Best Practices for Monitoring Environmental Effects of Marine Energy Devices

Annex IV Final Report

December 2014

A Workshop sponsored by Annex IV
in conjunction with the 2014 EIMR Conference

Stornoway, UK
April 29, 2014

A report prepared by PNNL for the OES under ANNEX IV on Assessment of Environmental Effects and Monitoring Efforts for Ocean Wave, Tidal and Current Energy Systems

Pacific Northwest
NATIONAL LABORATORY

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BEST PRACTICES FOR MONITORING ENVIRONMENTAL EFFECTS OF MARINE ENERGY DEVICES

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AUTHORS

Andrea Copping[1]
Luke Hanna[1]
Ian Hutchison[2]

[1] Pacific Northwest National Laboratory
[2] Aquatera Limited

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It is important to note that this report records and interprets the outcomes of the workshop to the best of our ability. However, all of the opinions and statements contained herein may not be supported by every participant.

ABBREVIATIONS AND ACRONYMS

3D	three-dimensional
BACI	before-after control impact
cm	centimeter(s)
DOE	U.S. Department of Energy
EIMR	Environmental Interactions of Marine Renewable
EMEC	European Marine Energy Center
ENSO	El Niño Southern Oscillation
FAD	Fish-Attracting Device
FLOWBEC	Flow and Benthic Ecology
IEA	International Energy Agency
km	kilometer(s)
m	meter(s)
MRE	marine renewable energy
m/s	meters per second
MW	megawatt(s)
OES	Ocean Energy Systems
ORPC	Ocean Renewable Power Company
PAM	Passive acoustic monitoring
PNNL	Pacific Northwest National Laboratory
RITE	Roosevelt Island Tidal Energy
SAMS	Scottish Association for Marine Science
SMRU	Sea Mammal Research Unit
SNL	Sandia National Laboratory
UK	United Kingdom
WEC	wave-energy converter

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1. INTRODUCTION

As the wave and tidal industry plans for initial commercial deployments, significant uncertainties remain about the risks to marine animals and habitats from wave and tidal devices; this uncertainty continues to slow and complicate siting and permitting (consenting) processes. Advancement of the industry can be simplified if the level of uncertainty is reduced, allowing regulators and the marine energy industry to focus monitoring on a small set of interactions for which risk remains uncertain, or where ongoing observation becomes a component of mitigation for high risk levels (with low risk uncertainty).

Early deployments of tidal and wave devices have yielded information about interactions of animals with devices and the potential effects of development on marine habitats. Similarly, laboratory studies and the creation of numerical models have provided insight into potential effects. These studies have allowed us to bound certain risks to the marine environment, help focus monitoring and research studies on the highest priority interactions, and diminish concerns about low-risk interactions. The interactions pursued in this report are those for which a high degree of uncertainly remains and those that are of greatest concern to regulators and stakeholders. Other risks have not been addressed, including those that may be of lesser concern (for example, risk from anti-fouling paints on marine energy devices) or those for which information collected for other industries are pertinent (such as the effect of anchors on the seabed).

Under the sponsorship of Annex IV, a 1-day workshop was held in conjunction with the EIMR (Environmental Impacts of Marine Renewables) conference in Stornoway, United Kingdom (UK), on April 29 2014. Support for the workshop was provided by the U.S. Department of Energy (DOE) and the EIMR conference, and was organized by Pacific Northwest National Laboratory (PNNL) with assistance from the DOE Wind and Water Power Technologies Office and the Northwest National Marine Renewable Energy Center.

1.1 Workshop Background

The workshop was designed to take the next logical step toward decreasing uncertainty and understanding the risks inherent in deploying wave and tidal devices in coastal marine waters. These risks are seen as barriers to smooth and efficient commercial deployment of marine energy projects; so a better understanding will simplify the siting and permitting processes. This workshop builds on the outcome of the workshop *Instrumentation for Monitoring around Marine Renewable Energy Converters* held in Seattle, Washington USA, in June 2013, which described and documented the best practices for monitoring around marine energy devices (http://tethys.pnnl.gov/publications/instrumentation-monitoring-around-marine-renewable-energy-converters).

Monitoring results from early deployments of single devices and very small arrays, as well as targeted research studies, have provided information about risks associated with several key interactions. However, the risks associated with many interactions continue to be uncertain, and little insight is available about how those risks might scale as we move toward larger deployments over longer time scales.

Perceived risks to the marine environment from wave and tidal devices can be examined by monitoring programs focused on decreasing the level of uncertainty associated with specific interactions. These perceived risks can be classified into three categories, as follows (and as shown in Figure 1):

- low-risk interactions that have been discounted or “retired” from ongoing monitoring (green);

- interactions that have a high level of uncertainty associated with the risk they may pose to the marine environment, and require further monitoring and perhaps an adaptive management approach prior to scaling up to arrays, to determine this level of risk (yellow); and
- interactions that are known to have high levels of risk, and are mitigated through improved siting, improved design or operation of the devices, and perhaps an adaptive management approach prior to scaling up to arrays. A key example is the underwater noise from pile driving for installation of tidal or wave devices, which can be mitigated by implementing standard environmental mitigation and management measures (red).

Many of the perceived risks currently fall in the middle of this spectrum (yellow region) and represent the bulk of the monitoring requirements that wave and tidal developers face when getting permission to deploy and operate projects. If evidence can be gathered through targeted monitoring programs and research to identify and eliminate or adequately reduce the risks that fall in the middle of the spectrum, less monitoring may be required for developing wave and tidal projects, thereby expediting the overall environmental permitting process (Figure 1). The scope of this undertaking may require a coordinated, strategic research investment by governments.

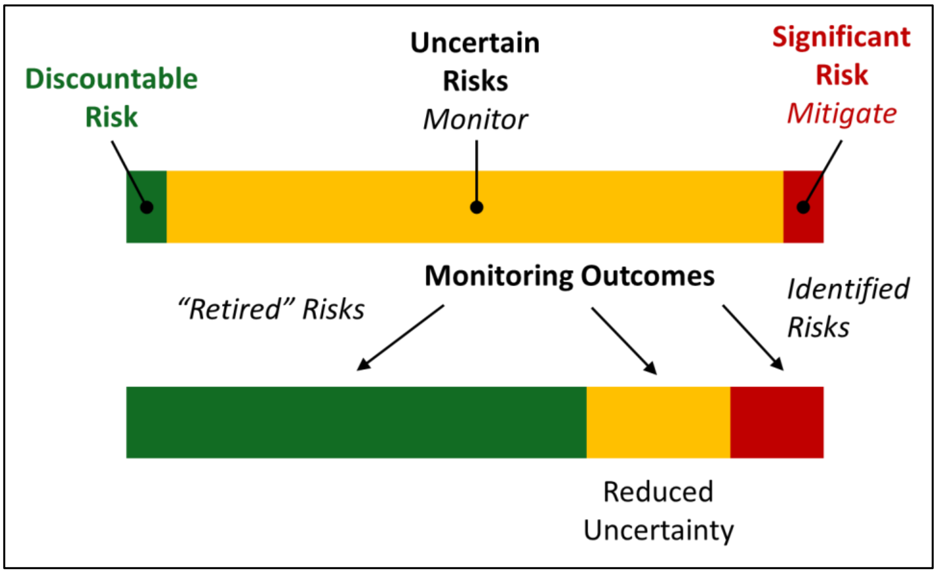

Figure 1. Categories of risk and uncertainty reduction pathways.

