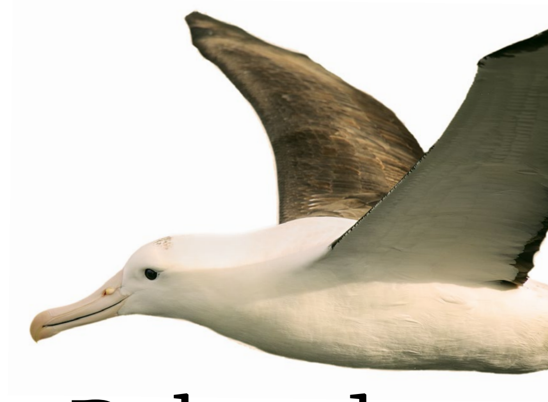
12.0

Chapter author: Célia Le Lièvre
Contributor: Deborah J. Rose



Adaptive Management Related to Marine Renewable Energy

As the marine renewable energy (MRE) industry scales up from single devices to commercial-scale deployments, developers and regulators will need evidence of the environmental effects of MRE to inform project development, strategic planning, and consenting/permitting (hereafter consenting) processes. Uncertainty surrounding the potential impacts of novel MRE technologies on sensitive marine animals, habitats, and ecosystem processes means that even robust baseline environmental information cannot comprehensively address all pre-deployment knowledge gaps (Copping 2018). Tools and practical approaches are needed to help with the sustainable development of the industry. Adaptive management (AM), also referred to as learning by/while doing, enables projects to be deployed incrementally, despite uncertainty, in a way that prevents unacceptable harm to the marine environment. If rigorously implemented, this approach may provide a reliable mechanism for closing knowledge gaps, thereby retiring risks (see Chapter 13, Risk Retirement and Data Transferability for Marine Renewable Energy) for future MRE developments. This chapter explores and suggests a pathway for applying a passive approach to AM for the consenting of single devices and array-scale MRE projects. Complementary information is available online at *https://tethys.pnnl.gov/state-of-the-science-2020-supplementary-adaptive-management*.

12.1. INTRODUCTION TO ADAPTIVE MANAGEMENT

AM is best defined as an iterative management process that seeks to reduce scientific uncertainty and improve management through rigorous monitoring and periodic review of management decisions in response to growing knowledge gained from monitoring data (Copping et al. 2019; Williams et al. 2009). Monitoring associated with AM is designed to address specific scientific questions and hence contribute to the wider scientific knowledge base, which can be used to amend decisions, refine policy, and improve consenting processes in light of new information (Le Lièvre 2019).

From a procedural perspective, AM is a six-step cycle (Figure 12.1) (Williams et al. 2009):

1. **Assess the problem.** Conduct baseline monitoring and environmental assessment to assess the problem and define measurable management objectives.
2. **Design management actions.** In the context of MRE, this refers to the design of the project proposals and mitigation plans, compensation, habitat enhancement measures, and monitoring - all which are informed by the environmental assessment.
3. **Implement the project.**
4. **Monitor.** Conduct follow-up monitoring to collect data after the project has been deployed.
5. **Evaluate.** Evaluate the monitoring results.
6. **Adjust.** Adapt management and monitoring methods and scope in light of what has been learned from observations.

AM learning outcomes can be applied to a particular project (changes in monitoring design, mitigation, or compensatory measures), and the learning should provide information that supports planning policies and regulation of future MRE proposals—a learning process called "double-loop" or "institutional" learning (Figure 12.1).

AM seeks to design and apply management actions as testable hypotheses (Walters 1986), to reduce uncertainty and accelerate understanding of ecological processes, which means that certain management actions may be put at risk in order to learn about receptors' responses to particular actions. However, often this compromise is not possible and AM processes focus on

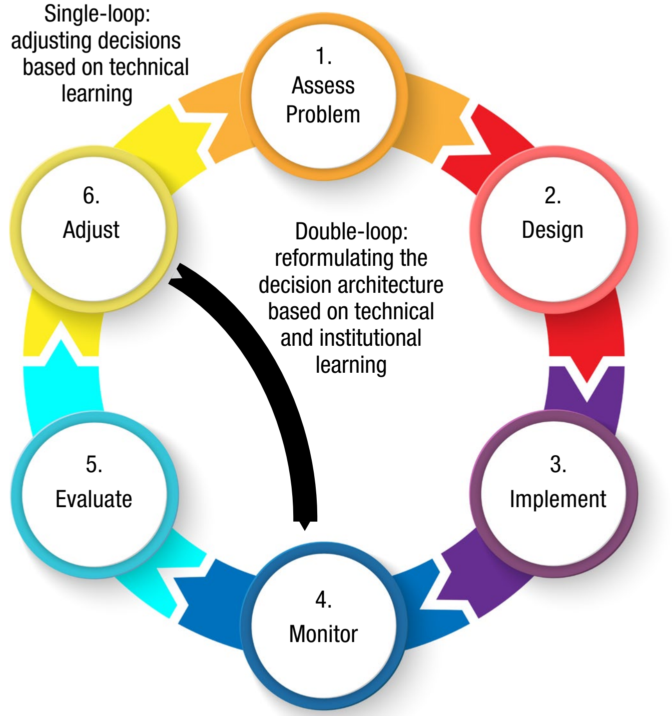


Figure 12.1. The adaptive management (AM) cycle. The original concept of AM concerned single loop learning, while later additions recognize the value of double loop learning, particularly to inform planning and siting for future MRE installations in a region. (Graphic by Robyn Ricks. Adapted from Williams 2011a; Williams and Brown 2018)

monitoring the effects of management measures that reduce uncertainty, and determine whether adjustments are needed to achieve specific mitigation objectives, even in the absence of testable hypotheses. By accounting for scientific uncertainty and providing new observational data to learn about the effects of management and generate new approaches to MRE development and management, this approach may be particularly beneficial for increasing the global understanding of MRE effects and evaluating the effectiveness of monitoring and mitigation actions. This process follows the feedback loops to promote learning for subsequent development phases of specific projects as well as for decision-making for future MRE development.

12.2. IMPLEMENTING ADAPTIVE MANAGEMENT IN AN MRE CONTEXT

Not a new concept, AM has been used in other natural resource management situations (Copping et al. 2019; Williams 2011a, 2011b; Williams and Brown 2014) and holds promise as a useful tool to support the consenting of MRE projects when the environmental effects are not well understood. It can be used to avoid unacceptable effects through its systematic and iterative approach of learning by doing and adapting as you learn, as well as assisting in determining effects uncovered during the consenting process. While monitoring results collected from single devices may help predict the effects of larger arrays, most environmental interactions may not be properly understood until multiple devices are actually deployed and monitored in real sea conditions (Copping 2018). An AM approach is therefore likely to be needed to address the risks and uncertainties associated with larger commercial arrays and their potential incremental effects on marine ecosystems.

12.2.1. THE USE OF IMPACT THRESHOLDS IN ADAPTIVE MANAGEMENT

AM can incorporate decision triggers such as thresholds to help guide implementation. Taking an AM approach based on thresholds requires the definition of acceptable and unacceptable risks. In consenting processes, acceptable risks may be quantified by the definition of impact thresholds, which set the level of effect that is acceptable with respect to the ecology, conservation objectives, and the conservation status of the affected species or natural habitats. Project-specific thresholds can determine the safe operating conditions within which MRE developments can be approved and operated, despite uncertainty, without causing unacceptable harm to valuable receptors/features. Results are used to help ensure that ongoing requirements are proportionate to the observed effects. If information from routine monitoring shows that the level of an effect or change is likely to cause an unacceptable impact, corrective mitigation actions should be taken. On the other hand, if the monitoring data indicate that risks have been overestimated during the consenting phase, monitoring and mitigation requirements may then be reduced and progressively removed in subsequent management decisions. The need to develop and adapt modeling approaches and tools that can ascertain thresholds relevant to wave and tidal energy arrays has been identified as a high research priority for addressing risks associated with consenting (ORJIP Ocean Energy 2017). In some jurisdictions, regulatory impact thresholds are already defined numerically for underwater noise exposure levels and direct mortality of sensitive receptors (e.g., National Oceanic and Atmospheric Administration [NOAA] marine mammal acoustic thresholds, Potential Biological Removal [PBR], ASCOBANS [Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas] by-catches reduction target of 1 percent of the population). While threshold levels might be specifically listed for sensitive species (e.g., NOAA/Southall underwater noise thresholds, NMFS 2018), they do not consider cumulative effects from other anthropogenic activities in their implementation.

