Pacific Northwest
NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

2016 Annex IV State of the Science Report

ENVIRONMENTAL EFFECTS OF MARINE ENERGY DEVELOPMENT AROUND THE WORLD

Andrea Copping
Pacific Northwest National Laboratory

OES OCEAN ENERGY SYSTEM
An IEA Technology Initiati
ANNEXIV

http://tethys.pnnl.gov/publications/state-of-the-science-2016

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

2016 State of the Science Report

- Marine Renewable Energy (MRE):
  - Industry in early stages of development, deployment, and commercialization
  - Need to streamline siting and permitting/consenting
- State of Science (SoS) report summarizes interactions and effects of MRE devices on the marine environment, the animals that live there, and the habitats that support them.
- SoS helps:
  - Inform regulators and researchers about potential risks from tidal and wave installations;
  - Assists MRE developers in developing engineering, siting, operational strategies, and monitoring options for projects that minimize encounters with marine animals and/or diminish the effects if such encounters occur.
- SoS information can simplify and shorten the time to permit/consent deployment of single and multiple device arrays, but site-specific knowledge will still be needed
- SoS 2016 serves an update and complement to 2013 Annex IV report:

Purpose of Annex IV

- Annex IV is a collaborative initiative of the Ocean Energy Systems (OES), under the International Energy Agency (IEA) Technology Network.

- Annex IV is led by the US, with 13 partner nations, and is designed to:
  - "*Facilitate efficient government oversight of ocean energy systems development by expanding our baseline knowledge of environmental effects and monitoring methods;*
  - *"Ensure that existing information and data on environmental monitoring are more widely accessible to those in the industry; national, state, and regional governments; and the public; and*
  - *"Facilitate knowledge and information transfer"*.

State of Science Report - Chapters

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Chapter Number	Title	Authors
1	Introduction	A. Copping
2	Potential Environmental Interactions Associated with the Deployment of Marine Renewable Energy Devices	L. Hanna, A. Copping
3	Collision Risk for Animals Around Tidal Turbines	G. Zydlewski, G. Staines, C. Sparling, E. Masden, J. Wood
4	Risk to Marine Animals from Underwater Sound from Marine Renewable Energy Devices	N. Sather. A. Copping
5	Changes to Physical Systems: Energy Removal and Changes in Flow	J. Whiting, A. Copping
6	Effects of EMF on Marine Animals from Electrical Cables and Marine Renewable Energy Devices	A. Gill
7	Changes in Habitats Caused by Marine Renewable Energy Devices: Benthic Habitats and Reefing Patterns	N. Sather, A. Copping, G. Zydlewski, G. Staines
8	Marine Spatial Planning and Marine Renewable Energy	AM. O'Hagan
9	Case studies that Examine Siting and Permitting/Consenting of Marine Renewable Energy Devices	T. Simas, J. Bald
10	Summary and Path Forward for Marine Energy Monitoring and Research	A. Copping, I. Hutchison

