Accelerating Ocean Energy to the Marketplace – Environmental Research at the U.S. Department of Energy National Laboratories

A. Copping[1], G. Cada[2], J. Roberts[3] and M. Bevelhimer[2]

[1] Marine Sciences Laboratory
Pacific Northwest National Laboratory
Seattle WA, USA
Email: andrea.copping@pnl.gov

[2] Oak Ridge National Laboratory
Oak Ridge TN, USA
Email: cadagf@ornl.gov
Email: bevelhimerms@ornl.gov

[3] Sandia National Laboratories
Albuquerque NM, USA
Email: jdrober@sandia.gov

Abstract

The U.S. Department of Energy (US DOE) has mobilized its National Laboratories to address the broad range of environmental effects of ocean and river energy development.

The National Laboratories are using a risk-based approach to set priorities among environmental effects, and to direct research activities. Case studies will be constructed to determine the most significant environmental effects of ocean energy harvest for tidal systems in temperate estuaries, for wave energy installations in temperate coastal areas, wave installations in sub-tropical waters, and riverine energy installations in large rivers.

In addition, the National Laboratories are investigating the effects of energy removal from waves, tides and river currents using numerical modelling studies. Laboratory and field research is also underway to understand the effects of electromagnetic fields (EMF), acoustic noise, toxicity from anti-biofouling coatings, effects on benthic habitats, and physical interactions with tidal and wave devices on marine and freshwater organisms and ecosystems.

Outreach and interactions with stakeholders allow the National Laboratories to understand and mitigate for use conflicts and to provide useful information for marine spatial planning at the national and regional level.

Keywords: environmental effects of ocean energy; marine and hydrokinetic energy; siting and permitting; U.S. National Laboratories.

1. Introduction

The potential to harvest energy from the movement of waves, tides, ocean currents and rivers (i.e. marine and hydrokinetic (MHK) energy) becomes increasingly attractive as a constituent of the renewable energy portfolio of many nations. In addition to significant technical challenges, the future of MHK as a significant and reliable energy source faces challenges that include financial investment in uncertain economic times and potential conflicts with current ocean uses such as navigation and commercial fishing. However the barrier most often cited is the uncertainty of siting and permitting MHK devices and arrays due to environmental concerns (1). Regulatory standards in the United States for protecting marine systems and animals, particularly under the Marine Mammal Protection Act and the Endangered Species Act, are particularly stringent (2). Providing regulatory confidence and allaying stakeholder concerns are likely to play a prominent role in getting pilot and demonstration projects in the water.

The US DOE has directed its National Laboratories to determine the effects of MHK devices and arrays on marine systems and marine animals. This paper will describe the studies underway to predict the most significant environmental effects that may occur due to installation, operation, maintenance and decommissioning of MHK devices and arrays.

2. Categorizing and Evaluating Environmental Effects

Understanding which of the many potential effects of MHK devices and arrays are likely to cause actual harm to the environment requires that an inventory of all effects be made, and each evaluated. We define each portion of an MHK device or the effect that device may have on an aquatic system as a *stressor* (3); examples of stressors are shown in Table 1.

Technology Type	Stressors	Potential Effect
Tidal	Rotating turbine blades	Strike, entrainment, impingement; Acoustic output interfering with marine mammal communication, navigation
Tidal	Seabed mount	Alteration of benthic habitat
Wave	Surface float	Attraction of fish (reef effect), allowing increased predation; Bird strike in bad weather
Wave	Mooring lines	Entanglement of migrating marine mammals, turtles, diving birds
Wave	Anchors	Changing soft bottom habitat to hard bottom
Ocean current	Placement at mid depth	Interference with migratory species
Riverine	Tethered to river bottom	Changes to sediment and benthic communities; Interference with fish migration
All	Electrical cables	Electromagnetic field emissions if damaged

Table 1 Examples of stressors caused by MHK devices.

We define *receptors* as those parts of the aquatic ecosystem that could be affected by stressors (3); examples are shown in Table 2.

The ability to understand and address particular combinations of specific stressors from MHK devices that will affect particular receptors requires a system to narrow the very large numbers of potentially significant interactions to a manageable number. The National Laboratories and their partner organizations have created a risk-informed approach, the Environmental Risk Evaluation System (ERES), to narrow the number of risk-relevant stressor/receptor interactions.

Simultaneously a “smart” database, called *Tethys,* is under development to house data needed by ERES, and to serve and accept data types from many sources. *Tethys* is a Wiki-based knowledge management system designed to facilitate knowledge creation, retrieval, annotation, and aggregation.