Threshold levels for lethal and sublethal impacts are rarely prescribed in policy or regulations and, as such, must be determined on a case-by-case basis; for example, through the examination of species conservation status (Le Lièvre et al. 2016). Both lethal and sublethal effects such as changes in animal behavior, density, and distribution are extremely challenging to measure because of the difficulty in confidently measuring direct mortality and monitoring population changes. Identifying and detecting the metrics of concern with the necessary levels of accuracy to inform management decisions is even more difficult to determine with certainty. Population models that seek to translate sublethal impacts to population-level consequences can be applied to MRE developments, but they may not always help identify the appropriate metrics to monitor. Uncertainty and the lack of consistent methods for detecting and estimating acceptable impacts or thresholds are significant limitations to the use of thresholds/triggers in AM (Johnson 2013). Conservative thresholds will help reconcile AM with the precautionary principle (see Section 12.3) and assure that actions are taken before an unacceptable impact occurs. However, at a larger development scale, unfavorable progress toward thresholds may not be detected in time and remedial actions may fail to effectively respond and avoid unacceptable impacts on sensitive receptors. AM-based thresholds may be more appropriate for the early (smaller) scale of the wave and tidal energy sector where project-led monitoring focuses on understanding device-specific stressor-receptor interactions such as collision risk. As the industry moves toward commercial deployment, taking an AM approach would be more acceptable if it were implemented through staged or phased approach to consenting processes, whereby projects are deployed in stages, starting with small numbers of devices or a small spatial area, and followed by subsequent expansion being dependent on monitoring findings. Monitoring should provide meaningful evidence showing that the effects of the larger-scale deployments are properly understood, prior to approving any subsequent phases.

12.2.2. MITIGATION OF RISK

If an MRE development is likely to adversely affect the marine environment, the mitigation hierarchy of the precautionary principle should apply. The mitigation hierarchy is a cautious approach to decision-making that consists of taking a sequence of steps to avoid, reduce, and minimize potential negative impacts and, as a last resort, to compensate for any residual impacts (Figure 12.2) (Elliott et al. 2019). Although the mitigation hierarchy provides a prescribed approach for reducing impacts, it may not reduce uncertainty and facilitate learning as emphasized by AM principles (Hanna et al. 2016). In the face of data gaps and uncertainty, the mitigation hierarchy may instead result in the continuation or reinforcement of mitigation or compensatory measures throughout the project, thereby hampering the generation of useful science for regulatory decision-makers. Conversely, the purpose of AM is to reduce scientific uncertainty through an iterative process of environmental monitoring and adjustment of management actions. As rightly observed by Hanna et al. (2016), "striking the appropriate balance between mitigating and compensating for potential impacts versus detecting change is a dilemma with which regulators and industry must concern themselves if they are to develop AM approaches that meaningfully reduce scientific uncertainty."

AM and the mitigation hierarchy are not incompatible and can be reconciled. The mitigation hierarchy offers a prescribed approach for avoiding unacceptable impacts that may materialize as a result of data gaps, uncertainties, or imperfect monitoring design in an AM process. As more data are gathered through continuous monitoring, the iterative phase of AM provides a mechanism for evaluating the effectiveness of mitigation and compensatory measures, learning from experience, and informing a more effective mitigation toolkit for future developments (Hanna et al. 2016).

Practically speaking, for single devices or small arrays, mitigation takes the form of post-deployment monitoring and feedback mechanisms as integral parts of the project design. At the large development scale, mitigation measures must be considered and, in some cases, implemented from the beginning of the project and not solely when monitoring data indicate an undesirable trend toward impact thresholds. At the top of the mitigation pyramid (Figure 12.2), impacts may be avoided through technology choice and/or by using well-informed designated development areas for MRE projects within an over-arching marine spatial plan (see Chapter 11, Marine Spatial Planning and Marine Renewable Energy). This technique, also known as macro-siting, may not always be feasible where sites with MRE resources correspond to biodiversity hotspots and protected sites. In these cases, the focus of mitigation in AM

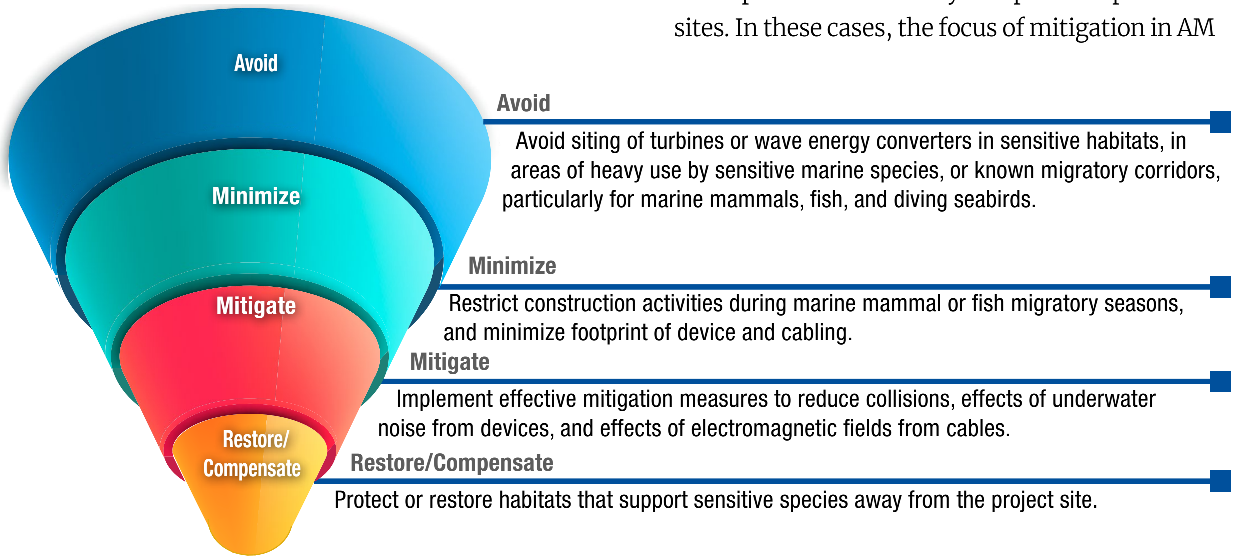


Figure 12.2. The mitigation hierarchy. The mitigation hierarchy is used to avoid impacts when possible, minimize remaining impacts, mitigate to diminish impacts, and provide compensation for unavoidable impacts. (Graphic by Robyn Ricks. Adapted from Elliott et al. 2019)

should be to assure that the impacts of consented MRE projects are reduced and mitigated to acceptable levels. Mitigation measures may consist of spatially arranging the MRE device layout, a mitigation measure also known as "micro-siting" or "smart device positioning".

Curtailment and shutdown protocols have been tested in combination with AM to mitigate and reduce the uncertainty surrounding collision risks with marine mammals (Copping et al. 2016; Fortune 2017). Where no close encounter events are allowed to occur, curtailment could limit the ability of AM to reduce uncertainty and could be poorly suited to undertaking AM. However, the approach taken by SeaGen shows that, despite strict protection of species for which zero tolerance of loss is acceptable, AM may still be employed to decrease uncertainty about collision risks by progressively reducing the precautionary shutdown perimeter of a tidal turbine from an excessive distance of 200 m to less than 30 m (see Section 12.4.2). Curtailment and temporary shutdowns of turbine operation may be overly restrictive in addition to being technically difficult to implement for certain turbine designs. Likewise, these measures are arguably insufficient to address all negative impacts, especially those resulting from displacement and disturbance-related habitat loss or changes in oceanographic systems.

12.2.3. POST-INSTALLATION MONITORING

Creating a successful AM scheme is highly contingent upon the design of monitoring programs that are sufficiently well designed to detect changes, as well as management triggers that can meaningfully inform regulators (Le Lièvre et al. 2016). AM also requires a consenting regime that has the flexibility to encompass such an approach if it is being used as a tool to enable deployments in areas in which the knowledge base is incomplete. Post-installation monitoring is generally required by regulators to validate model predictions in environmental assessments. In the context of AM, the primary purpose of post-installation monitoring is to provide an evidence base for reducing the scientific uncertainty associated with impact assessments and for informing decision-making related to future MRE proposals (Bennet et al. 2016). AM is used to enable deployments when the existing uncertainty causes significant delays in consenting. However, designing and implementing successful AM is contingent on the efficacy of monitoring and the ability to detect change, as well the effectiveness of management actions.

At the project level, post-installation monitoring also serves to verify that project effects do not exceed levels of acceptable change and to adjust the mitigation or compensatory measures initially adopted on the basis of precaution. Likewise, post-consent monitoring design should provide data that can be used to refine the accuracy of both impact thresholds and detected effects, as well as to determine whether additional monitoring and mitigation are required to address predicted and unforeseen impacts.

Poor monitoring precision produces inaccurate evidence leading to inappropriate management decisions. If the statistical power of monitoring data is too low, regulators may make decisions believing that monitoring indicates no change beyond their thresholds of tolerance (Le Lièvre et al. 2016). Monitoring programs will yield more useful information if a question-directed approach is used and data collection methods are designed to answer well-defined and hypothesis-driven environmental questions (Copping et al. 2019). A question-led approach to monitoring will help design surveys that provide useful data for validating model predictions and supporting AM processes (Hanna et al. 2016). Question-directed monitoring also may help address the problem of data-rich information-poor (DRIP), i.e., an undesirable situation in which, despite extensive data collection in the field, post-consent monitoring results do not provide useful information that can be used to reduce scientific uncertainty (Ward et al. 1986; Wilding et al. 2017). This is crucial because DRIP monitoring undermines the success of AM and, in turn, the confidence regulators have in the process.