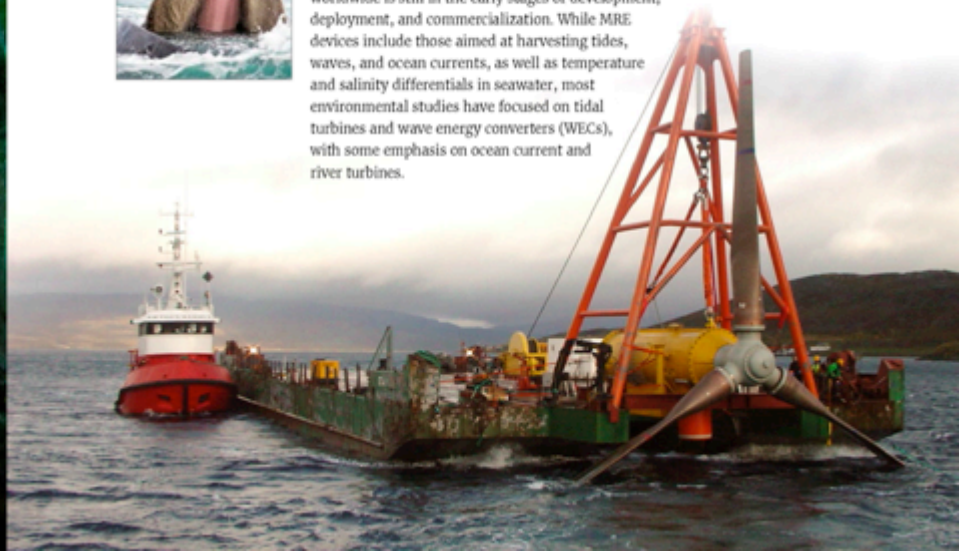
PUBLIC REVIEW DRAFT

1.0 Introduction

Chapter author: A. Copping

This report summarizes the state of the science of interactions and effects of marine renewable energy (MRE) devices on the marine environment, the animals that live there, and the habitats that support them. This report serves an update and a complement to the 2013 Annex IV report that can be found at *http://tethys.pnnl.gov/publications/final-annex-iv-report-2013*.

MRE development is also referred to as ocean energy development, or marine and hydrokinetic energy development; we use the acronym MRE throughout this document for consistency. MRE development worldwide is still in the early stages of development, deployment, and commercialization. While MRE devices include those aimed at harvesting tides, waves, and ocean currents, as well as temperature and salinity differentials in seawater, most environmental studies have focused on tidal turbines and wave energy converters (WECs), with some emphasis on ocean current and river turbines.



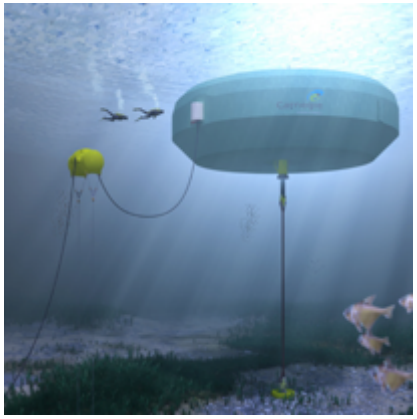
Chapter 1 - Introduction

Focus:

- Introducing the State of Science report

Highlights:

- Discusses benefits of MRE for climate change mitigation and energy security.
- The need to organize the international community around environmental effects of MRE.



PUBLIC REVIEW DRAFT

2.0

Summary of Potential Environmental Interactions Associated with the Deployment of Marine Renewable Energy Devices

Chapter authors: L. Hanna, A. Copping

As MRE technologies are installed, they will interact with and affect the surrounding marine environment in a variety of ways. Depending on the specific technology, certain stressors or components of each device may affect marine animals and habitats, also referred to as environmental receptors. Table 2.1 lists the key potential stressor-receptor interactions associated with MRE technologies (Boehlert and Gill 2010; Copping et al. 2013; Aquatera Limited 2012), and provides a brief description of each potential interaction.

Chapter 2 – Interactions around MRE Devices

Focus:

- Overall risk of MRE devices to marine animals and habitats

Highlights:

- Scientific uncertainty drives much of the risk perceived now; more data collection and research can help to reduce uncertainty.
- Most important and potentially highest risk interactions include:
  - Collision of animals with tidal turbines,
  - Underwater noise from MRE devices on animals,
  - EMF from cables and devices.
- Generally little impact expected from single devices, larger arrays will require more investigation.

PUBLIC REVIEW DRAFT

3.0 Collision Risk for Animals around Tidal Turbines

The potential for marine animals to collide with the moving parts of tidal devices, particularly the rotors of horizontal-axis tidal-stream turbines, is a primary concern for consenting/permitting and licensing of tidal developments. The importance of this issue, associated definitions, and the need to understand collision risk in general, and for mammals, fish, and seabirds, in particular, are discussed in the following sections.

Chapter authors: G. Zydlewski, G. Staines, C. Sparling, E. Masden, J. Wood

3.1 IMPORTANCE OF THE ISSUE

Animal interactions with tidal turbines is an active area of research because many questions remain today and ecological consequences are still mostly implied by expert opinion (Busch et al. 2013). Most recently, application of risk frameworks and collision risk modeling (Romero-Gomez and Richmond 2014; Hammar et al. 2015) has greatly informed research directions including the need to assess risk to populations with respect to environmental changes associated with climate (Busch et al. 2013).