Receptor Group	Receptors	Potential Effect
Marine mammals	Toothed whales; Baleen whales; Pinnipeds	Interaction with tidal turbine blades; Confusion from acoustic output of turbine; Entanglement in mooring lines; Interference with migratory routes
Turtles	Endangered migrating turtles	Entanglement in mooring lines; Interference with navigation.
Seabirds	Diving birds; Endangered species	Strike from tidal turbine blades; Strike on wave buoy; Entanglement in mooring lines
Fish	Reef fish; Large migratory species; Salmon	Attraction to surface floats, increasing predation; Interference with migratory patterns
Ecosystem	Estuaries used for tidal energy generation; Open coast used for wave energy generation	Removal of energy from estuarine system causing water quality changes; Removal of energy from open water causing changes in sediment transport

Table 2 Examples of receptors in the marine environment

Built as an extension to Semantic Media Wiki, *Tethys* is designed to accept a wide array of data types, as well as rich external annotation, and tacit knowledge. *Tethys* is designed with a browse-style interface in addition to a searchable database; searches can be embedded in browse pages to provide context for search results. Access control can be maintained down to the document level, if needed.

ERES will draw data from *Tethys*, creating cases of specific MHK technologies, waterbodies, site characteristics, and receptors, and will be used to assign risk to each risk-relevant stressor/receptor pair and run risk models to determine the individual and collective risk of the case. Risk levels will be assigned using existing environmental effects data from MHK projects; in the absence of data, early ERES runs will rely on expert opinion. As more cases are assessed for risk, and additional laboratory and field data are collected, ERES will gain predictive capability to estimate the environmental risk of new projects based on the technology, location and marine resources present.

The process for pursuing a risk case involves defining attributes for four dimensions of the case: the MHK technology peculiar to the case; the waterbody where deployment is planned; the attributes of the deployment site; and the receptors that may be affected by the technology. Several states are delineated for each attribute, spanning to potential range of that attribute. Each case is then defined by the specific states for each attribute, describing the technology, geography, site characteristics, and receptors at risk. A small subset of the assessment table for a tidal energy case in a partially mixed estuary is shown in Figure 1; a full risk case examined by ERES would consist of anywhere from 20 to 100 risk attributes. The output of such a table will contribute information to the risk models developed to predict risk for that case.

Dimension	Attribute	State1	State2	State3	State4
MHK Technology	Max device speed (RPM)	10-15	15-20	20-30	>30
MHK Technology	Generation direction	One way	Two way	---	---
MHK Technology	Turbine swept area (m2)	20-60	60-100	100-200	200-500
Waterbody Feature	Estuarine	Fjord	Mixed	Partially mixed	Salt wedge
Receptors	Endangered salmonids	Yes	No	---	---

Figure 1 Subset of a tidal turbine case for risk assessment using the Environmental Risk Evaluation System (ERES).

Data that describe environmental effects of MHK devices that are currently available from European and other MHK projects will be added to *Tethys* and used to define risk for ERES cases. As environmental effects data become more readily available from US installations of MHK devices, modelling outputs inform effects of energy removal, and more laboratory experiments are undertaken to relate stressors and receptors, those data will be included, adding to the effectiveness and efficiency of the results.

3. Modelling the Effects of Energy Removal by MHK Devices

The amount of energy that can be removed from a natural system by MHK devices has a theoretical limit beyond which the natural system will begin to break down, at a level that is measureable (4). This breakdown could be manifested as changes in water quality, changes in sediment transport and associated changes in shoreline (beach) configurations and effects on benthic communities, and eventually changes in marine food webs. The National Laboratories are using a suite of numerical models to explore the limits of energy removal from marine and riverine systems by current and wave generation devices. Initial hydrodynamic modelling tools include tailoring of FVCOM (5) and EFDC (6) to simulate energy removal by tidal turbines from estuarine systems (Figure 2), as well as ocean/river currents. Wave modelling tools such as SWAN (7) and BOUSS-2D (8) can be used independently or coupled to EFDC or FVCOM to explore environmental effects of energy removal by wave devices from coastal systems (Figure 3).

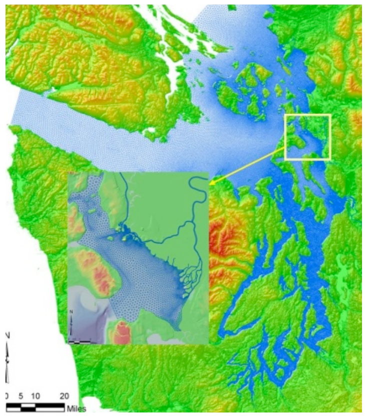

Figure 2. Example of grid for application of FVCOM in a tidal estuary, allowing for detailed simulation of energy removal from tidal energy devices (Puget Sound, WA USA)

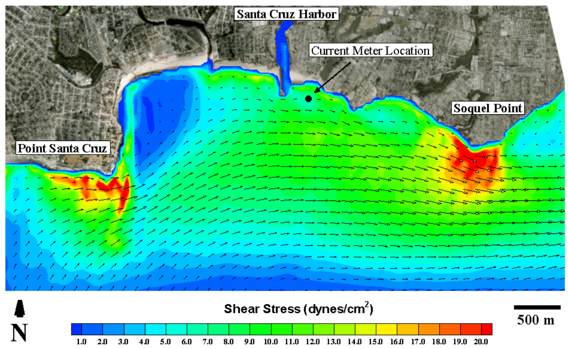

Figure 3. Example of combined wave and current shear stresses and velocities modeled using SWAN coupled with EFDC (Santa Cruz Bight, CA USA).