To date, the application of AM has been primarily directed at reducing uncertainty about the nearfield effects of single or limited numbers of MRE devices and their moving parts. Post-consent monitoring has mainly been implemented to determine whether collisions occur in tidal environments or to assess underwater noise at wave energy sites; hence, monitoring is not necessarily designed to follow a before-after-control impact (BACI) approach. For larger array-scale deployments, the MRE industry may benefit from applying more systematic BACI studies whereby changes in receptors of value to stakeholders are monitored prior to installation, during construction, and during operation of an MRE project (Bennet et al. 2016; Magagna et al. 2012). Embracing a BACI or similar monitoring design will be useful in framing relevant monitoring questions and evaluating changes in response to installation and operation of multiple devices.

AM includes other actions beyond monitoring. For individual projects, additional information gained through single-loop learning may not be sufficient to reduce uncertainty about population impacts, and may not deliver the full benefit that AM has to offer to the MRE sector. Small-scale MRE projects sited in areas where marine animals are widely dispersed will significantly complicate the evaluation of impacts on populations at the individual project level (Fox et al. 2018). By adopting a bottom-up approach where data gained from multiple projects feed into broader marine governance processes through, for example, strategic environmental assessments and strategic research studies supported by government bodies, it may be possible for monitoring to yield additional information, thereby enabling greater regulator confidence and supporting risk retirement during future consenting processes. The MRE sector will particularly benefit from the double-loop learning cycle of AM (Jones 2005), in which lessons learned from past and current projects can inform collective AM for future planning of MRE projects and scientifically informed licensing decisions (Figure 12.1). In principle, double-loop learning in AM may fill many data gaps, allowing developers to save significant time when developing detailed environmental assessments to inform consenting. This will, however, only be possible if monitoring data and methods for data collection, analysis, and presentation are consistent and shared at the appropriate level (Copping 2018).

Examples of MRE applications of AM processes are discussed later. The AM taken in the MeyGen tidal project (Section 12.4.1) in Scotland required phased development with monitoring requirements specifically designed to answer key scientific questions about biological impacts before receiving consents to proceed to the next phase. Similarly, the AM framework for the PacWave project (formerly Pacific Marine Energy Center South Energy Test Site) in the United States (U.S.) required that monitoring results be reviewed by designated regulatory agencies to implement predefined corrective actions, if the project effects exceed certain thresholds or mitigation criteria (Section 12.4.7). The AM approach taken for the Ocean Renewable Power Company's RivGen, U.S. (Section 12.4.6), SeaGen, United Kingdom (UK) (Section 12.4.2), DeltaStream, UK (Section 12.4.3), and Ocean Power Technology's Reedsport Wave Park, U.S. (Section 12.4.5), required that if specific monitoring results were found, a set of triggers could re-start consultation with the regulator and/or an advisory group, in order to adopt changes in project design, operations, and/or monitoring studies. An example of this occurred during consenting with the Reedsport Implementation Committees which had the ability to determine whether a change in the project was required as a result of meeting a screening criterion, and whether the prescribed management practices continued to be appropriate (Section 12.4.5).

12.3. ADAPTIVE MANAGEMENT AND THE PRECAUTIONARY PRINCIPLE

The precautionary principle is used as a preventive action in the face of uncertainty, shifting the burden of proof to the proponents of an activity, exploring a wide range of alternatives to possibly harmful actions, and increasing public participation in decision-making (Kriebel et al. 2001). The primary way the precautionary principle has been applied to MRE is through the mitigation hierarchy of avoidance, reduction, minimization, and compensation (Figure 12.2). While application of the precautionary principle provides a rational approach to avoiding irreversible harm, its implementation through the mitigation hierarchy offers reduced flexibility for addressing scientific uncertainty and promoting iterative learning for future developments. Regulators are faced with an uncertainty paradox, i.e., a paradoxical situation in which regulators take a precautionary approach, requesting an extensive amount of data and information from developers to understand the risks, but the data, in turn, cannot deliver decisive evidence to meet the requested level of certainty (Van Asselt and Vos 2006). While the monitoring of single devices may help understand the incremental effects of sizable arrays, the 2016 State of the Science report stressed that it is unlikely risk will scale in a simple linear fashion as the number of devices increase (Copping et al. 2016). Relying on the precautionary principle alone could lead to situations in which developers and regulators will never understand whether the perceived negative interactions of MRE technologies really exist and, if they do, how they can be resolved and minimized efficiently for future projects (Copping 2018; Todt and Lujan 2014). The purpose of the precautionary principle is the use of rigorous science to prevent unacceptable harm to marine life. Critical to the achievement of rigorous science is the flexibility to integrate scientific methods and data outputs into regulatory decision-making (Tickner and Kriebel 2008). With this in mind, AM may play an important role in the application of the precautionary principle, while working to reduce uncertainty and provide early warnings of adverse effects on marine receptors.

The interplay between AM and the precautionary principle is ambiguous. AM has sometimes been described as an alternative to the paralyzing effect of the precautionary principle (Pembina Institute for Appropriate Development v. Canada 2008). More pragmatic views see AM and the precautionary principle as complementary approaches in biodiversity conservation (Cooney 2006; Morgera 2017). Complementing the application of the precautionary principle with AM is increasingly accepted as a best practice for delivering proportionate and risk-based MRE consenting (Köppel 2014; Le Lièvre 2019). In most nations, reliance on the precautionary principle is subject to the principle of proportionality, which, in simple terms, requires that measures adopted on the basis of precaution must be proportionate to the perceived level of environmental risk. As such, it is generally accepted that precautionary measures should be of a temporary nature pending the availability of additional scientific evidence (Gillespie 2013). As new data are gathered through continuous monitoring, the intensity of monitoring and mitigation requirements should be proportionally responsive to the extent and probability of the environmental threat (Trouwborst 2006). This is the Achilles heel of AM. The use of AM allows for provisional decisions to be made despite uncertainty and responds to knowledge deficits by constantly monitoring and re-evaluating the mitigation initially considered appropriate on the precautionary basis. As such, AM may be viewed as a good practice for applying proportionate precautions and risk management to MRE consenting.

Implementing AM while adhering to the precautionary principle demands the use of rigorous procedural safeguards and a commitment to communicating uncertainty with transparency. AM cannot be used to offer unbounded discretion to decision-makers. AM should not be proposed without any degree of certainty that mitigation measures will be effective. Likewise, AM cannot substitute for demonstrating that substantive legal and regulatory conservation standards will be met throughout the lifespan of MRE projects. The conditions under which AM is acceptable depend on the form of AM and the strength of the application of the precautionary principle in the jurisdiction in which the consenting is taking place. A distinction has been made between prescriptive and flexible AM (Copping et al. 2019). Flexible AM has been predominantly used to address uncertainty about the interactions of single devices that have negligible adverse effects on marine features. At the scale of larger arrays, the value of using prescriptive AM lies in its capacity to incorporate new monitoring feedback into decision-making, while providing regulators with a degree of certainty that corrective mitigation measures will be taken before acceptable thresholds of change or disturbance are exceeded (Hanna et al. 2016). Hanna et al. (2016) also point out that this latter approach would provide developers with greater certainty about the costs of implementing AM. AM may still be used flexibly in larger developments to provide the regulator with a safeguard for prohibiting further deployment phases until specified corrective actions have been taken.

Overall, the question of whether AM is consistent with the precautionary principle should be informed by a case-by-case evaluation of the level of scientific uncertainty and the gravity of the anticipated threat. AM was described as "safe-fail" (Grieg and Murray 2008), meaning that AM should be applied when failure is an acceptable outcome. This suggests that AM may not be appropriate for all receptors, especially at a large deployment scale. If the overriding goal is to protect features of high conservation value, the need to protect these sensitive features may be more important than the desire to address the uncertainty associated with MRE projects. The conservation status of affected species or habitats should always inform the regulator and developers' appetite for risk (Le Lièvre et al. 2016). The adoption of conservative thresholds and trigger levels that incorporate precautionary margins and acknowledge the extant levels of uncertainty will be key for AM to work consistently with the precautionary principle. Implementing AM in this manner offers a relevant response mechanism for reducing scientific uncertainty while assuring that no unintended adverse impacts will occur as a result of insufficient or imprecise data available during the initial approval phase.

12.4. EVALUATING THE SUCCESS OF ADAPTIVE MANAGEMENT AT SELECTED MRE DEVELOPMENT SITES

AM implementation has supported the deployment of several wave and tidal projects, thereby contributing to the testing of certain monitoring technologies, and it has answered some fundamental questions about the environmental interactions of single devices and small arrays. The case studies described in the following sections demonstrate how AM has been applied to consented projects, including the MeyGen tidal project (Scotland), the SeaGen tidal turbine (Northern Ireland), the DeltaStream tidal turbine (Wales), the Roosevelt Island Tidal Energy project (U.S.), Ocean Power Technology's Reedsport Wave Park (U.S.), and the Ocean Renewable Power Company's TidGen and RivGen turbine power systems (U.S.).