1.1 Goal and Objectives of the Workshop

The goal of this workshop was to develop a series of recommendations aimed at designing a realistic monitoring program that investigates high-uncertainty risks associated with early commercial-scale wave and tidal developments.

Specific objectives to reach this goal included the following:

- identifying specific interactions that cause delays in siting and permitting (consenting) marine renewable energy farms because of high levels of uncertainty;
- developing optimum approaches to measure the interactions;
- determining the approximate costs of monitoring the interactions, and exploring the less expensive and more effective options; and
- determining what research is needed to support and accelerate the state of monitoring the interactions.

1.3 Bounding Assumptions for the Workshop

To support the objectives of the workshop, the following specific assumptions and bounding principles were put forward:

- Interactions between tidal and/or wave farms and the marine environment must focus on important questions for marine energy industry/regulators, such as the ability to "retire" the risk or to proceed to a viable mitigation strategy.
- Monitoring studies put forward must have a reasonable capability of measuring environmental change within the tidal or wave-energy development system.
- Monitoring studies must have a high degree of scientific rigor and transferability to other projects.

Participants in the workshop were asked to focus their efforts during the 1-day workshop by accepting the following conditions:

- Only the interactions specified for the morning breakout sessions will be addressed and considered to be important for the development of monitoring programs.
- Only existing acoustic (passive and active) and optical instruments can be considered, although packages of integrated instruments can be specified.
- Only existing platforms for instrumentation deployment are available for use (or variations on those platforms).
- Only existing data processing (pre- and post-) procedures are available (or variations built on existing concepts).
- The interactions recommended for monitoring must represent high risk, but not impossible risk (i.e., not including risks that ensure there is no chance of deployment).

Participants were also asked to consider the duration and periodicity of monitoring that will contribute to better understanding of the interactions and to consider necessary tolerances for identifying species, life history stages, and spatial interactions between organisms and devices.

2. STRUCTURE OF THE WORKSHOP

The workshop included 43 invited participants; in addition, 61 observers participated in several sessions. The two-tiered participation was the result of a need to keep the official participant list small enough to ensure that substantial interaction could occur in each breakout session, while the interest of additional observers could be accommodated in the larger plenary sessions and in two breakout rooms. Each breakout session had a session chair and two note-takers. Although all comments were recorded, this report does not attribute specific comments to an individual within a group

The process for meeting the workshop objective of designing realistic monitoring programs for wave and tidal projects entailed choosing a subset of specific interactions between the devices and the marine environment, and examining methods, instruments, and tolerances needed to measure those interactions. A set of representative indigenous species was chosen as the marine resources potentially at risk. More details about the interactions and representative species can be found in the Section 2.3.

All participants and observers met in a plenary session at the beginning of the day to review the objectives and task structure of the workshop, and so that participants could provide final comments on the proposed scenarios, as well as add or clarify the details of the workshop objectives. Participants were assigned to one of four breakout groups, and the morning set of breakout groups focused on approaches to monitoring that could significantly reduce uncertainty around one of four priority environmental interactions. A set of indigenous species was chosen to represent the marine resources potentially at risk.

After lunch, a second set of breakout groups continued the discussions from the morning breakout sessions. The afternoon sessions focused on integrated monitoring programs for either tidal or for wave scenarios. The wave and tidal scenarios considered the development of specific numbers of devices, in a representative body of water, supporting the representative species discussed in the morning sessions. More details about the development scenarios can be found in the section describing the afternoon breakout sessions (Section 2.2).

The last session of the day was a plenary session conducted to share the outcomes of the breakout groups and to discuss the next steps in the process; observers were encouraged to participate in the open discussion.

2.1 Morning Breakout Sessions

The following four interactions related to wave and tidal devices were chosen because of their inherent uncertainty that hampers our understanding of the significance of the risk associated with each of these interactions:

1. **Blade Interaction and Evasion (Breakout Session 1A)**: Marine animals transiting through an area with tidal devices run the risk of colliding with tidal turbine blades, or evading the device.
2. **Attraction (Breakout Session 1B):** The acoustic output emitted by certain wave and tidal devices or the physical presence of the device in the marine environment have the potential to attract marine animals.
3. **Avoidance and Barrier Effects (Breakout Session 1C):** Wave and tidal energy devices deployed in an array have the potential to alter the behavior of marine animals, causing them to avoid the area. If the avoidance became severe enough, it could lead to the creation of a barrier effect, displacing animals from their preferred habitats.
4. **Mooring Line Interaction (Breakout Session 1D):** Most wave technologies and several tidal devices require mooring lines to secure them to the seabed, which might present risks of entrapment or entanglement to transiting marine mammals.

Groups were assigned to discuss approaches to monitoring that can reduce uncertainty for each of the interactions. Specific wave or tidal development scenarios were not the focus of this discussion, but were used for context, when appropriate.

Participants were asked to discuss and make recommendations about the following questions:

- What potential interactions are likely to happen?
- Should these be considered high-priority risks that require monitoring?
- What specific priority monitoring can we define that will reduce uncertainty for these high-priority interactions?
- What research investments could be made that would reduce uncertainty, inform future large-scale development, and potentially reduce the need for costly monitoring in future?
- Can you estimate the costs of these monitoring or research activities?

The results of each breakout group seek to answer these questions.

2.2 Afternoon Breakout Sessions

The afternoon breakout sessions were organized around four different scenarios, two of which were similar to the morning sessions. The objective of the afternoon breakout sessions was to further investigate how effective environmental monitoring programs can be designed for specific interactions as well as wave and tidal projects at the small array scale, in general. The four scenarios discussed in the afternoon were as follows:

1. **Monitoring for a small wave project (Breakout Session 2A):** Participants were asked to develop a monitoring program for a small wave deployment that would focus on priority environmental interactions.
2. **Monitoring for a small tidal project (Breakout Session 2B):** Participants were asked to develop a monitoring program for a small tidal deployment that would focus on priority environmental interactions.
3. **Attraction and avoidance around a tidal turbine (Breakout Session 2C):** Participants were asked to design a research program including specific technology packages for monitoring attraction and avoidance around a small-scale tidal energy project.
4. **Collision monitoring around a tidal device (Breakout Session 2D):** Participants were asked to design a research program including specific technology packages for monitoring collision and evasion around tidal energy devices.