Scenarios will be developed that simulate the presence of tidal or wave devices in a body of water, allowing for the optimum design and build out possibilities for commercial arrays. Initial efforts will be based on placing momentum sinks at strategic locations in the models. As our understanding of the specific effects of individual and multiple MHK devices have on water flow, more realistic simulations of MHK devices and arrays will be used in building scenarios. The model outputs will also be used to design the optimum geometry for commercial arrays, to optimize power generation to reduce wake effects, and to minimize environmental effects to the body of water. Model runs, assumptions, and scenarios will be added to *Tethys*, and used to inform risk factors in ERES.

4. Measuring the Effects of MHK Devices on Living Organisms

As MHK devices are deployed in coastal, estuarine and inland waters, the organisms native to oceans and rivers will face new stressors; understanding the potential effects of those stressors will assist with predicting the risk associated with specific MHK installations (9). The National Laboratories are establishing protocols to determine the reaction of a variety of marine and freshwater organisms to the effects of alternating and direct current electromagnetic fields (EMF) over a range that represents probable outputs of MHK devices. Representative values of EMF will be created in the laboratory, and the responses of marine and freshwater fish and invertebrates will be quantified. Biological responses to be examined include short-term changes in individual behavior, changes in shoaling behavior, changes in distribution of mobile organisms, and injury to sessile species from long-term exposure. A similar Laboratory program is underway to understand the effects of acoustic frequencies that span the probable outputs of MHK devices. The first round of organisms for which exposure/response curves will be established for EMF and acoustic outputs are shown in Table 3.

Marine Fish	Freshwater Fish	Invertebrates
Oncorhynchus tshawytscha (Chinook salmon)	*Polyodon spathula* (paddlefish)	*Metacarcinus magister* (Dungeness crab)
Sebastes spp. (Rockfish)	*Lepomis macrochirus* (bluegill sunfish)	Freshwater crayfish
Hippoglossus stenolepis (Pacific halibut)	*Ictalurus punctatus* (Channel catfish)	Freshwater snails

Table 3. Some of the marine and freshwater organisms tested for effects of EMF and acoustic stressors from MHK devices.

Additional studies are also being conducted on the effects of physical interactions with devices, effects of MHK installation and operations on benthic habitats, as well as toxicity tests on organisms from the effects of anti-biofouling paints used on MHK devices. These data will be added to *Tethys* to assist with risk definition under the ERES.

5. Engaging Stakeholders to Optimize Siting and Permitting of MHK Installations

Successful siting and permitting of MHK devices requires that all the interested parties are involved early and throughout the process. Key players include MHK device developers, project developers, regulatory (consenting) government agencies, government and university scientists, non-governmental organization members, and the interested public. Determining the interest and influence of each group supports an optimized pathway to siting and permitting MHK installations under a regulatory environment that may vary from region to region (10).

The National Laboratories and their partner organizations are working to increase the information available to regulators, so that they can knowledgeably write permits for MHK pilot and demonstration projects. By assuring that research results are made available in accessible formats, we are able to increase regulatory confidence and encourage stakeholder participation. Stakeholders are invited to participate in defining risk cases and preferred formats for receiving information on research results. By providing input to the marine spatial planning processes that are underway at the regional and national level in the U.S., we can assure that siting of MHK plays a significant role in decisions relating to coastal resource use.

6. Future Research Directions on MHK Environmental Effects

Research and development activities at the U.S. Department of Energy National Laboratories are in the early stages of understanding the effects of MHK devices and arrays on the marine and freshwater animals and the ecosystem that support them. Work will continue to build the *Tethys* database, and to refine and assess the risk from MHK devices through case studies in tidal, wave and riverine systems. Modelling assessments will be used to build scenarios of energy removal from planned tidal and wave generation sites. Laboratory experiments on the effects of EMF, acoustics and other stressors on aquatic organisms will be followed by larger-scale (mesocosm) studies and later by monitoring of interactions with prototype MHK devices in the field. Results from the laboratory and mesocosm studies will help to refine the field work, in an adaptive management framework. Ultimately the work of the National Laboratories will converge on the application of monitoring technologies to recognize the environmental effects of MHK devices, and apply a science-based system of mitigation strategies to allow MHK development in an environmentally responsible manner.

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