12.4.1. MEYGEN TIDAL PROJECT

The MeyGen tidal energy demonstration project in Pentland Firth (Scotland) is the world's largest commercial tidal development and has applied an AM approach through a staged consenting process. Development consent was granted by Marine Scotland, on behalf of the Scottish Minister, for the construction and operation of 61 fully submerged turbines with a consented capacity of 86 MW. The Scottish Minister, on the advice of nature conservation bodies, consented the whole project on the condition that the first phase of development was implemented with only six turbines and those turbines were monitored before the deployment of additional turbines (Marine Scotland 2013). The conclusions derived from the environmental assessment process, prescribed under the European Union (EU) Habitats Directive (1992), were that significant adverse effects might occur as a result of predicted levels of collision with protected species, including seabirds, grey seals (*Halichoerus grypus*), harbor seals (*Phoca vitulina*), Atlantic salmon (*Salmo salar*), and sea lampreys (*Petromyzon marinus*).

Phase 1a was limited to six turbines and subject to a comprehensive monitoring program designed to measure the behavior of mobile species near the turbines and the findings were to be used to validate collision risk models. All subsequent project phases are subject to prior approval to assure development consents are given with full knowledge of the potential impacts on protected species. AM enabled the developer to achieve the full project consent necessary for investor confidence, while delivering a phased approach following the survey-deploy-monitor licensing policy for licensing (Marine Scotland 2016). In 2017, Marine Scotland granted development consent to install Phase 1b, which comprised four more turbines of 6 MW each. Deployment of Phase 1c is intended to take place in 2021–2022 and will be highly contingent upon monitoring outcomes from Phases 1a and 1b. If deployed, Phase 1c will consist of a further 49 turbines, bringing the total capacity of Phase 1 to 86 MW. Further information about the specifics of the AM plan and results of environmental monitoring for MeyGen can be found in Chapter 3 (Collision Risk for Animals around Turbines); however, some results are commercially sensitive and not yet publicly available.

12.4.2. SEAGEN TIDAL TURBINE

The Northern Ireland Environment and Heritage Service and Marine Current Turbines (MCT) installation applied an AM approach to the deployment and operation of MCT's SeaGen turbine in Strangford Lough (Northern Ireland). Strangford Lough is designated as a Special Area of Conservation (SAC) and Special Protection Area (SPA) under the EU Habitats Directive (1992) and Birds Directive (2009). The main environmental concern was whether the turbine would have an adverse impact on the use of the Lough by harbor seals, a feature of the SAC that has an unfavorable conservation status (Keenan et al. 2011). There was also uncertainty about whether there was a risk of collision for harbor seal and harbor porpoises (*Phocoena phocoena*) with the turbine blades. Although not a protected species of the SAC, harbor porpoises are subject to a strict protection regime to keep them from harm, including death, physical injury, and disturbances, under the Habitats Directive (1992). In this case, the key aspects of AM focused on marine mammals. A comprehensive environmental monitoring plan was developed as a condition of the license and was complemented by an AM approach that required continuous review of monitoring data and management measures by an independently chaired Scientific Steering Group. Monitoring objectives for marine mammals included a zero-risk mortality tolerance for collision with the turbine blades (Savidge et al. 2014). Associated mitigation measures included a restriction to daylight operation and the use of Marine Mammal Observers (MMOs) onboard the tidal platform; the MMOs had the ability to shut down the turbine whenever marine mammals were observed to cross the agreed-upon shutdown action perimeter of 200 m (Fortune 2017). The effectiveness of an active experimental sonar system was also tested as a mitigation measure to assist in the detection of marine mammals (Hastie et al. 2014).

After three years of post-installation monitoring, marine mammals appeared to be unlikely to collide with the turbine within the agreed-upon shutdown action perimeter. Monitoring activities showed that seals and harbor porpoises tend to avoid the SeaGen turbine, which reduced the likelihood of marine mammal collisions (Keenan et al. 2011). Field data provided indications that SeaGen did not create a barrier effect for harbor seals transiting through the Strangford Narrows; they continued to use haulout sites during turbine operation (Sparling et al. 2017). Monitoring data also demonstrated that active sonar was effective in mitigating collision risk in a manner comparable to MMOs (Fortune 2017). Mitigation monitoring changed from daylight only with MMOs on the turbine structure to 24-hour manual observation of active sonar, which allowed the turbine to be operated on a 24-hour basis, but with the significant requirement for trained personnel to be on duty whenever the turbine was operating. As knowledge of the environmental effects of SeaGen increased, the precautionary shutdown distance was progressively reduced from 200 m to 100 m, and then to less than 30 m (Savidge et al. 2014). Final removal of the shutdown protocol, with associated fine-scale monitoring around the turbine blades using a new multibeam sonar system, albeit authorized, was not implemented before the device stopped operating in 2015, prior to eventual decommissioning in 2019. The mitigation requirements resulted in missed opportunities to gain relevant knowledge about how marine mammals interact with the operating turbine blades. Despite this, the AM process allowed MCT to install and operate the SeaGen turbine over a period of five years, thereby increasing the developer's confidence in the technology and its capacity to deliver power to the grid (Fortune 2017).

12.4.3. DELTASTREAM TIDAL TURBINE

An AM approach was used to license Tidal Energy Limited's grid-connected 400 kW DeltaStream tidal energy project in Ramsey Sound, off the Pembrokeshire coast in Wales. Ramsey Sound is within a SAC and adjacent to an SPA designated under the EU Habitats Directive (1992) and Birds Directive (2009). The license for installation and operation was granted in 2011 by Natural Resources Wales for a 12-month deployment period of a single 400 kW turbine mounted on a steel triangular gravity-based frame. DeltaStream was successfully deployed and connected to the grid in 2015. The greatest environmental concerns were for the collision with the turbine of a variety of cetacean species protected from killing or disturbance under the Habitats Directive (1992), including harbor porpoise and grey seal. The DeltaStream project relied on a threshold-based approach to AM where acceptable collision thresholds were set using a potential biological removals (PBR) approach (Copping et al. 2016.). PBR is a widely used method of determining the level of additional manmade mortality a population can sustain without adversely affecting its size and stability (Wade 1998). A detailed Collision Monitoring and Adaptive Management Plan established the approach to marine mammal monitoring to determine the real level of collision risks in the face of uncertainty (Copping et al. 2016; Sparling, personal communication). The nearfield monitoring planned for this project included a passive acoustic monitoring system with several hydrophones directly mounted on the turbine substructure together with an active acoustic monitoring system that used a multibeam sonar to detect animals approaching the device (Malinka et al. 2018). Unlike the SeaGen turbine project, the DeltaStream project had no shutdown mitigation requirements, but it applied a flexible AM approach in which the need for mitigation could be identified and required by the Environmental Management Body to reduce the risk of collision-related mortalities and ensure that thresholds were not breached (Copping et al. 2016; Sparling, personal communication). The mitigation steps outlined in the collision risk management plan included the potential for limiting turbine operation during sensitive times and the use of acoustic deterrents. By consenting the project without the need for a shutdown protocol, the deployment of the DeltaStream turbine was designed to provide information about close-range interactions between marine mammals and the operating device to work in conjunction with an acoustic strike detection system that appeared to be highly reliable to detect collisions. However, as the project progressed, the ability of the nearfield monitoring to confidently detect collisions using a strike-detection system became highly uncertain. The DeltaStream project illustrates the challenges of monitoring in the presence of thresholds in AM (as discussed in Section 12.2.1), because these thresholds require the ability to accurately monitor and detect certain metrics of concern to confirm whether an unacceptable impact occurs or a threshold/trigger has been reached. Because of equipment failure and subsequent liquidation of Tidal Energy Limited, the DeltaStream turbine and monitoring system was never operated for any significant length of time.

