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ANNEX IV – INTERNATIONAL COLLABORATION TO INVESTIGATE ENVIRONMENTAL EFFECTS OF WAVE AND TIDAL DEVICES

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ABSTRACT

The pace of development for wave and tidal energy projects worldwide continues to be hindered by uncertainty surrounding potential environmental effects of the devices and the balance of system. To respond to this uncertainty the Ocean Energy Systems (OES) international agreement developed a collaborative initiative (Annex IV). Over an initial three-year period (2010-2012) Annex IV collected metadata on environmental effects around marine energy projects, as well as ongoing research into interactions of wave and tidal devices and the marine environment. Housed on the US-based *Tethys* online knowledge base the Annex IV metadata was used to investigate high priority interactions. The work of Annex IV was guided by expert input at two workshops held in Dublin (2010 and 2012). The three priority environmental interactions are documented in a report available from OES and on *Tethys*:

1. The interaction of aquatic animals with turbine blades;
2. The effects of underwater noise from tidal and wave devices on marine animals; and
3. The effects of energy removal on physical systems.

Each priority interaction (or "case study") examined published literature, compliance and investigative reports, and information gathered directly from device developers and researchers. This information was used to reach preliminary conclusions on the importance of each interaction to the environment; assess the level of certainty surrounding each interaction; and highlight key research gaps that hinder a deeper understanding of the interaction.

INTRODUCTION

Numerous ocean energy technologies and devices are being deployed around the world; however, few data exist about the environmental effects of these deployments and there remains considerable uncertainty around the potential risk to marine animals and habitats from the installation and operation of these devices. Although pilot scale and demonstration projects have been deployed in Europe and to a lesser extent in North America, the lack of environmental data and high levels of uncertainty are currently impeding the industry's ability to successfully permit large scale commercial wave and tidal projects.

To reduce the high levels of uncertainty and address data gaps, there is a clear need to share information, research findings, and lessons learned from the marine energy deployments and projects worldwide. Cost effective targeted use of research and monitoring efforts will help to reduce risk to the marine environment.

In 2009, the Ocean Energy Systems agreement (under the auspices of the International Energy Agency) recognized the need to share information, leading the group to Annex IV, a collaborative project that involved seven nations. Focused on aggregating information on environmental effects of marine energy development, Annex IV distributes information to a broad audience of marine energy stakeholders, provides analyses that inform the marine energy industry, and provides a collaborative space for discussion among researchers.

The first phase of Annex IV culminated in 2012, with a searchable database of current literature and reports on environmental effects of marine energy development, housed on the US-based *Tethys* online knowledge base (Tethys.pnnl.gov), as well as an analysis of three key interactions of devices and the marine environment: 1) interaction of aquatic animals with turbine blades; 2) effects of underwater noise from tidal and wave devices on marine animals; and 3) effects of energy removal on physical systems. Through these analyses and others like them, a greater understanding of the environmental effects and monitoring methods will help to foster public acceptance and advance marine energy technologies. This paper discusses the results of those analyses.

METHODOLOGY

Three priority interactions between marine energy devices and the marine environment were chosen as case studies for analysis. For each case study, the best available information within the public domain was surveyed, analysed, and compiled into one comprehensive report. Case study topics were chosen to meet the following criteria: 1) the topic must be a common environmental concern or question among multiple nations; 2) the topic must be raised as a significant issue in permitting (consenting) of marine energy sites in more than one

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nation; and 3) there must be sufficient information available to make an assessment.

Scientific papers and technical reports comprised the majority of the material for the case studies. Additional information from deployed wave and tidal projects was gathered by querying project and device developers, researchers and other practitioners, and the results organized as metadata forms hosted as part of the Annex IV collection on the widely accessible *Tethys* website (tethys.pnnl.gov).

Each case study begins by defining the problem addressed, presents available evidence from marine energy monitoring and/or research studies, and concludes with a discussion of the lessons learned and data gaps illuminated by the available information. References used for each case study are cited and can be accessed through the Annex IV Final Report (Copping et al. 2012).

OBSERVATIONS

Each case study was analysed using environmental effects information from full scale deployments when available, as well as with information from smaller scale devices deployed in open water, testing in laboratory flume and tanks, and outputs from numerical models. Information sources were examined to determine whether the outcome informed the case study, and to identify significant gaps in data needed to better understand the interaction of interest.

Case Study #1 – Interactions of Marine Animals with Tidal Turbine Blades

Direct observations of marine animals interacting with turbine blades are restricted to locations where deployments of tidal devices have occurred; to date these have consisted of small-scale devices and/or single devices, most often in the water for relatively short periods of time. Marine animals could potentially be at risk from turbine blades through a variety of mechanisms including: blade strike; collision between the animal and any part of the device; and changes in animal behaviour such as attraction and avoidance that might adversely affecting feeding or mating behaviour.