2.3 Indigenous Species

A set of indigenous species was chosen to allow participants to focus on specific interactions and the necessary monitoring to record those interactions; the same set of species was chosen for both wave and tidal development. Most species are found in the waters postulated for the wave and tidal scenarios, although baleen whales and reefing fish were added to broaden the scope of the monitoring studies to other regions. The species were as follows:

- one species of mid/high-frequency cetacean (for example, harbor porpoise)—likely present year-round and in moderate numbers from a large population;
- one species of low-frequency cetacean (for example, baleen whale)—likely present sporadically and in small numbers from an endangered population;
- one species of pinniped (for example, harbor seal)—likely present year-round and in moderate numbers from a large population;
- one species of large pelagic fish (for example, basking shark)—likely present sporadically and in small numbers from an endangered population;
- one species of diving bird (for example, auk or petrel)—likely present year-round and in large numbers from a large population;
- one species of migratory fish (for example, salmon)—likely present one to two months each year and in large numbers from an endangered population; and
- one species of reefing fish—likely present year-round and in large numbers from a large population.

2.4 Scenarios for Marine Energy Devices

Hypothetical scenarios were developed for wave and tidal project developments in order to provide context for discussing the monitoring of interactions with the marine environment. Originally scenarios were developed for both small and large developments of wave and tidal arrays. However, as the workshop unfolded, it became clear that small arrays provided a more realistic backdrop for discussion because this is the scale of development that the regulatory and science community is currently addressing. The scenarios, as they were described to the participants, are presented in the following sections.

2.4.1 Proposed Wave Scenario

The waterbody proposed has the attributes of certain locations in the Pentland Firth, with a water depth of ~60 m. The nearest wave-energy converter (WEC) is deployed about 1 km away from a moderately elevated shoreline, (a vantage point ~30 m elevation above sea level). The wave scenario includes 10 linear attenuator WECs (similar to Pelamis, with a similar power take off), each rated at 1 MW. Each device is moored with a three-mooring line yoke, and deployed in one row of 10 WECs. The starting point for the scenario is at our current state of understanding of environmental effects.

2.4.2 Proposed Tidal Scenario

The waterbody proposed has the attributes of certain locations in the Pentland Firth, with a water depth of ~50 m, and a channel width of 10 km. The seabed is made up of scoured cobbles. The nearest turbine is deployed about 1 km away from a moderately elevated shoreline, (a vantage point ~30 m elevation above sea level). The tidal regime semi-diurnal with peak currents of 5 m/s, without periods of truly slack water, and there is no significant spatial gradients in the resource. The tidal scenario includes 10 three-bladed horizontal-axis turbines (no shroud, duct, or diffuser) with a rotor-swept area of 25 m, and a tip-speed ratio of 4. All turbines will be deployed at 10 diameters cross-stream spacing (250 m) and 20 diameters down-stream spacing (500 m). The turbines are bottom-mounted on a jacket support structure and have no surface expression. Each turbine is rated at 1 MW. The starting point for the scenario is at our current state of understanding of environmental effects.

3. MONITORING FOR SPECIFIC INTERACTIONS

The four interactions examined included collision/blade interaction, attraction, avoidance/barrier effects, and mooring line interactions, as described in the following sections.

3.1 Collision/Blade Interaction – Breakout Session 1A

Participants

Name	Affiliation
Brian Polagye*	NNMREC, University of Washington
Jocelyn Brown-Saracino+	New West Technologies, LLC/U.S. Department of Energy
Gordon Hastie	University of St. Andrews
Beth Mackey	Royal Haskoning DHV
Anne Marie O’Hagen	HMRC University College Cork

Ed Rolling	Meygen Ltd.
Greg Trowse	Fundy Tidal inc.
Ian Davies	Marine Scotland Science
Merin Broudic	Swansea University
Jonathan Gordon	University of St. Andrews
Sarah Dolman	Whale and Dolphin Conservation
Benjamin Williamson	University of Aberdeen

* denotes session chair; + denotes session recorder.

Discussion within the group focused on instrumentation to measure interactions of marine animals around tidal devices, although some of the packages and techniques were also applicable to interactions with wave devices. The group also discussed how each project's monitoring effort might be more widely applicable, how data streams might be handled, and how the costs of monitoring might affect development processes. The discussions focused largely on marine mammals, diving seabirds, and fish.

3.1.1 Monitoring for Collision/Blade Interaction

A number of single tidal and hydrokinetic (river) devices (for example, devices tested at European Marine Energy Center (EMEC), Ocean Renewable Power Company's (ORPC's) TidGen in coastal Maine) and small arrays (for example, Verdant's Roosevelt Island Tidal Energy [RITE] project in New York) have been deployed for short periods of up to 6 years (SeaGen in Strangford Lough). To date no reports or observations of collisions between a tidal turbine and a marine mammal, seabird, fish, or sea turtle, have been reported, but few observation systems have been in place to track every potential interaction. Modeling exercises that help inform the potential for collision and possible consequences range from the consequence modeling done by PNNL and Sandia National Laboratory (SNL) in the United States (Carlson et al. 2013) to encounter models created by the Scottish Association for Marine Science (SAMS) (Wilson et al. 2007) in Scotland. Laboratory and flume studies have challenged fish with an operating turbine; to date fish have passed through the turbine uninjured (Castro-Santos and Haro 2014). Field studies of fish interacting with turbines in coastal Maine do not show evidence of injury from fish passing through or near the turbine (Viehman and Zydlewski 2014). The consensus from the scientific community is that a collision between a marine animal and a tidal blade is likely to be a very rare occurrence, and one that will be very difficult to observe. However, this interaction remains of concern to regulators and stakeholders because of the potential negative consequence if animals are harmed in large numbers, particularly animals representing small or endangered populations.

There are currently no commercial off-the-shelf systems that are appropriate for monitoring collision or evasion of animals in the nearfield (approximately 2 to 10 rotor diameters from the turbine or WEC). The most promising approach appears to be an integrated instrumentation package. Such a package is likely to be costly to build and would require significant field validation and testing.

The inherent costs of creating and operating an integrated package raised questions with the group about the potential for creating delays in getting tidal projects in the water. In particular, if a focused research program is intended to create a path forward, what tools are available to assist with tidal projects under development now? This question remains unanswered.

The group discussed who ought to bear the costs of a testing program. Developers are unlikely to be capable of bearing the whole cost. Collaborative research funding among governments, industry, and other entities will be needed to fill the gap.

3.1.2 Priority Monitoring for Collision/Blade Interactions

The group felt that monitoring for collision/blade interaction of marine animals with tidal devices is very challenging, but that the combination of placing entirely new technologies in the water, regulatory imperatives, and stakeholder concerns required that monitoring programs be put in place for early-stage deployments. However, the strong consensus was that collision and evasion are topics that would benefit from focused research efforts; measurement of these interactions was deemed not ready for implementing within routine monitoring programs.

As tidal arrays are developed, the inherent risk of collision/blade interaction may rise slightly if swimming animals become disoriented by multiple devices, but inherently the risk is associated with one animal (or in the case of fish, one group) interacting with one machine. Monitoring measures must follow this interaction at the scale where it may be observed or documented

3.1.3 Research to Support Collision/Blade Interactions

The group felt that field validation and testing should occur at one or more of the early development sites in order to gather sufficient data to inform the interaction ("move the needle"). However, testing at one or a small number of sites raises issues about whether the results could be considered to be broadly applicable. Significant discussion within the group focused on the issues of extrapolating data from one site to many, under different ocean conditions and with different assemblages of species. Strong emphasis was placed on identifying what information and data might be transferable in order to help inform the interaction at other sites. It was decided that the amount of data collected at a single site was likely to be small, and that greater power could be derived from bringing together data from several sites to further define the probable interactions of animals and turbine blades.