12.4.4. ROOSEVELT ISLAND TIDAL ENERGY PROJECT

In 2012, the U.S. Federal Energy Regulation Commission (FERC) issued a 10-year Pilot License (FERC No.12611) to Verdant Power for the installation of up to 30 hydrokinetic turbines to be deployed during three phases in the east channel of the East River (New York, U.S.). The first phase of Verdant Power's Roosevelt Island Tidal Energy (RITE) project consisted of three turbines mounted on a tri-frame with a total capacity of 105 kW (Verdant Power 2010a). Three additional redesigned tri-frames and nine turbines will be installed in 2020, with a total capacity of 420 kW. The last phase will culminate with the installation of 6 tri-frames supporting 18 additional turbines, with a total capacity of 1 MW. The project represents the application of AM to support the execution of a series of seven RITE Monitoring of Environmental Effects (RMEE) plans (Verdant Power 2010b). In this particular case, AM was not applied to adapt the management of the project. Instead, AM was directed at reducing scientific uncertainty within the RMEE plans to address key environmental questions related to the characterization of species and the effects of the turbine (and generated operating noise) on the presence, distribution, and abundance of aquatic species. The RMEE plans consisted of seven focal monitoring studies addressing (1) the micro-scale interaction of aquatic species with the turbine, (2) the fish composition in the immediate vicinity of the project, (3) the occurrence of protected fish species under the Endangered Species Act (1973), (4) the potential for turbine impacts on seabirds, (5) the occurrence of underwater noise generated by the project, and (7) the installation's impact on recreation (Verdant Power 2019). During the AM process, the usefulness of the data collected was reviewed to suggest adjustments of the RMEE plans and/or suspend their implementation until the data yielded sufficient information to provide complete understanding of the fundamental questions to be answered under each RMEE plan. Hydroacoustic data enabled Verdant to suspend use of the seasonal Dual-Frequency Identification Sonar (DIDSON) observation plan based on the finding that further DIDSON data collection would not yield additional information about fish interactions (Verdant Power 2018). The DIDSON system also was found to have achieved its objective of providing real-time observation of fish behavior at the micro-scale to enable refinement of the Fish Interaction Model. With these data incorporated, the model suggested that there was a low probability that fish would collide with the turbine blades of the up to 30 turbines planned for installation. AM allowed Verdant to discontinue surveys that do not yield meaningful information and redirect monitoring efforts toward continually enhancing monitoring plans for species of concern.

12.4.5. REEDSPORT WAVE PARK

Ocean Power Technology (OPT)'s Reedsport Wave Park project received a full commercial-scale license in August 2012 to operate up to 10 grid-connected PowerBuoy wave energy converters (WECs), each of which has a capacity of 1.5 MW. A preliminary consent was also secured by OPT to install additional WECs during future phases, which could have brought the overall capacity to 50 MW. Reedsport Wave Park was proposed under a phased consenting approach using AM as a cornerstone. Under terms of the license, Phase 1 consisted of installing a single 150 kW unit largely intended to test the mooring system and the WEC operation, and to collect data about electromagnetic fields (EMFs) and the underwater noise of the device. An AM process was embedded in a Settlement Agreement, which included following a long-term process of engagement with stakeholders and regulatory agencies (OPT 2010). The AM process for OPT aimed at "managing the development and operation of the project in an adaptive manner to avoid and minimize adverse effects to aquatic resources, water quality, recreation, public safety, crabbing and fishing, terrestrial resources and cultural resources" (OPT 2010). Specifically, the project AM was intended to support the implementation of monitoring studies and to identify and adjust measures required to address any unanticipated effects of the project and its potential expansion (OPT 2010). The Settlement Agreement included detailed environmental studies for pinnipeds and cetaceans, EMFs, fish, and seabirds, as well as changes in waves, currents, and sediment transport. The requirements of the agreement relied on the screening criteria that could define changes in project design, monitoring, or management practices if prescribed by an advisory body (or Implementation Committee), to avoid or minimize potential adverse impacts. The screening criteria included detailed baseline characterizations of marine mammal behavior (in the absence of devices) and their response to EMFs and underwater noise. Particular attention was given to whether marine mammals were likely to collide with or become entangled in mooring systems. If the project had an adverse effect on baseline conditions, OPT was required to prepare an avoidance, minimization, and mitigation plan (Response Plan) that included alternative management measures. Alternative management measures were not determined at the start but were left to the later determination of the developer and approval by the competent Implementation Committee. At this point in time, the extent to which AM contributed to reducing uncertainty and informing the future expansion of Reedsport Wave Park cannot be evaluated, because the FERC license was surrendered two years after the project was approved. The license was surrendered mainly because of difficulties related to financing Phase 1 and technical complications resulting from installation of the floating gravity-based anchor, as well as the unfortunate sinking of the subsurface buoyancy float. The project was withdrawn before the AM process could be applied to the full project timeline (O'Neil et al. 2019).

12.4.6 ORPC'S TIDGEN AND RIVGEN POWER SYSTEMS

Ocean Renewable Power Company (ORPC) has a track record of implementing AM to reduce scientific uncertainty when modifying project operations and monitoring methodologies at the scale of single devices (e.g., TidGen and RivGen projects). Using conditional licensing, with AM as a basis, ORPC was granted a Pilot Project License (FERC No. 12711-005) by FERC in 2012 to install and operate TidGen, a single horizontal-axis tidal turbine, in Cobscook Bay, Maine (U.S.) (FERC No. 12711-005). An AM plan that served as the foundation for monitoring and science-based decision-making was required under the Pilot License. The AM plan was developed by ORPC's Adaptive Management Team (AMT) in consultation with regulatory agencies, stakeholders, and local communities. Using the AM process, ORPC, with the support of the AMT, was able to demonstrate that their single tidal unit would have minimal effects on marine wildlife. The process resulted in a number of license modifications that clarified the monitoring requirements and, in some cases, lowered the frequency of monitoring required for specific surveys (ORPC 2017). The core objective of monitoring was to collect data about fisheries and marine life interactions with the turbine and to measure the effects of underwater noise on sockeye salmon (*Oncorhynchus nerka*), marine mammals, and seabirds (ORPC 2013). Data were collected under six monitoring plans; AM provided a strategy for evaluating the monitoring results and making informed decisions about the modification of monitoring plans, as needed.

Initially, the Pilot License for the TidGen project imposed a seasonal restriction window on pile-driving operations because of the presence of migrating Atlantic salmon. Alleviation of seasonal restrictions under the AM plan was dependent on the results of underwater monitoring, which demonstrated that sound levels produced by pile-driving hammer techniques (outside the restriction period) did not exceed the acceptable threshold established by the National Marine Fisheries Service (NMFS 2018). Underwater noise measurements from the installation of TidGen indicated that noise levels were below the thresholds of concern for Atlantic salmon when sound absorption measures, including the placement of plywood between the impact hammer and the follower, were used during pile driving (ORPC 2013). Using these thresholds and transferring underwater noise data from a previous project allowed ORPC to request the removal of seasonal restrictions on pile-driving for Phase 1 operations, which was granted by FERC.

Monitoring for marine mammals during the installation and operational phase included incidental and dedicated observations made by trained MMOs. Incidental observations were performed over several seasons to observe marine mammal presence and behavior around the turbine prior to, during, and after key installation and maintenance activities, including pile-driving (ORPC 2013). Mitigation for the presence of marine mammals entering or approaching a 152 m marine mammal exclusion zone during pile-driving included curtailment and delay of installation activities (ORPC 2013). Cessation of pile-driving activities was required until the marine mammal had moved beyond 305 m (1000 ft) from the exclusion zone or 30 minutes had passed since the last sighting (ORPC 2013). Dedicated marine mammal observations indicated minimal changes in animal presence and behavior as a result of generated noise levels during pile-driving activities (ORPC 2013). Marine mammals were not visually observed to enter the exclusion zone; therefore, the shutdown and delay procedures were not triggered during the installation period (ORPC 2013). Incidental marine mammal sightings did not indicate any behavioral changes or evidence of adverse encounters or collisions during the installation and operation of TidGen (ORPC 2014). These findings resulted in a FERC license order that allowed ORPC to fully transition from dedicated observations, whereby marine mammals are recorded by certified MMOs as part of a dedicated survey effort, to incidental marine mammal observations (ORPC 2014).

In a similar approach, during 2014 and 2015 AM allowed for the deployment of the RivGen demonstration project in the Kvichak River in Alaska, U.S., without requiring a FERC Pilot License. A fish monitoring plan required the use of underwater video cameras to monitor fish interactions with the device and the evaluation and mitigation of possible adverse effects on sockeye salmon. The video footage revealed the absence of physical injuries and no altered behavior of the fish in the immediate vicinity of the turbine. It was determined that mitigation measures were not necessary. In this way, AM was able to contribute to the retirement of collision risk for fish around the single RivGen tidal unit (ORPC 2016). These findings were also presented by ORPC at the Cobscook Bay Tidal Energy Project AMT meeting in 2014 and 2015 (ORPC 2015, 2016), suggesting that transfer of data is a real possibility from the industry perspective and can definitely be used to inform future developments (see Chapter 13, Risk Retirement and Data Transferability for Marine Renewable Energy). The 2015 monitoring project is referenced in the FERC license for the next stage of the Iguigig Hydrokinetic Project (FERC No. 13511-003) and the methods used previously will be implemented again, more extensively (FERC 2019). The short sampling periods in 2014 and 2015 limited broader transferability of the data.