Chapter 3 – Collision with Tidal Turbines

Focus:

- Risk to animals from collision with the blades of a tidal turbine

Highlights:

- Animals considered to be at potential risk include marine mammals, fish, and diving seabirds.
- No observations have ever been made of a marine mammal collision with a device, significant collisions by fish.
- Technologies to observe collision are not well developed and difficult to operate in high-energy environments.
- Important to quantitatively estimate number of animals potentially in area of turbines, and to understand their capability to sense and evade devices.
- Collisions with tidal turbines are examined for individual animals; results must be put in context of risk to populations.

PUBLIC REVIEW DRAFT

4.0

Chapter authors:
N. Sather, A. Copping

Risk to Marine Animals from Underwater Sound Generated by Marine Renewable Energy Devices

The effects of acoustic output from tidal and wave devices on marine animals were previously addressed in the 2013 Annex IV report. The purpose of this chapter is to provide an update of new knowledge relating the effects of underwater sound from wave and tidal devices to marine animals.

Chapter 4 – Underwater Noise

Focus:

- Potential effects of underwater noise on marine animals from wave and tidal devices.

Highlights:

- Marine animals use underwater sound as terrestrial animals use light to see, especially for navigation and communication.
- Sound from MRE devices may add to other anthropogenic sounds and could disturb animals, especially marine mammals and fish.
- Noise from single turbines and WECs are being measured, and predictions can be made about what arrays may sound like to marine animals.
- Excess underwater noise could cause physical harm including loss of hearing ability, physical harm to tissues, and/or behavioral changes.
- Additional data are needed to understand how sounds may affect animals.

PUBLIC REVIEW DRAFT

5.0

Chapter authors: J. Whiting, A. Copping

Changes in Physical Systems: Energy Removal and Changes in Flow

The effects of altering natural water flows and removing energy from physical systems in the ocean by the installation and operation of MRE devices were previously addressed in the 2013 Annex IV report (Copping et al. 2013). The purpose of this chapter is to summarize previous information about flow changes and energy removal caused by wave and tidal devices, including changes in sediment transport and water quality, and to update these findings with new knowledge.

5.1 GOAL AND OBJECTIVES

The goal of this chapter is summarize the state of knowledge of changes in the physical ocean systems caused by MRE projects worldwide. Objectives include the following:

- Identify recent wave and tidal projects with a monitoring program that addresses physical changes in the environment.
- Analyze details of recent laboratory experiments and numerical modeling simulations that help to inform the understanding of potential physical effects from MRE devices.
- Compare the cumulative understanding from recent studies with knowledge gaps identified in the previous Annex IV report to identify progress.
- Diagnose persisting knowledge gaps based on a review of available research.

Chapter 5 – Changes in Physical Systems

Focus:

- Effects on ocean waters of MRE development.

Highlights:

- Placement of MRE devices in the oceans can change circulation and remove energy from the system, as well as potentially change patterns of sediment movement.
- The amount of change that will occur from single devices or small arrays is likely to be immeasurably small.
- Numerical models suggest that changes may be measureable only with the operation of very large arrays that are probably too large to be realistically considered for most waterbodies.

PUBLIC REVIEW DRAFT

6.0

Chapter author: A. Gill

Effects of EMF on Marine Animals from Electrical Cables and Marine Renewable Energy Devices

To meet the objectives of the Annex IV, Phase 2, State of the Science report, this chapter focuses on the topic of electromagnetic fields (EMFs). EMFs are poorly understood and are conceptually a challenge to understand, perhaps because our inability as humans to sense them leads to less focus on EMF as environmental risks.

This chapter aims to identify the key questions that have arisen from various sectors in relation to EMFs and to provide an up-to-date synthesis of the current knowledge base. With this knowledge, the reader should be able to better appreciate EMFs as an environmental effect that should be taken into account when considering the sustainable management of human activities within the marine environment and promoting MRE.