Other significant areas of study that were raised and are not yet resolved include the following:

- the need to understand the fate of individual animals versus groups of animals, and the various ways that monitoring and research methods might differ;
- the need to provide as much information at the species level as possible to justify the practice of lumping species into functional groups;
- the relative importance and feasibility of continuous monitoring versus subsampling over time, including duty cycles for instruments and sampling during key times such as migratory seasons;
- the high costs of collecting and processing large data sets ("data mortgage") compared to the value of collecting and processing small data sets; and
- the distances over which animals can be detected and classified using acoustic and optical systems.

3.2 Attraction – Breakout Session 1B

Participants

Name	Affiliation
Anna Redden*	Acadia University
Sarah Henkel+	NNMREC, Oregon State University
Jason Wood	SMRU USA
John Horne	University of Washington

Lars Golmen	Runde Environmental Centre and NIVA
Elizabeth Masden	Environmental Research Institute, UHI
Ian Bryden	UHI
Michael Bell	Heriot Watt University
Beth Scott	University of Aberdeen
Paul Bell	National Oceanography Centre, Liverpool
Gayle Zydlewski	University of Maine

* denotes session chair; + denotes session recorder.

Discussion within the group focused on methods for determining how to measure the attraction of marine animals to wave and tidal devices, the scales over which attraction might be determined, and the uncertainties associated with these measurements. The discussion focused largely on the attraction of fish to marine energy devices.

3.2.1 Methods for Determining Attraction

Few research activities have focused on the potential effects of the attraction of marine animals to wave and tidal devices. Much of our current understanding stems from research focused on Fish-Attracting Devices (FADs), and observed attraction of marine animals to structures and man-made objects in the marine environment.

The group discussed the various instruments currently available for observing fish and seabirds around marine energy devices, including a range of active acoustic devices, but determined that there are significant research questions that could support improved and cost-effective monitoring. Tagging of fish and seabirds would allow for a better understanding of the three-dimensional (3D) movements of the animals around devices, and would delineate what specific parts and operational modes of marine energy devices attract the fish or birds, allowing for potential engineering changes to reduce the effect.

To understand the reef effect of fish attraction it is necessary to characterize and understand the variability of fish assemblages in both time and space, including consistently measuring fish density as a function of depth and time. The heterogeneity of fish and seabird populations in high-energy development areas make it difficult to enact classic before-after control impact (BACI) designs; before and after survey programs show promise, but comparing these results to control areas is difficult.

3.2.2 Priority Monitoring for Attraction

The group felt that attraction could be examined for fish as part of the early years of a monitoring program, but should not become an integral part of a long-term program. Coupled with additional strategic research investigations, data from early-stage deployments should provide the necessary data for regulators to determine the level of risk associated with the attraction of fish to devices.

3.2.3 Research to Support Attraction

There continue to be many questions about the best use of available acoustic and optical instruments for examining attraction at scale relevant to the device, tidal range, home range of the fish, and seasonality of fish presence and movement. Research that hones these techniques could inform monitoring programs and shorten their lengths.

Examining the attraction of animals to marine energy devices must be carried out in close proximity to a device, but scaling from a single device or a development site to a region is difficult because of inherent heterogeneity and patchiness. The group felt the best approach is to index marine energy sites by attributes such as the foraging behavior of large fish or diving birds, rather than by strictly measuring the number of organisms in a volume surrounding the devices. Further scaling to classify by habitat type can benefit from the use of accurate habitat maps, radar to identify surface physical characteristics, and hydrographic models.

The group also explored the potential to link the presence of animals with other biological factors. For example, using bird attraction/behaviors around devices could help to better explain fish schooling behaviors in the vicinity. Similarly, the characteristics of a marine energy device, such as acoustic output, could act as a trigger and allow researchers to examine the attraction of fish to the device.

A high level of uncertainty associated with determining whether marine animals are attracted to marine energy devices necessitates an estimate of how much change must be seen to determine if a difference has occurred. The group felt that probabilistic models may be used to estimate what levels of change will constitute important biological interactions around devices.

3.3 Avoidance – Breakout Session 1C

Participants

Name	Affiliation
Andrea Copping*	PNNL
Luke Hanna+	PNNL
Annie Linley	National Oceanography Centre, Liverpool
Marc Murray	Aquamarine Power
Bob Rumes	RBINS-MUMM
Ben Wilson	SAMS Research Services, Ltd.
Juan Bald	AZTI-Tecnalia
Graham Daborn	Acadia Centre for Estuarine Research
Mark Jessop	Coastal and Marine Research Centre, University College Cork
Dave Thompson	SMRU, St. Andrews University

* denotes session chair; + denotes session recorder.

The group discussed the processes that account for the avoidance or barrier effects of animals around marine energy devices. With few marine energy devices in the water and no arrays, there have been no data to indicate that this phenomenon will occur. However, seabirds flying in the vicinity of offshore wind arrays have shown tendencies to fly around the farms, and it has been postulated that large arrays may act as a barrier to prevent the flocks from reaching key feeding or breeding habitats. The group discussed which marine animals may be at risk, mechanisms for monitoring their avoidance, and the importance of research in this area.

3.3.1 Marine Animals at Potential Risk

The marine animals considered to be at potential risk for alterations in behavior that could be deleterious include marine mammals and migratory fish with an emphasis on salmon and basking sharks. Avoidance of marine energy devices could lead to animals not reaching their preferred habitats including feeding locations, mating areas, and nursery grounds. Populations of many of these animals are depleted or of special concern, which makes avoidance/barrier effects of particular interest to regulators and stakeholders. The migratory marine mammals most likely to be affected by large arrays of devices are large baleen whales that migrate along open coastlines. There is limited opportunity for tidal energy development in areas frequented by baleen whales. Thus wave arrays are more likely to be of concern. Migratory salmon and other small- to mid-sized fish may migrate past tidal devices in estuaries and shallow coastal areas. Basking sharks may encounter either tidal or wave devices.

3.3.2 Priority Monitoring for Avoidance

The group felt that avoidance has not yet become an issue that warrants monitoring, in part because the few single devices or very small arrays that are going in the water currently are unlikely to cause sufficient disturbance to encourage animals to avoid the area. In addition, no obvious way to monitor such interactions has been devised. As larger arrays are planned, this interaction may require further scrutiny.

3.3.3 Research to Support Avoidance

The group agreed that one of the most challenging aspects of determining avoidance or barrier effects is the lack of good quantitative data for species of concern. To determine whether effects are occurring, there must be multiple years of data that 1) track the timing and spatial variability of migratory animals over several cycles of major oceanic variations (like the El Niño Southern Oscillation in the Pacific and the North Atlantic Oscillation in the Atlantic) and that 2) account for interannual variation, including long-term trends in climate and other factors. Following the collection of robust baseline data, interactions of migratory animals with marine energy devices would need to be tracked for several years, across the same thresholds of time and space, to determine whether changes had occurred and if those changes could be attributed to the presence of the marine energy devices. Discussions also ensued around the changing baseline of climate change that contributes to the health and welfare of many marine populations.