Knowledge gained at the RivGen demonstration project facilitated the issuance of a recent Pilot License authorizing the installation and operation of the current phase of the RivGen project in the Kvichak River, near the village of Iguigig. The RivGen project consists of two in-stream turbine generator units (TGUs), each of 35 kW capacity, to be deployed in two distinct phases. Installation of TGU 1 (Phase 1) was completed in 2019. Installation of TGU 2 (Phase 2) is planned for 2020 (FERC No. 13711-003). The project relies heavily on AM to address environmental unknowns and take corrective actions if monitoring indicates any unanticipated adverse effects on aquatic animals (FERC No. 13711-003, Article 403). The Pilot License includes requirements for real-time video monitoring and the immediate shutdown of the project within one hour if injuries or mortality of outmigrating sockeye smolts are detected as a result of turbine operation. The Emergency Shutdown Plan, which includes provisions for monitoring and reporting, will serve as a source of information for recommending corrective mitigation actions (FERC 2019). If fish monitoring data provide evidence of negative interactions (injuries or mortality) on migrating salmon, the AMT may have to consider additional monitoring efforts and implement work timing windows to reduce and/or eliminate negative impacts on fish populations (FERC No. 13711-003, Article 403). Conversely, if no adverse effects are observed throughout the first year of operation, the AMT may submit recommendations to FERC to modify the monitoring protocol and shutdown plan.

Overall, the RivGen and TidGen projects provide examples of how AM may be used to understand environmental risks, inform best management practices, and modify license requirements based on increased data collection and understanding of environmental effects and species interactions (Johnson 2016).

12.4.7 PACWAVE SOUTH PROJECT

Oregon State University (OSU) developed a detailed AM framework to support a license application to install and operate a grid-connected wave energy test facility: the PacWave South Project, formerly known as Pacific Marine Energy Center South Energy Test Site. The project consists of four grid-connected berths to support testing of up to 20 commercial-scale WECs with a maximum installed capacity of 20 MW. As part of their AM framework, OSU has committed to implementing monitoring programs for underwater noise, habitat changes, and EMFs to confirm assumptions about the levels and durations of potential effects, coupled with processes for taking corrective actions in consultation with competent regulatory agencies (OSU 2019a). The AM framework for PacWave South seems to embody a prescribed approach to AM, whereby monitoring results are evaluated in consultation with an Adaptive Management Committee (AMC) and agency stakeholders to review project effects, make changes to monitoring, and engage specific responsive actions where these effects exceed certain thresholds or mitigation criteria. The AM framework will also inform decisions, including those about the need to adopt additional protection, mitigation, and enhancement measures to assure that the potential effects are within the thresholds and meet the criteria prescribed for the project.

For example, with respect to benthic habitats, if monitoring results indicate that WECs and their components have a statistically significant impact beyond the range of seasonal/interannual variability on macrofaunal species composition or abundance, OSU will be obliged to submit a draft plan to implement the following mitigation actions with accompanying implementation timelines and monitoring provisions to assess the effectiveness of the measures (OSU 2019a):

- Limit use of specific anchor types in future installations.
- Modify and manage the deployment frequency or location to enable recovery of macrofauna.
- Use permanent anchoring systems (e.g., for the life of the project).
- Conduct additional *in situ* monitoring.

Similarly, if underwater noise monitoring results show persistent exceedance of published harassment thresholds (120 dB re 1 µPa) at a distance of 100 m from the WECs or their mooring systems, OSU is obliged to instruct testing clients to diagnose and repair or modify the WECs or mooring systems within 60 days, to continue monitoring activities, and to demonstrate the effectiveness of the noise abatement measures. In addition, OSU is required to notify NMFS about whether further exceedances of harassment thresholds occur after implementation of the corrective actions. If, despite repairs and modifications, the noise level is not reduced below acceptable thresholds, further actions are prescribed, including the provision of a draft plan specifying the following, among other actions:

- alternative or additional methods of monitoring to identify the source and cause of the noise and to inform specific actions necessary to reduce the noise below the threshold
- modifications to the operation of the WECs (e.g., modify controls to change the motion of the WECs)
- necessary repairs and modifications to reduce noise levels.

If after taking these steps, noise levels are not abated within 14 days, the operation of WECs will be temporarily ceased to halt noise threshold exceedances (OSU 2019a).

While it goes beyond the scope of this chapter to detail the catalog of measures and the AM process applied by PacWave South, the approach is relatively similar with respect to EMFs. If post-installation field measurements and modeling results detect EMF emissions greater than biologically relevant levels (e.g., 3 mT), OSU has the obligation to notify the AMC and instruct testing clients to adopt specific actions, including, but not limited to, installing additional shielding of subsea cables or other components such as hubs or subsea connectors. Further *in situ* monitoring is prescribed to verify the abatement of excess EMF levels, and if EMF levels cannot be minimized, a draft mitigation plan must be prepared to implement specified mitigation actions until the source of exceedance is reduced to below the acceptable threshold.

Further information can be found in the FERC license application (OSU 2019a) and the accompanying AM Framework (OSU 2019b).

12.5. CONCLUSIONS AND RECOMMENDATIONS

This chapter provides an explanation of AM and how its underlying principles may be applied to developing effective approaches for addressing uncertainty and knowledge gaps in consenting processes. To date, AM has contributed to risk retirement by allowing single devices or small arrays to be deployed under a structured incremental approach with embedded mitigation and monitoring, thereby providing valuable information about device-specific stressor/receptor interactions. As the industry moves toward commercial deployment, implementation guidance should be issued by responsible governmental bodies to support a common understanding of AM and guide the design of AM plans at the scale of MRE arrays. The industry will particularly benefit from guidance documents that specify the circumstances under which AM is acceptable and establish clear and mandatory elements of AM plans, including the design of and conditions for post-installation monitoring, stakeholder engagement, information sharing, and thresholds for AM intervention.

As the industry moves forward, MRE developers that use AM for marine renewables could learn from their fisheries counterparts by using clearly controlled rules for monitoring and evaluating project effects relative to predefined thresholds, including the ability to adjust mitigation and monitoring as part of a formal structured AM process (McDonald et al. 2017; Sainsbury et al. 2000). Monitoring approaches must be question-driven and the questions must be directly connected to thresholds/triggers to avoid unacceptable impacts. In practice, designing monitoring that informs and works with thresholds may be extremely challenging; it requires the ability to confidently measure and monitor the appropriate metrics of concern with the required levels of accuracy and precision to inform management decisions.

It is important to realize that engaging in an AM approach may not result in quick wins: AM is a long process that requires forethought and commitment, and AM comes with a degree of risk for developers. Developers must accept that the operational schemes of their projects might be altered or terminated if monitoring indicates harm is being done to sensitive species or other valuable uses. Large MRE projects consented on the basis of AM informing project phasing might never achieve full build out, and regulators might require project decommissioning if the related impacts are deemed unacceptable. Likewise, the success of AM largely depends on the regulator's risk acceptance and attitude about proportionality. Before engaging in an AM approach, regulators and developers should undertake an explicit, structured analysis of the resources they have available and consider the need for and practicality of reducing uncertainties. While AM offers some flexibility to consent and deploy MRE projects despite uncertainty, AM at larger deployment scales has the potential to become an onerous process that creates significant financial uncertainty for project developers. To date, AM is the only known method capable of dealing with the levels of existing uncertainty associated with MRE projects as well as the interaction of MRE projects with other industries and other challenges, including climate change. Advancing the use of AM for MRE will require the development of mechanisms that minimize undue financial risks for developers, while assuring adequate protection of the marine environment and consistency relative to the precautionary principle.

12.6. REFERENCES

Bennet, F., Culloch, R., and Tait, A. 2016. Guidance on effective adaptive management and post-consent monitoring strategies (RiCORE Project Report No. RiCORE-D5-2D5-4). Report by Robert Gordon University for European Commission; Aberdeen, Scotland. *https://tethys.pnnl.gov/publications/guidance-effective-adaptive-management-post-consent-monitoring-strategies*

Birds Directive (Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds). OJ L 20, 26.1.2010, p. 7-25. [European Union]

Cooney, R. 2006. A long and winding road? Precaution from principle to practice in biodiversity conservation. In E. Fisher, J. Jones, and R. von Schomberg (Ed.), *Implementing the Precautionary Principle; Perspectives and Prospects* (pp. 223-244). Cheltenham, England: Edward Elgar Publishing Limited. *https://tethys.pnnl.gov/publications/long-winding-road-precaution-principle-practice-biodiversity-conservation*

Copping, A. 2018. The State of Knowledge for Environmental Effects: Driving Consenting/Permitting for the Marine Renewable Energy Industry. Report by Pacific Northwest National Laboratory for Ocean Energy Systems. *https://tethys.pnnl.gov/publications/state-knowledge-environmental-effects-driving-consentingpermitting-marine-renewable*

Copping, A., Gartman, V., May, R., and Bennet, F. 2019. The Role of Adaptive Management in the Wind Energy Industry. In R. Bispo, J. Bernardino, H. Coelho, and J. L. Costa (Eds.), *Wind Energy and Wildlife Impacts* (pp. 1-25). Cham, Switzerland: Springer. *https://tethys.pnnl.gov/publications/role-adaptive-management-wind-energy-industry*

Copping, A., Sather, N., Hanna, L., Whiting, J., Zydlewski, G., Staines, G., Gill, A., Hutchinson, 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*

Elliott, K., Smith, H. C. M., Moore, F., van der Weijde, A. H., and Lazakis, I. 2019. A systematic review of transferable solution options for the environmental impacts of tidal lagoons. *Marine Policy*, 99, 190-200. doi:10.1016/j.marpol.2018.10.021 *https://tethys.pnnl.gov/publications/systematic-review-transferable-solution-options-environmental-impacts-tidal-lagoons*

Endangered Species Act of 1973, as amended. 16 U.S.C. ch. 35 § 1531 et seq. [U.S.]