Chapter 6 – Electromagnetic Fields

Focus:

- Effects of EMF on Marine Animals from Electrical Cables and Devices

Highlights:

- Additions of EMFs from power export cables and energized parts of devices can add to naturally-occurring magnetic fields, and have the potential to disturb certain marine animals.
- Some animals including some elasmobranchs and invertebrates, are known to be electro- or magneto-sensitive and could be disturbed by EMFs from MRE devices.
- Power cables will generally be buried and effectively shield the environment from EMF.
- Most studies to date have focused on behavioral responses of animals to EMF.
- Lab and field studies have shown no evidence that EMFs, at the levels expected from MRE devices, will have an effect on any species.

PUBLIC REVIEW DRAFT

7.0

Chapter authors:
N. Sather, A. Copping,
G. Zydlewski,
G. Staines

Changes in Habitats Caused by Marine Renewable Energy Devices: Benthic Habitats and Reefing Patterns

The installation of MRE devices alters marine habitats through mechanisms that induce physical change. These changes in habitat have the potential to alter or eliminate species occurrence at a localized scale, provide opportunities for colonization by new species, alter pat-

All MRE devices must be attached to the sea bottom in some manner, either with gravity foundations, piled into the seafloor, or by one of several anchoring solutions. The placement on the seafloor, as well as movement of anchor lines, cables, and mechanical moving parts, can all affect the surrounding rocky or soft-bottom seabed and the benthic organisms these habitats support (Figure 7.1). Similarly, the presence of MRE devices on the seafloor or suspended in the water column may attract fish and benthic organisms, causing them to change their behavior and settling locations, perhaps affecting population movement, structure, or success.

Chapter 7 – Changes in Habitats

Focus:

- Changes in benthic habitats and reefing of fish, due to MRE devices.

Highlights:

- MRE devices can change the bottom habitats by disturbing sediments under their foundations, as well as around anchors and mooring lines.
- Devices will attract fish and invertebrates, that will remain around the parts of the devices and systems.
- No evidence collected to date shows that significant negative effects will occur to benthic areas around MRE developments, or that marine animals reefing around devices will harm fish populations.

PUBLIC REVIEW DRAFT

8.0

Marine Spatial Planning and Marine Renewable Energy

Chapter authors:
A.M. O'Hagan

Marine spatial planning (MSP) is a comparatively recent approach to planning and managing sea uses and users in a way that helps achieve sustainable development of marine areas. The rationale for MSP is to provide a stable and transparent planning system for maritime activities and users within agreed-upon environmental limits to ensure marine ecosystems and their biodiversity remain healthy.

MSP works across multiple sectors, within a specified geographic context, to facilitate decision-making about the use of resources, development, conservation, and the management of activities in the marine environment both now and in the future. To be effective, MSP should be integrated across sectors, ecosystem-based, participatory, strategic, adaptive, and tailored to suit the needs of a predetermined marine area. Currently, marine activities tend to be managed on a sector by sector basis, thereby limiting the consideration that can be given to other marine activities likely to occur in the same space, as well as the effects of that activity on the receiving environment. Processes such as environmental assessments address the impacts of an activity on the environment before a development or activity occurs, but this can be limited to a specific site and cumulative impacts remain a challenge for those processes. Failure to take a more holistic approach to planning can result in conflicts between different marine users and activities and also conflicts with the physical environment (Figure 8.1). Conflicts usually result in "reactive" management rather than more proactive management where agreed-upon desired outcomes can be facilitated.

Figure 8.1 Representation of different potential marine users and conflicts of interest (Sutherland 2005).