These research studies need to take into account the periodicity and duration of animal use of a marine energy site; the scale of the site because it will affect the spatial extent that a research study must cover; and the importance of developing an adaptive research study to account for annual variations in prey abundance or changes in the physical environment of the ocean.

Research studies for pinnipeds and large and small cetaceans may yield results using observations (boat-based and aerial), as well as passive acoustics (for cetaceans) and acoustic tags for pinnipeds (and cetaceans, where this type of research is allowed).

Avoidance of marine energy devices by fish could be informed by targeted research studies that emphasize better understanding the differences in fish behavior patterns during migration versus feeding. While the scale of research to determine these behavior differences for fish will vary with their size and migratory range, the same tools can be used for a variety of sizes, including forage fish, salmon, and basking sharks, and active and passive tags as well as traditional hook and line surveys can be used for smaller fish.

The group discussed the attributes of a monitoring program that might grow out of a research investment, and felt that the adaptive aspects of the program are essential to respond to changes in the populations or ocean environment, particularly because these studies tend to be long term and very expensive. They felt it was necessary to determine how many data are needed to statistically verify avoidance, including how many years of passive acoustic data might be needed for fish or cetaceans, or how many seals need to be tagged to justify scaling back the monitoring.

3.4 Mooring Line Interactions –– Breakout Session 1D

Participants

Name	Affiliation
Ian Hutchison*	Aquatera
Jude Hamilton+	Aquatera
Jenny Norris	EMEC
James Waggitt	University of Aberdeen
David O'Sullivan	Marine Scotland
Tom Wilding	SAMS
Steven Benjamins	SAMS
Laura Carse	Pelamis Wave Power
Chris Eastham	SNH
Teresa Simas	WAVEC
Antoine Carlier	French Institute for Exploration of the Sea

* denotes session chair; + denotes session recorder.

The group discussed the relative risks that may be posed by mooring lines from marine energy devices, the need for better baseline understanding of animal distributions, methodologies for examining the issue, and some pertinent recent work. Marine mammals and large fish (e.g., basking sharks) were the only receptors considered to be potentially at risk of entanglement. Overall, the group did not consider that mooring lines likely to constitute a significant risk for marine mammals or large fish.

3.4.1 Relative Risks Posed by Mooring Lines

A recent study commissioned by Scottish Natural Heritage (Benjamins et al. 2014) on entanglement and megafauna by SAMS/University of Exeter concluded that moorings such as those proposed for marine energy devices will likely pose a relatively modest risk in terms of entanglement for most marine megafauna, particularly when compared to the risk posed by fisheries. However, some circumstances were identified where moorings associated with marine renewable energy (MRE) devices could potentially pose a risk, particularly 1) in cases involving large baleen whales and, 2) if derelict fishing gears become attached to mooring lines, thereby posing an entanglement risk for a wide range of species (including fish and diving seabirds).

Other recent literature-based work by DOE (Kropp 2013) has examined information about the entanglement of marine animals and generally does not consider the threat from marine energy mooring lines to be significant.

In identifying the potential risks posed by mooring lines, the group considered it important to consider the physical nature of mooring lines likely to be used for anchoring MRE devices, particularly when considering entanglement risk. The example given was a large link chain used for anchoring Pelamis wave devices—each link approximately 15−20 cm long, therefore heavy and inflexible in nature with no likelihood of looping. It was also noted that consideration of the scale of the project, device configuration, type of mooring system, and migratory behaviors of key species is also important.

The following potential interactions associated with mooring lines were identified by the group:

- large cetaceans; entanglement, entrapment, barrier to movement and collision

- small cetaceans/seals; increased prey (FAD effects)
- fish (reefing); aggregation
- fish (migratory); none
- birds; increased prey (FAD effects) and collision
- benthos; abrasion.

None of these interactions was identified as "high risk" within the context of the workshop scenarios provided; but it was noted that entanglement may be a higher risk for projects at sites where summer feeding areas of baleen whales could be affected, depending on the configuration of the mooring lines used for the devices.

The group generally felt that a single set of mooring lines for a WEC or floating tidal turbine is unlikely to pose a threat to these large animals; only the development of large arrays consisting of multiple moorings could result in a number of lines in the water column. It was determined that the probability of an interaction leading to serious injury or fatality is extremely low.

To date, marine energy deployments in the UK have not been required to monitor for potential entanglement or entrapment. Until an event occurs and a large whale or shark suffers from an interaction with a mooring line, this is unlikely to be considered a priority issue.

The group discussed the additional risk from entanglement from derelict fishing gear caught on mooring lines to marine animals, including fish, seabirds, sea turtles, and marine mammals. Marine energy devices are likely to act as FADs, bringing both predators and human fishers close to the devices. This attraction provides a two-fold potential risk—a greater chance of derelict fishing gear hanging up on mooring lines and enticing marine animals closer to the entrapment/entanglement threat. It was agreed that routine monitoring of devices, mooring systems, and arrays was sufficient to identify possible fishing gear/other debris becoming entangled in mooring lines and to trigger any necessary recovery work to reduce the potential for interaction.

3.4.2 Priority Monitoring for Mooring Line Interactions

It was agreed that targeted monitoring of mooring line interactions is not a priority and therefore not required at this time.

3.4.3 Research to Support Mooring Line Interactions

A targeted research effort might provide information that could retire the risk as being insignificant, or could yield methods for an appropriate monitoring program. It was agreed that short-duration, high-intensity studies would be more cost-effective than long-term studies at reduced effort.

Key research challenges and solutions that could advance the state of understanding include the following:

- Understanding how large animals respond to mooring line – arrays of passive acoustic monitoring (PAM) devices could provide presence/absence data and could possibly be used to track movement of vocalizing animals through an array using triangulation.
- Determining how closely animals approach mooring lines – the error associated in triangulation is unlikely to provide accurate data to inform whether a close encounter with a mooring line has occurred. Land or boat-based visual observations are unlikely to be

suitable for tracking animals through an array and would not provide data for inclement weather, high sea states, or for periods of darkness.

- Risk of impact of indirect entanglement due to discarded fishing gear becoming caught in mooring lines. Routine inspections and reporting of incidents to regulators could satisfy this need.
- Effects of FADs to potentially increase entanglement risk for predators. It is important to understand the attraction of *prey* species of fish around devices and moorings because the presence of fish does not necessarily indicate potential foraging opportunities for predatory birds and mammals.

Relevant research under way:

- Pelamis Wave Power is currently investigating the sound produced by mooring lines ("strumming") at the single device scale. The study premise is that noise from moorings might provide cues that serve to attract animals, or alternately might provide cues that allow them to evade the lines. However, these cues cannot be interpreted until larger numbers of arrays have been deployed and data about the behavior of animals around them can be gathered.