Federal Energy Regulatory Commission (FERC). 2019. Environmental Assessment for Hydropower License: Igiugig Hydrokinetic Project - FERC Project No. 13511-003. Office of Energy Projects, Washington, D.C. *https://tethys.pnnl.gov/publications/environmental-assessment-hydropower-license*

Fortune, F., Gilmore, P., and Bennet, F. 2017. Adaptive Management Systems - Don't make the same mistakes twice! Webinar conducted by European Technology and Innovation Platform for Ocean Energy (ETIP) Ocean. *https://tethys.pnnl.gov/events/webinar-adaptive-management-systems-dont-make-same-mistakes-twice*

Fox, C. J., Benjamins, S., Masden, E. A., and Miller, R. 2018. Challenges and opportunities in monitoring the impacts of tidal-stream energy devices on marine vertebrates. *Renewable and Sustainable Energy Reviews*, 81(2), 1926-1938. doi:10.1016/j.rser.2017.06.004 *https://tethys.pnnl.gov/publications/challenges-opportunities-monitoring-impacts-tidal-stream-energy-devices-marine*

Gillespie, A. 2013. Conservation, Biodiversity and International Law. Cheltenham, England: Edward Elgar Publishing. *https://tethys.pnnl.gov/publications/conservation-biodiversity-international-law*

Greig, L., and Murray, C. 2008. Peer Review of Rockfort Quarry Adaptive Management Plan. Jagger Hims Ltd., Collingwood, Ontario. *https://www.peelregion.ca/planning/pdf/rockfort/rockfort2.pdf*

Habitats Directive (Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora). OJ L 206, 22.7.1992, p. 7-50. [European Union]

Hanna, L., Copping, A., Geerlofs, S., Feinberg, L., Brown-Saracino, J., Bennet, F., May, R., Köpel, J., Bulling, L., and Gartman, V. 2016. Adaptive Management White Paper. IEA Wind Task 34: Assessing Environmental Effects (WREN) Technical Report. Report by Berlin Institute of Technology of International Energy Agency. *https://tethys.pnnl.gov/publications/assessing-environmental-effects-wren-adaptive-management-white-paper*

Hastie, G. D., Gillespie, D. M., Gordon, J. C. D., Macaulay, J. D. J., McConnell, B. J., and Sparling, C. E. 2014. Tracking Technologies for Quantifying Marine Mammal Interactions with Tidal Turbines: Pitfalls and Possibilities. In M. A. Shields and A. I. L. Payne (Eds.), *Marine Renewable Energy Technology and Environmental Interactions* (pp. 127-139). Dordrecht: Springer Netherlands. *https://tethys.pnnl.gov/publications/tracking-technologies-quantifying-marine-mammal-interactions-tidal-turbines-pitfalls*

Johnson, C. J. 2013. Identifying ecological thresholds for regulating human activity: Effective conservation or wishful thinking? *Biological Conservation*, 168, 57-65. doi:10.1016/j.biocon.2013.09.012 *https://tethys.pnnl.gov/publications/identifying-ecological-thresholds-regulating-human-activity-effective-conservation-or*

Johnson, N. 2016. Adaptive Management in the Marine Renewable Energy Industry. Webinar conducted by Ocean Energy Systems Annex IV. *https://tethys.pnnl.gov/events/adaptive-management-marine-renewable-energy-industry-webinar*

Jones, G. 2005. Is the management plan achieving its objectives? In G. L. Worboys, M. Lockwood, and T. De Lacy (Eds. Second ed.), *Protected Area Management: Principles and Practice* (pp. 555-557). Melbourne, Australia: Oxford University Press. *https://tethys.pnnl.gov/publications/management-plan-achieving-its-objectives*

Keenan, G., Sparling, C., Williams, H., and Fortune, F. 2011. SeaGen Environmental Monitoring Programme: Final Report. Report by Royal Haskoning for Marine Current Turbines; Edinburgh, Scotland. *https://tethys.pnnl.gov/publications/seagen-environmental-monitoring-programme-final-report*

Köppel, J., Dahmen, M., Helfrich, J., Schuster, E., and Bulling, L. 2014. Cautious but Committed: Moving Toward Adaptive Planning and Operation Strategies for Renewable Energy's Wildlife Implications. *Environmental Management*, 54(4), 744-755. doi:10.1007/s00267-014-0333-8 *https://tethys.pnnl.gov/publications/cautious-committed-moving-toward-adaptive-planning-operation-strategies-renewable*

Kriebel, D., Tickner, J., Epstein, P., Lemons, J., Levins, R., Loechler, E. L., Quinn, M., Rudel, R., Schettler, T., and Stoto, M. 2001. The precautionary principle in environmental science. *Environmental Health Perspectives*, 109(9), 871-876. doi:10.1289/ehp.01109871 *https://tethys.pnnl.gov/publications/precautionary-principle-environmental-science*

Le Lièvre, C. 2019. Sustainably reconciling offshore renewable energy with Natura 2000 sites: An interim adaptive management framework. *Energy Policy*, 129, 491-501. doi:10.1016/j.enpol.2019.02.007 *https://tethys.pnnl.gov/publications/sustainably-reconciling-offshore-renewable-energy-natura-2000-sites-interim-adaptive*

Le Lièvre, C., O'Hagan, A., Culloch, R., Bennet, F., and Broadbent, I. 2016. Legal feasibility of implementing a risk-based approach to MRE consenting and compatibility with Natura 2000 network (RiCORE Project Report No. 2.3 & 2.4). Report by University College Cork for European Commission; Aberdeen, Scotland. *https://tethys.pnnl.gov/publications/legal-feasibility-implementing-risk-based-approach-mre-consenting-compatibility-natura*

Magagna, D., Greaves, D., Conley, D., O'Hagan, A. M., Holmes, B., Witt, M., Simas, T., Olivares, C. H., Leitão, J. C., Mouslim, H., Torre-Enciso, Y., Sundberg, J., and Rousseau, N. 2012. How Experiences of the Offshore Wind Industry Can Aid Development of the Wave Energy Sector: Lessons Learnt From EIA Studies. Paper presented at the 22nd International Offshore and Polar Engineering Conference, Rhodes, Greece. *https://tethys.pnnl.gov/publications/how-experiences-offshore-wind-industry-can-aid-development-wave-energy-sector-lessons*

Malinka, C. E., Gillespie, D. M., Macaulay, J. D. J., Joy, R., and Sparling, C. E. 2018. First *in situ* passive acoustic monitoring for marine mammals during operation of a tidal turbine in Ramsey Sound, Wales. *Marine Ecology Progress Series*, 590, 247-266. doi:10.3354/meps12467 *https://tethys.pnnl.gov/publications/first-situ-passive-acoustic-monitoring-marine-mammals-during-operation-tidal-turbine*

Marine Scottland. 2013. MeyGen Decision - Decision Letter Consent and Conditions. Scottish Government. *https://tethys.pnnl.gov/publications/consent-granted-scottish-ministers-construct-operate-meygen-tidal-energy-project*

Marine Scottland. 2016. Survey, Deploy and Monitor Licensing Policy Guidance. Scottish Government. *https://tethys.pnnl.gov/publications/survey-deploy-monitor-licensing-policy-guidance*

McDonald, G., Harford, B., Arrivillaga, A., Babcock, E. A., Carcamo, R., Foley, J., Fujita, R., Gedamke, T., Gibson, J., Karr, K., Robinson, J., and Wilson, J. 2017. An indicator-based adaptive management framework and its development for data-limited fisheries in Belize. *Marine Policy*, 76, 28-37. doi:10.1016/j.marpol.2016.11.027 *https://tethys.pnnl.gov/publications/indicator-based-adaptive-management-framework-its-development-data-limited-fisheries*

Morgera, E. 2017. The ecosystem approach and the precautionary principle. In M. Faure, E. Morgera, and J. Razzaque (Eds.), *Elgar Encyclopedia of Environmental Law: Biodiversity and Nature Protection Law* (Vol. III, pp. 70-80). Cheltenham, England: Edward Elgar Publishing. *https://tethys.pnnl.gov/publications/ecosystem-approach-precautionary-principle*

National Marine Fisheries Service (NMFS). 2018. 2018 Revision to: Technical Guidance for Assessing the Effects of Anthropogenic Sound on Marine Mammal Hearing (Version 2.0): Underwater Thresholds for Onset of Permanent and Temporary Threshold Shifts (NMFS-OPR-59). Report by National Oceanic and Atmospheric Administration for U.S. Department of Commerce; Silver Spring, Maryland. *https://tethys.pnnl.gov/publications/2018-revisions-technical-guidance-assessing-effects-anthropogenic-sound-marine-mammal*