The limited information available provides no evidence that direct interaction of marine mammals, birds, or fish with tidal turbine blades has caused harm to the animals, particularly from blade strike or collision. Changes in animal behaviour including avoidance and attraction to tidal turbines could increase risk; however, detecting these changes is difficult due to the limited number of small deployments that have occurred to date. Furthermore, scaling interactions of animals with tidal turbines from the limited number of deployed devices to large-scale long-term commercial developments is very challenging. Additional observations around deployed tidal devices are needed, with a particular focus on behavioural effects of marine mammals, fish, and sea turtles.

Case Study #2 – Effects of Underwater Noise from Tidal and Wave Devices on Marine Animals

The underwater sound generated from tidal and wave devices has the potential to interfere with basic communication and navigation of certain marine animals, most notably marine mammals and some fish species (Pelc and Fujita 2002; Cummings and Thompson 1971). Understanding the effects that sound from wave and tidal devices may have on animals requires accurate measurement of the amplitude and frequency of the sound from the devices, as well as extensive observations to understand potential changes in animal behaviour.

Improvements are needed to characterizing the acoustic environment into which marine energy devices will be deployed, as well as the ability to accurately measure the amplitude and frequency spectrum of sound from these devices, as they vary over time and space. Existing evidence indicates that operational noise from individual marine energy devices or small arrays is unlikely to have large-scale effects on animal behaviour or survival. However, the complex propagation of sound through seawater makes it very difficult to predict possible additive or synergistic sound effects that might be generated from large arrays. Long term monitoring around arrays is needed to inform these effects. Modelling outputs may assist in understanding acoustic effects of multiple devices arrays, but field data will be needed to validate the models. As each tidal and wave device or array is deployed, a full suite of acoustic and behavioural studies is needed, including measuring the ambient sound field and propagation potential of the waterbody prior to deployment of the marine energy device; documenting the sound of installation; accurately measuring the sound of the operational device; and observing species of interest around the device using multiple tools such as observers, active acoustics, and remote sensing capabilities like satellite tags and aerial surveys.

Case Study #3 – The Environmental Effects of Marine Energy Development on Physical Systems

Introduction of marine energy converters into a waterbody has the potential to affect the natural processes of that water body and all the essential marine ecosystem functions that depend on circulation within the system. Effects may be caused by changes in water flow, as well as the effects of removing energy from the system in the form of electricity through an export power cable (Polagye et al. 2011). Numerical models are sophisticated enough to simulate natural conditions, as well as the flow blockage and energy removal from the system; field measurements are vital however to validate and ground the models in reality. Modelling potential effects of flow and energy removal is the most practical means to predict future changes, and will support the design of cost-effective monitoring programs for large commercial marine energy arrays.

Measurements of water flow and water quality in areas of tidal energy development have shown no apparent changes from the presence of the devices (Keenan et al 2011). This evidence is not surprising as no large arrays have been deployed to date. Models of energy removal by tidal turbines indicate that very large numbers of turbines will be required in waterbodies to have a significant effect on flow and estuarine circulation (Yang et al. 2013). There is some indication from modelling studies of wave energy converters that moderate effects on shorelines and coastal currents may occur near wave arrays (Palha et al. 2010; Reeve et al. 2011; PMSS Ltd. 2007), and moderate to severe changes in sediment transport and water quality may occur in the vicinity of large wave arrays nearshore (Roberts et al. 2012).

Data collected in the field for model validation is currently the greatest barrier to accurately modelling the effect of flow changes and energy removal from marine energy devices. There is also a need to develop better models that examine and couple effects in the nearfield and farfield environments, and better modelling solutions to simulate cumulative effects of many marine energy arrays in a waterbody that will include interactions among and between devices and arrays.

CONCLUSIONS

Information gathered from the three case studies under Annex IV provides insight into the state of knowledge of potential environmental effects from the deployment and operation of wave and tidal devices.

The two clearest outcomes from the three case studies are that there continues to be a dearth of quantitative environmental information from tidal and wave devices that have been deployed in coastal waters; and that there are inadequate research and modelling data to adequately characterize the potential effects of marine energy devices, particularly at the large commercial scale. In response to these needs, many regulators and developers have recognized the need to take an adaptive management approach ("learning by doing") to the design and implementation of monitoring data collection pre- and post-installation of marine energy devices. Future Annex IV activities will continue to support and analyse these outcomes.

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