4. MONITORING AROUND WAVE AND TIDAL DEPLOYMENTS

4.1 Deploying a Small Wave Project – Breakout Session 2A

Participants

Name	Affiliation
Sarah Henkel*	NNMREC, Oregon State University
Luke Hanna+	PNNL
Laura Carse	Pelamis Wave Power
Marc Murray	Aquamarine Power
Teresa Simas	WAVEC
Juan Bald	AZTI-Tecnalia
Anne Marie O'Hagen	HMRC University College Corg
Bob Rumes	RBINS-MUMM
Lars Golmen	Runde Environmental Centre & Niva

* denotes session chair; + denotes session recorder.

The group discussed the monitoring necessary to deploy a small commercial wave project, including which groups of animals may be of concern and the optimal methods for monitoring for their presence.

4.1.1 Marine Animals Potentially at Risk

In the vicinity of WEC deployments, marine mammals are considered to be the most important target for monitoring because they are protected species in many nations, and because many are susceptible to underwater noise generated by WECs that may interrupt communication or echolocation. Marine mammals and seabirds may be at risk of displacement from their optimum habitats by WECs; migratory and resident fish and some shellfish (for example quahogs) might be at risk for displacement by nearshore (shallow water) WECs. However marine energy devices also act as artificial reefs, increasing habitat for organisms such as shellfish and attracting fish and other organisms. In each case, the group felt it was necessary to examine the effects on individuals before attempting to extrapolate to potential effects on populations.

4.1.2 Monitoring for Animals around WECs

The group discussed a method of evaluating the acoustic effects of devices on marine mammals by focusing initially on characterizing ambient noise within the project area, and measuring the WEC-generated noise. When coupled with acoustic thresholds for specific marine mammals and passive acoustic measurements, this information could be used to determine whether the levels generated by the WECs could affect the animals, as well as the proclivity of the animals to frequent the area of proposed WEC deployment. The group endorsed the concept of using indicator species to monitor around WECs.

Monitoring of small-scale deployments of WECs can help to inform larger scale developments, not only by testing the efficacy and robustness of the wave-energy generating technology, but also by developing information about potential environmental effects that will translate into useful predictions for larger scale arrays; e.g., monitoring for occurrence of biofouling, the presence of invasive species, FAD effects, or energy removal. For example on the Isle of Lewis, which is made up predominantly of rocky nearshore habitats with minimal sediment transport, results from monitoring around a small-scale array may help to inform how much energy is removed from the nearshore environment and may help to predict the effects of energy removal from the nearshore environment due to larger arrays. However, changes in sediment transport from small arrays may be too small to measure accurately.

4.2 Deploying a Tidal Turbine - Breakout Session 2B

Participants

Name	Affiliation
Ian Hutchison*	Aquatera
Gayle Zydlewski+	University of Maine
David O'Sullivan	Marine Scotland
Elizabeth Masden	ERI
Ben Wilson	SAMS Research Services Ltd

* denotes session chair; + denotes session recorder.

This group discussed priority monitoring around tidal turbines to provide an increased level of certainty for moving the industry forward efficiently, key instrumentation and monitoring methods, and funding needs to achieve research goals.

4.2.1 Priority Monitoring

Marine mammals are the primary concern for monitoring around tidal turbines in most nations, although commercially and recreationally important fish garner attention in many jurisdictions. Key questions that are being faced include whether the animals are capable of detecting and avoiding devices, as well as determining the characteristics of a collision pattern and whether a collision is likely to cause injury or be lethal. The group felt these questions could be addressed computationally or physically; work is going on the in United States (PNNL and SNL) and in the UK Sea Mammal Research Unit (SMRU). It is not clear whether it would be preferable to focus these approaches on single device impacts or attempt to address them on a small array scale.

4.2.2 Instrumentation and Approaches for Monitoring

The group agreed that the optimum approaches to examining collision or evasion will use multiple instruments in sequence or parallel. The best available instruments for detecting collision were thought to include the use of active acoustics, especially multi-beam sonar systems, coupled with strain gauges on the turbines to measure impacts, and optical cameras to view close encounters and identify the species and other characteristics of animals close to turbines. Each of these instruments has its limitations: there are few algorithms or software packages that can be used operationally with acoustics; available light at tidal turbine depths is often an issue and requires artificial light that can change animal behavior; and strain gauges will provide little information about small species or near misses of turbines by swimming animals. There are currently no coupled instrumentation packages that can be put into operational use to cover all aspects needed to answer questions of evasion and collision.

4.2.3 Costs of Monitoring for Tidal Deployment

The group felt that rising competition among developers will not lead to filling the necessary data and information gaps, and that co-funding and data sharing among tidal developers and researchers will be needed to continue supporting efficient and effective development of the industry. Another high-priority issue identified was that there is no central repository for data collected that could address the evasion and collision issues.

4.3 Tidal Research Focused on Attraction and Avoidance - Breakout Session 2C

Participants

Name	Affiliation
Andrea Copping*	PNNL
Jude Hamilton+	Aquatera
Beth Scott	University of Aberdeen
Sarah Dolman	Whale and Dolphin Conservation
Jonathan Gordon	University of St. Andrews
Beth Mackey	Royal Haskoning DHV
Paul Bell	National Oceanography Centre, Liverpool
Mike Bell	Heriot Watt University
Graham Daborn	Acadia Centre for Estuarine Research
Anna Redden	Acadia University
Ian Bryden	University of the Highlands and Islands

* denotes session chair; + denotes session recorder.

The group discussed the importance of sufficient baseline data to being able to identify and measure attraction and avoidance around tidal turbines, preferred approaches for monitoring for these interactions, and the value of modeling for attraction and avoidance.

4.3.1 Setting the Stage for Examining Attraction and Avoidance

The group reiterated the importance of good baseline data for all animal groups of potential concern around turbines, which could be used later determine whether these animals are attracted in a manner that may harm them, or whether they avoid the tidal development areas to an extent that their livelihood or population health is affected. Because of limited resources, the group felt that all baseline data will initially be collected at a scale that is suitable for government funding. It was noted that in the UK, attraction is only an issue if it results in collision, but that it seems to be more of a stand-alone issue in the United States and Canada.

4.3.2 Methods for Monitoring Attraction and Avoidance

Monitoring for attraction and avoidance in tidal areas will use similar approaches, each of which has its strengths and weaknesses. Land-based (for activities that are close to shore and have a suitable platform height) and boat-based observations are excellent ways to understand how animals are behaving around tidal turbines, but they do not allow for data collection in rough weather or at night, and they cannot examine what animals are doing at depth. Aerial surveys are efficient but provide almost no information about animal behavior and are also weather-dependent. Telemetry studies for pinnipeds are a great tool but the costs of installing the tags, concerns about the animals' welfare, and costs of analyzing the data determine that only a small number of animals in an area are tagged. Active acoustic data are cheap and easy to collect, although there are concerns that the signals could cause localized impacts on marine mammals. This technique only examines a relatively small slice of the area around a turbine. In addition, the lack of adequate algorithms means that only a few species can be accurately identified and tracked.

New approaches to determining attraction like that of the FLOWBEC project (Flow and Benthic Ecology 4D) and developments under way at the University of Washington in the United States are showing promise. The purpose of these efforts is to acquire a 3D view of animal movements with bottom-mounted, upward facing platforms (FLOWBEC) or platforms facing the turbines (University of Washington). The ideal outcome would be identification of animals near a turbine, including marine mammals and fish, to determine if they are attracted to the turbine. Other efforts to view attraction are under way using a series of active acoustic cameras in the United States and UK.