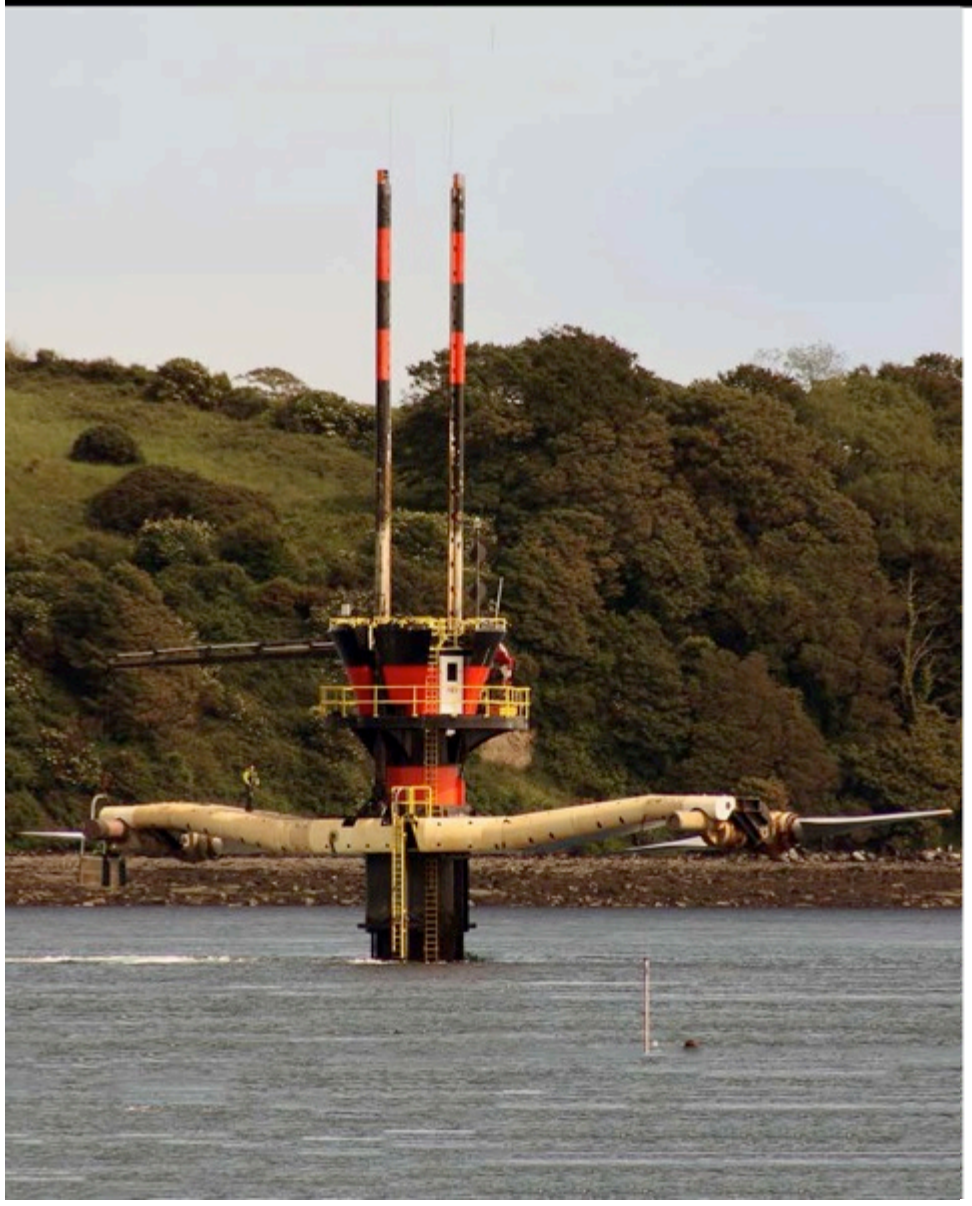
Chapter 8 – Marine Spatial Planning

Focus:

- Marine Spatial Planning (MSP) and the role of MRE development.

Highlights:

- MSP involves planning and managing sea uses and users to support sustainable development of marine areas.
- Annex IV representatives were surveyed about use of MSP in their nations.
- Several nations have formal MSP processes, others have coastal management plans that embody principles of MSP, and several have no MSP in place.
- MSP must use a stable and transparent planning system for maritime activities and users within agreed environmental limits, working across multiple sectors, including the MRE industry.



PUBLIC REVIEW DRAFT

9.0

Chapter Authors: T. Simas and J. Bald

Case Studies that Examine Siting and Permitting/ Consenting of Marine Renewable Energy Devices

The consenting process, including the environmental impact assessment of ocean energy projects, is still regarded as a challenge to marine renewable energy scale-up to create a cost-competitive viable MRE industry. Specifically, uncertainty about the appropriate application of environmental legislation, which can prolong the consenting processes (adding cost and delay) is a key focus area. Currently the environmental effects and impacts of MRE devices on the marine environment, and vice versa, are significant areas of uncertainty. Furthermore, the scarcity of data on the environmental interactions of new technologies often means they are characterized as a threat, requiring extensive supporting environmental information, the collection of which can be costly and time consuming.