Ocean Power Technologies (OPT). 2010. Reedsport OPT Wave Park Settlement Agreement. Report by Ocean Power Technologies; Reedsport, Oregon. *https://tethys.pnnl.gov/publications/reedsport-opt-wave-park-settlement-agreement*

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). 2014. 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) 2015. Cobscook Bay Tidal Energy Project: 2014 Environmental Monitoring Report. Report by Ocean Renewable Power Company; Portland, Maine. *https://tethys.pnnl.gov/publications/cobscook-bay-tidal-energy-project-2014-environmental-monitoring-report*

Ocean Renewable Power Company (ORPC). 2016. Cobscook Bay Tidal Energy Project: 2015 Environmental Monitoring Report. Report by Ocean Renewable Power Company; Portland, Maine. *https://tethys.pnnl.gov/publications/cobscook-bay-tidal-energy-project-2015-environmental-monitoring-report*

Ocean Renewable Power Company (ORPC). 2017. Cobscook Bay Tidal Energy Project: 2016 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*

Offshore Renewables Joint Industry Programme (ORJIP) Ocean Energy. 2017. The Forward Look: An Ocean Energy Environmental Research Strategy for the UK. Report by Aquatera Ltd for The Crown Estate, Marine Scotland Science, Welsh Assembly Government, Scottish Natural Heritage, Natural Resources Wales; Stromness, Scotland. *https://tethys.pnnl.gov/publications/forward-look-ocean-energy-environmental-research-strategy-uk*

O'Neil, R., Staines, G., and Freeman, M. 2019. Marine Hydrokinetics Regulatory Processes Literature Review. Report by Pacific Northwest National Laboratory for U.S. Department of Energy; Richland, Washington. *https://tethys.pnnl.gov/publications/marine-hydrokinetics-regulatory-processes-literature-review*

Oregon State University (OSU). 2019a. Final License Application for the PacWave South Project (FERC Project No. 14616). Volume III: Appendix I: Potection, Mitigation, and Enhancement Measures. Report by Oregon State University; Corvallis, Oregon. *https://tethys.pnnl.gov/publications/pacwave-south-license-application*

Oregon State University (OSU). 2019b. Final License Application for the PacWave South Project (FERC Project No. 14616). Volume III: Appendix J: Adaptive Management Framework. Report by Oregon State University; Corvallis, Oregon. *https://tethys.pnnl.gov/publications/pacwave-south-license-application*

Pembina Institute for Appropriate Development v. Canada, 2008 FC 302, para. 32. [Canada]

Sainsbury, K. J., Punt, A. E., and Smith, A. D. M. 2000. Design of operational management strategies for achieving fishery ecosystem objectives. *ICES Journal of Marine Science*, 57(3), 731-741. doi:10.1006/jmsc.2000.0737 *https://tethys.pnnl.gov/publications/design-operational-management-strategies-achieving-fishery-ecosystem-objectives*

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*

Sparling, C., Thompson, D., and Booth, C. 2017. Guide to Population Models used in Marine Mammal Impact Assessment. JNCC Report No. 605. Report by Joint Nature Conservation Committee (JNCC), Peterborough, England. *https://tethys.pnnl.gov/publications/guide-population-models-used-marine-mammal-impact-assessment*

Tickner, J., and Kriebel, D. 2008. The role of science and precaution in environmental and public health policy. In E. Fisher, J. Jones, and R. Von Schomberg (Eds.), *Implementing the Precautionary Principle: Perspectives and Prospects* (pp. 58-78). Cheltenham, England: Edward Elgar Publishing. *https://tethys.pnnl.gov/publications/implementing-precautionary-principle*

Todt, O., and Luján, J. L. 2014. Analyzing Precautionary Regulation: Do Precaution, Science, and Innovation Go Together? *Risk Analysis*, 34(12), 2163-2173. doi:10.1111/risa.12246 *https://tethys.pnnl.gov/publications/analyzing-precautionary-regulation-do-precaution-science-innovation-go-together*

Trouwborst, A. 2006. Precautionary Rights and Duties of States. Leiden, Netherlands: Martinus Nijhoff Publishers. *https://tethys.pnnl.gov/publications/precautionary-rights-duties-states*

van Asselt, M., and Vos, E. 2006. The Precautionary Principle and the Uncertainty Paradox. *Journal of Risk Research*, 9(4), 313-336. doi:10.1080/13669870500175063 *https://tethys.pnnl.gov/publications/precautionary-principle-uncertainty-paradox*

van Hees, S. 2018. Large-scale Water-related Innovative Renewable Energy Projects and the Habitats and Birds Directives: Legal Issues and Solutions. *European Energy and Environmental Law Review*, 27(1), 15-36. *https://tethys.pnnl.gov/publications/large-scale-water-related-innovative-renewable-energy-projects-habitats-birds*

Verdant Power. 2010a. Roosevelt Island Tidal Energy Project FERC No. 12611 (Volume 1 of 4). Report by Verdant Power LLC; New York, New York. *https://tethys.pnnl.gov/publications/final-pilot-license-application-roosevelt-island-tidal-energy-project*

Verdant Power. 2010b. Roosevelt Island Tidal Energy Project FERC No. 12611 (Volume 4 of 4). Report by Verdant Power LLC; New York, New York. *https://tethys.pnnl.gov/publications/roosevelt-island-tidal-energy-project-rite-proposed-monitoring-plans-rite-monitoring*

Verdant Power. 2018. Appendix B: P12611- Addendum to Verdant Power RITE Draft License Application. Report by Verdant Power LLC; New York, New York. *https://tethys.pnnl.gov/publications/addendum-verdant-power-rite-draft-license-application*

Verdant Power. 2019. Roosevelt Island Tidal Energy Project, FERC No. P-12611, Article 401 RMEE Plan Amendments. Report by Verdant Power LLC; New York, New York. *https://tethys.pnnl.gov/publications/roosevelt-island-tidal-energy-project-ferc-no-p-12611-article-401-rmee-plan-amendments*

Wade, P. R. 1998. Calculating Limits to the Allowable Human-Caused Mortality of Cetaceans and Pinnipeds. *Marine Mammal Science*, 14(1), 1-37. doi:10.1111/j.1748-7692.1998.tb00688.x *https://tethys.pnnl.gov/publications/calculating-limits-allowable-human-caused-mortality-cetaceans-pinnipeds*

Walters, C. 1986. Adaptive Management of Renewable Resources. Basingstoke, England: MacMillan Publishers Ltd. *https://tethys.pnnl.gov/publications/adaptive-management-renewable-resources*

Ward, R. C., Loftis, J. C., and McBride, G. B. 1986. The "data-rich but information-poor" syndrome in water quality monitoring. *Environmental Management*, 10(3), 291-297. doi:10.1007/BF01867251 *https://tethys.pnnl.gov/publications/data-rich-information-poor-syndrome-water-quality-monitoring*

Wilding, T. A., Gill, A. B., Boon, A., Sheehan, E., Dauvin, J. C., Pezy, J.-P., O'Beirn, F., Janas, U., Rostin, L., and De Mesel, I. 2017. Turning off the DRIP ('Data-rich, information-poor') – rationalising monitoring with a focus on marine renewable energy developments and the benthos. *Renewable and Sustainable Energy Reviews*, 74, 848-859. doi:10.1016/j.rser.2017.03.013 *https://tethys.pnnl.gov/publications/turning-drip-data-rich-information-poor-rationalising-monitoring-focus-marine*

Williams, B. K. 2011a. Adaptive management of natural resources—framework and issues. *Journal of Environmental Management*, 92(5), 1346-1353. doi:10.1016/j.jenvman.2010.10.041 *https://tethys.pnnl.gov/publications/adaptive-management-natural-resources-framework-issues*

Williams, B. K. 2011b. Passive and active adaptive management: Approaches and an example. *Journal of Environmental Management*, 92(5), 1371-1378. doi:10.1016/j.jenvman.2010.10.039 *https://tethys.pnnl.gov/publications/passive-active-adaptive-management-approaches-example*

Williams, B. K., and Brown, E. D. 2014. Adaptive Management: From More Talk to Real Action. *Environmental Management*, 53(2), 465-479. doi:10.1007/s00267-013-0205-7 https://tethys.pnnl.gov/publications/adaptive-management-more-talk-real-action

Williams, B. K., and Brown, E. D. 2018. Double-Loop Learning in Adaptive Management: The Need, the Challenge, and the Opportunity. *Environmental Management*, 62, 995–1006. doi:10.1007/s00267-018-1107-5 https://tethys.pnnl.gov/publications/double-loop-learning-adaptive-management-need-challenge-opportunity

Williams, K., Szaro, R., and Shapiro, C. 2009. Adaptive management: The U.S. Department of the Interior technical guide. Report by U.S. Geological Survey for U.S. Department of the Interior, Washington, D.C. https://tethys.pnnl.gov/publications/adaptive-management-us-department-interior-technical-guide

NOTES

Adaptive Management Related to Marine Renewable Energy

Le Lièvre, C. 2020. Adaptive Management Related to Maritime Renewable Energy. 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. 242-261). doi:10.2172/1633206

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.