Currently, no intensive efforts are being made to determine the species avoidance of tidal turbines, and there may not be until there are significant numbers of devices in the water in an area to warrant field measurements.

4.3.3 Modeling Tools to Evaluate Attraction and Avoidance

The group felt that modeling could advance our understanding of avoidance and attraction. Although models need to be ground-truthed, these efforts can help direct and evaluate field-measurement campaigns. The group suggested that data from short-duration, intense modeling studies could be used to further investigate avoidance by animals at a scale larger than a single turbine installation. Models could also be used to examine the energetics involved in avoiding a turbine or array of turbines, allowing us to understand whether there will be an unacceptable cost to an animal population. Looking forward, once sufficient data have been collected to validate models at early deployment sites, regulators may be able to rely on models to determine the potential effects of large-scale tidal development on marine animals. The group felt the real value of modeling will come with the development of integrated models that examine energetics, behavior, and environmental factors affecting animals of concern.

4.4 Requirements for a Collision/Evasion Monitoring Program around a Tidal Turbine - Breakout Session 2D

Participants

Name	Affiliation
Brian Polagye*	NNMREC, University of Washington
Jocelyn Brown-Saracino+	U.S. Department of Energy
Benjamin Williamson	University of Aberdeen
Ben Wilson	SAMS Research Services Ltd
John Horne	University of Washington
Ed Rolling	Meygen Ltd
Greg Trowse	Fundy Tidal Inc.
Ian Davies	Marine Scotland
Merin Broudic	Swansea University
Mark Jessopp	CMRC University College Cork
Jason Wood	SMRU USA

* denotes session chair; + denotes session recorder.

This group continued discussions started in Session 1A about collision and blade interaction, further developing a research approach to observing collision and evasion, with an emphasis on approaches, methodologies, and costs.

4.4.1 Instrumentation and Methods for Examining Collision and Evasion

In addition to the instruments for the acquisition and analysis of data, marine animal observers also play a role in the overall monitoring system, because they can provide identification to the species level for seabirds and marine mammals that is often difficult using automated methods.

The group discussed the placement of monitoring instruments on the turbine as well as standing off from the turbine, and considered to what extent integration and communication are needed among these groups of instruments. An example might be a sequence where passive acoustic instruments mounted at a distance from the turbine are used to characterize the vocalizations of an incoming cetacean, followed by a hand-off to an active acoustic instrument and perhaps a camera mounted on the turbine.

The group characterized the instrumentation needs and tolerances for examining collision (

Table 1) and evasion (Table 2) for key marine and avian groups of animals.

Table 1. Instruments that can be used to observe collision around a tidal turbine, by key animal groups.

Instrument	Fish	Sharks	Seals/Sea Lions	Porpoise /Dolphin	Large Baleen	Seabirds
Passive acoustics	No	Maybe	Maybe	Maybe	Maybe	Maybe
Active acoustics	Maybe	Yes	Yes	Yes	Yes	Maybe
GPS tag	No	Maybe	Maybe	Maybe	Maybe	Maybe
Active tag[a]	No	No	No	No	No	No
Optical cameras (site dependent)	Yes	Yes	Yes	Yes	Yes	Yes
Strain gauges (on blades)[b]	Maybe	Maybe	Maybe	Maybe	Maybe	Maybe
Accelerometers (on blades)[c]	Strong Maybe	Strong Maybe	Strong Maybe	Strong Maybe	Strong Maybe	Strong Maybe

(a) Can provide a very accurate 3D resolution of animal position in the water, and may result in excellent data on evasion and on fate of organism, but it will be harder to determine if a collision has occurred.
(b) This requires much more characterization to understand the effectiveness because no benchmark studies have been conducted to assess false positive or false negative rates of response.
(c) These are more sensitive than strain gauges, but include a greater risk of false positives.

Table 2. Instruments that can be used to observe evasion around a tidal turbine, by key animal groups.

Instrument	Fish	Sharks	Seals/Sea Lions	Porpoise /Dolphin	Large Baleen	Seabirds
Passive acoustics	No	No	No	Yes	Weak Maybe[a]	Weak Maybe[b]
Active acoustics	Yes	Yes	Yes	Yes	Yes	Yes
GPS tag	No	Maybe	Strong Maybe	Maybe	Maybe	Strong Maybe
Active tag	Yes	Yes	Yes/Maybe[c]	No[d]	Maybe	Yes
Optical cameras (site dependent)	Maybe	Maybe	Maybe	Maybe	Maybe	Maybe

(a) Would need further development and validation.
(b) Would need further development and validation; some participants thought that one could hear bird splashes entering the water.
(c) Site dependent.
(d) Tagging is operationally difficult (prohibitively so in the opinion of the group).

5. LESSONS LEARNED

Participants in several breakout groups at the workshop came to similar conclusions independently: there are many interactions between marine energy devices and marine and avian animals that cannot be routinely monitored at this time.

5.1 Strategic Research Investments

The set of interactions discussed at the workshop that could benefit from strategic investments can be parsed into the following three categories:

1. There are interactions that can be effectively monitored now with specific instruments, platforms, and technologies. However, significant research challenges remain in the design and installation of the instruments, as well as in the acquisition, analysis, and interpretation of data streams.

2. Other interactions would benefit from the input of targeted research efforts in the near term. These inputs could help to decrease the costs and perhaps the length of monitoring over the life of wave or tidal project.
3. Certain interactions can only be advanced with key research investments up front. For these interactions, there is no viable path forward for monitoring. In addition, some of these interactions could be “retired” as risks from marine energy devices to the marine environment, resulting in significant savings and certainty for project developers and regulators, respectively.

Examples of interactions that fit into each category are captured in Table 3.

Table 3. Examples of interactions between marine animals and marine energy devices.

Category of Interaction	Interactions	Key Methods and/or Instruments Available or Needed
Interactions that can be monitored now	Harbor porpoise interaction with tidal devices, observations of evasion (within one to two diameters of the device) and/or avoidance (at greater distances from the device).	C-PODs, floating hydrophones, mostly available now, although more research is needed on integration of instruments and data streams. Boat-based and aerial observations. Passive acoustic arrays to detect, localize, and characterize species. Additional research could benefit passive acoustic monitoring location and characterization.
	Large whales changing movement patterns around wave arrays.	Boat-based and aerial observations. Active tags on seals. Additional research on use and cost-effectiveness of tags could provide benefit.
	Harbor seals changing movement patterns around tidal arrays	Acoustic cameras and multi-beam instruments placed on both sides of the turbine. Additional algorithm development could improve species recognition.
	Monitoring interactions of fish around tidal turbines, including evasion and passage through the turbine.	
Category of Interaction	Interactions	Key Methods and/or Instruments Available or Needed
Interactions that would benefit from research investment upfront	Interactions of marine animals, notably marine mammals and large fish, with tidal turbine blades.	Instruments that can observe interactions of animals around tidal turbines are being considered, but no such instrument exists that can monitor accurately at a reasonable cost of time and effort. The likely rare occurrence of these events makes it significantly more difficult to measure.
	Marine mammals and other animals evading/avoidance specific parts of a tidal or wave device, such as the surface expression, rotors, etc.	Instruments needed to examine close interactions such as optical cameras and acoustic cameras, and integrated packages of acoustics and optics. Research needed to improve integration of instruments and algorithms for data analysis.
Interactions where targeted research is essential for moving	The population implications of individual marine mammals, seabirds, sea turtles, and large fish avoiding tidal or wave arrays.	Targeted studies to improve baseline assessment of populations including distributions, population structure, feeding and migrating behavior.