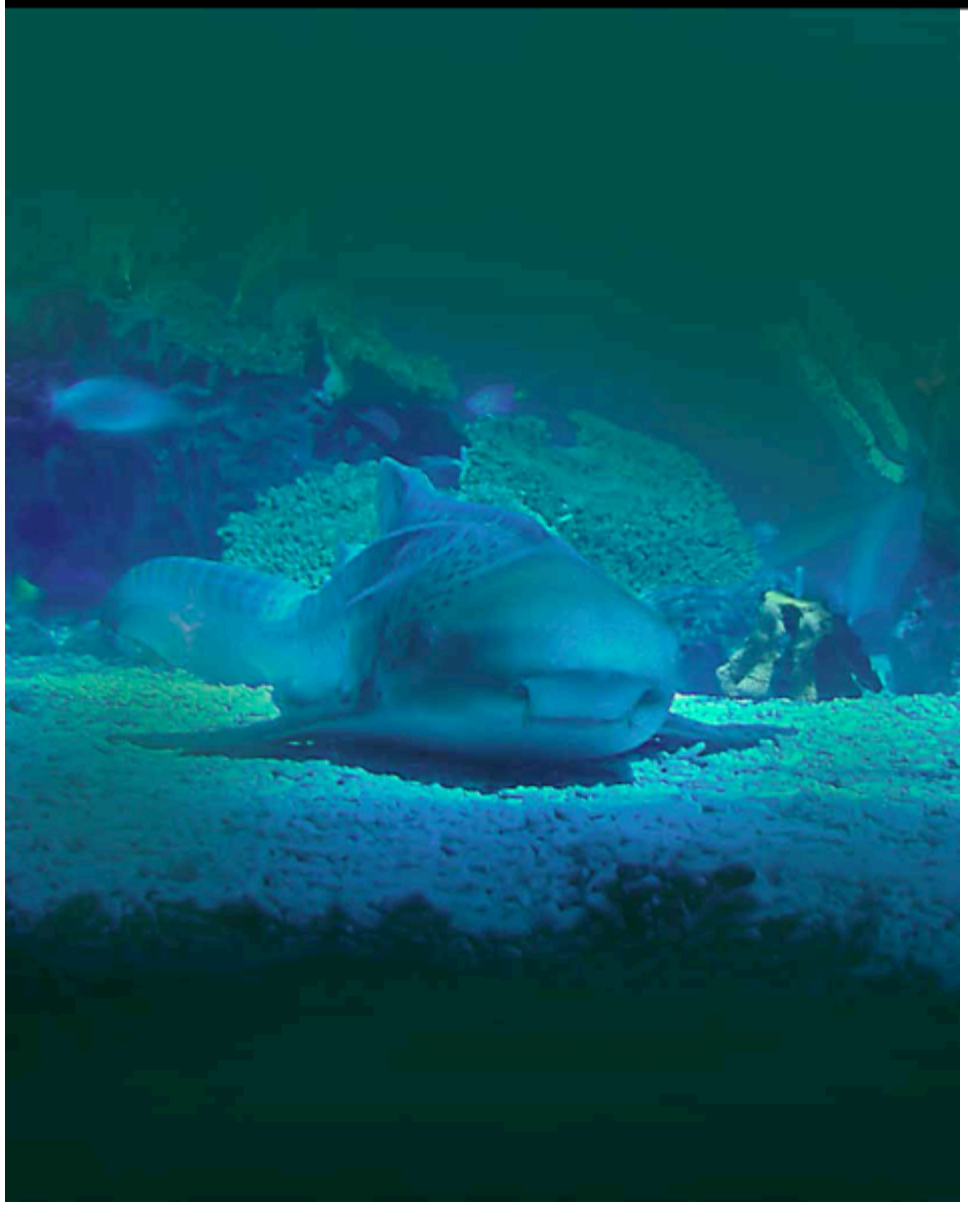
Chapter 9 – Consenting Case Studies

Focus:

- Examined four consented projects to learn lessons to help MRE development.