5.2 Delineating Key Research Investigations

An important next step toward effective and affordable monitoring solutions will be to develop a better understanding of where strategic research investments could lower the cost and duration of monitoring needed for commercial-scale arrays. These investments could also further delineate the most appropriate methods for monitoring and data analysis, and support reduced monitoring for certain risks that do not affect the wellbeing of the marine environment, while focusing effort on important interactions.

Targeted research studies can inform all areas of monitoring needs, with the greatest return on research investment coming in areas where no viable monitoring techniques currently exist. There can also be excellent returns on research investments where the high cost of instrumentation and data acquisition can be made more efficient or where risks can be determined to be lower than anticipated. The process that could be used is illustrated here in Figure 2.

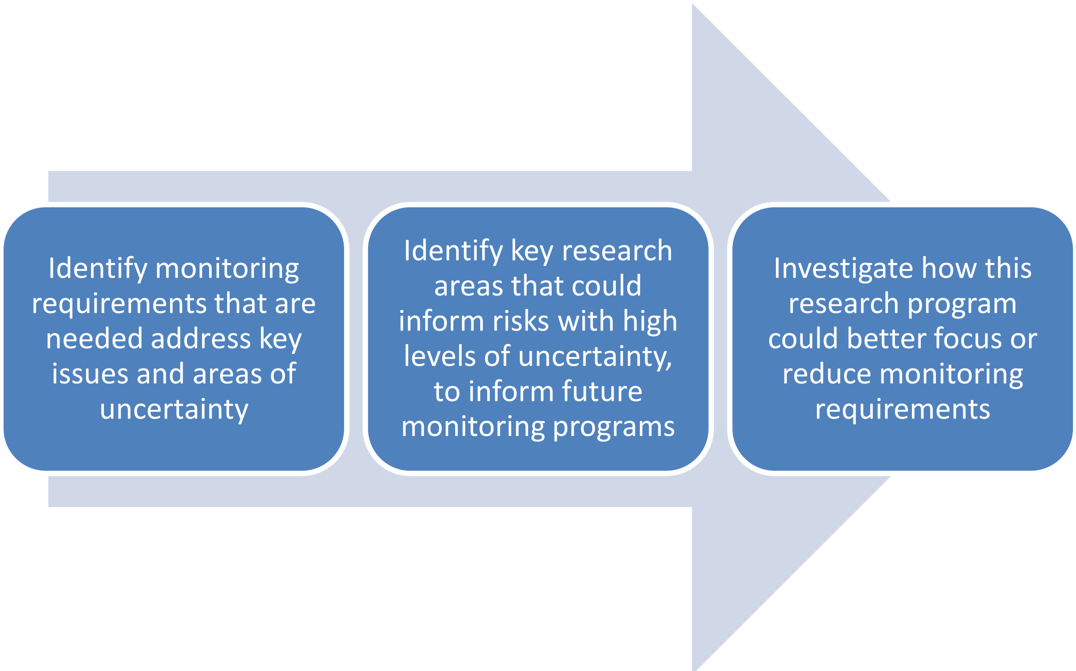

Figure 2. Process for identifying monitoring needs, targeted research studies, and evaluating the effect of the research investments.

6. WORKSHOP OUTCOMES AND NEXT STEPS

6.1 Outcomes of the Workshop

The experts who gathered for the workshop in Stornoway in April 2014 took significant steps toward exposing areas of technical limitations and recommending pathways forward for the most important environmental interactions that confront the marine energy industry. The four interactions chosen for the workshop—collision/evasion; attraction; avoidance; and mooring line interactions—were clearly not all of equal importance at this early stage in commercial development. The major issue—collision/evasion—received the most attention and garnered some excellent suggestions for strategic research investigations that could further delineate the interaction risk, as well as methodologies that could improve the efficacy and efficiency of monitoring activities required by regulators. Attraction of fish to marine energy devices is also of interest to regulators, but this interaction is not as universally of concern, nor are regulators in all nations requiring observations and data after tidal or wave device installation. The other two interactions—avoidance and mooring line interactions—do not appear to be of great concern at the moment, although participants acknowledged that they could become much more important as large commercial-scale arrays are deployed.

Based on the discussions from the breakout sessions, it became clear that interactions could be parsed into

- interactions that can be effectively monitored now with specific instruments, platforms, and technologies. However, significant research challenges remain in the design and installation of the instruments, as well as in the acquisition, analysis, and interpretation of data streams.
- interactions that would benefit from the input of targeted research efforts in the near term. These inputs could help to decrease the costs and perhaps the length of monitoring over the life of wave or tidal project.
- interactions that can only be advanced with key research investments up front. For these interactions, there is no viable path forward for monitoring, in the absence of such investment. In addition, some of these interactions could be "retired" as risks from marine energy devices to the marine environment, resulting in significant savings and certainty for project developers and regulators, respectively.

Guidance has been developed to help focus targeted research studies that will improve and inform monitoring programs, and will also lead to the decrease or elimination of long-term monitoring around devices and arrays as certain risks are determined to be well understood and can be "retired" from consideration.

6.2 Next Steps

The outcomes of this workshop add to the collected knowledge of several previous efforts including the following:

- Ecological Effects of Wave-Energy Development in the Pacific Northwest
- A Scientific Workshop, October 11–12, 2007 (Boehlert et al. 2007)
- Environmental Effects of Tidal Energy Development, Proceedings of a Scientific Workshop March 22– 25, 2010 (Polagye et al. 2010)
- Instrumentation for Monitoring around Marine Renewable Energy Converters: Final Workshop Report 2013 (Polagye et a. 2014).

To assist with the development of marine energy, the research community seeks to better understand the nature of environmental interactions around wave and tidal devices and to improve upon methods for measuring, analyzing, and interpreting the results.

Coupled with the need for strategic research investments to improve monitoring activities is the need to ensure that the results of research studies and monitoring outcomes are well communicated among all sectors, with a special emphasis on ensuring that the research community, regulators, and developers understand one another's needs and capabilities, and that they are speaking the same language.

At the same time that the research community is tracking down environmental interactions, regulators are working to better determine what data they need to make cogent permitting (consenting) decisions, and project developers are becoming increasingly aware of the need to design, develop, and operate devices in a manner that is sensitive to identified risks to marine organisms and habitats.

By working together the three sectors—the research community, the regulators, and the marine energy developers—can begin to decrease the number of risks that require intensive and continuous monitoring, moving certain interactions toward mitigation measures, while “retiring” others.

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