Highlights:

- Consenting processes were reviewed:
  - WaveRoller wave technology, installed in Portugal;
  - TidGen® Power System tidal technology, installed in the United States;
  - SeaGen tidal technology installed in Northern Ireland; and
  - BIMEP (Biscay Marine Energy Platform), a designated wave test site in the Basque country, Spain.
- Project success is supported by:
  - Carrying out strong stakeholder outreach throughout the process.
  - Developing robust monitoring plans, adaptive management strategies, and a sound Environmental Impact Assessments.
- At present, there are no dedicated policies that streamline development of wave and tidal projects.



PUBLIC REVIEW DRAFT

Summary and Path Forward for Marine Renewable Energy Monitoring and Research

10.0

Chapter authors: A. Copping, I. Hutchison

This report has summarized and placed in context information about the environmental effects of MRE development, to the extent that the information is publicly available. The lessons learned, research gaps, and recommendations from each of the chapters in this report are summarized in the ensuing sections. A path forward in the face of scientific uncertainty is also discussed. A path forward in the face of scientific uncertainty is also discussed.

10.1 POTENTIAL INTERACTIONS OF MRE DEVICES WITH THE ENVIRONMENT

(Chapter 2)

Uncertainty associated with interactions between MRE devices and marine animals and/or habitats continues to cause a high degree of risk for permitting/consenting pathways, which in turn causes uncertainty and delays in establishing the industry. By examining all of the possible interactions that might occur, a set of high-priority interactions has been identified. In most cases, interactions that most concern regulators and stakeholders are also the focus of the efforts of researchers working in this field, as well as the focus of work undertaken by developers during the consenting/permitting process. These researchers are actively seeking to understand the high-priority interactions, determining appropriate methods for recording or observing the interactions, and collaborating to develop appropriate instrumentation and data analysis methods to cost-effectively collect data during the life of MRE projects. Monitoring required of developers also focuses largely on these highly uncertain and unknown interactions.

Chapter 10 – Path Forward

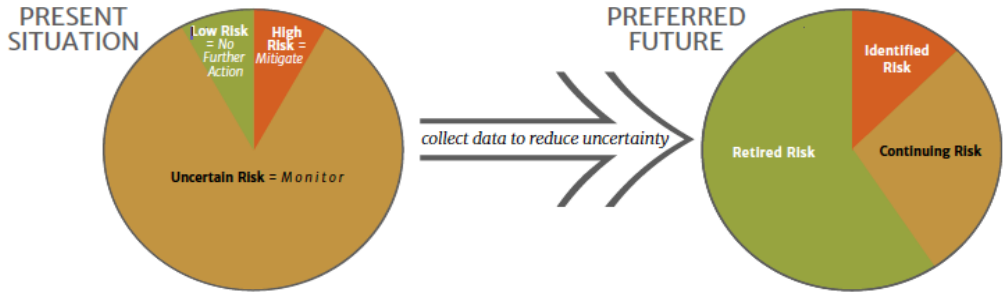
Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

Focus:

- Summary of document and a path forward for the industry in the face of scientific uncertainty.

Highlights:

- Interactions with MRE devices are perceived to be risky largely due to uncertainty.
- Additional information will help to retire insignificant risks, while other risks may be determined to need mitigation. Monitoring requirements will be reduced as we learn more.
- There are no methods for monitoring certain interactions now; these require strategic research investments to proceed.



2016 State of the Science Report

Pacific Northwest NATIONAL LABORATORY
Proudly Operated by Battelle Since 1965

- 2016 State of Science report was released in April 2016 and is available at: *http://tethys.pnnl.gov/publications/state-of-the-science-2016*

- Executive Summary is available at same site, in seven languages.
- Also 8 short science summaries of key stressors, receptors.

Andrea Copping
Andrea.copping@pnnl.gov
+1 206.528.3049

Nikki Sather
Nichole.sather@pnnl.gov

Jonathan Whiting
Jonathan.whiting@pnnl.gov

PHASE 2
ANNEX IV NATIONS:

Canada
China
Ireland
Japan
New Zealand
Nigeria
Norway
Portugal
South Africa
Spain
Sweden
United Kingdom
United States