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Screening Analysis for the Environmental Risk Evaluation System

Task 2.1.1.2: Evaluating Effects of Stressors
Fiscal Year 2011 Progress Report

Environmental Effects of Marine and Hydrokinetic Energy

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September 2011

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Summary

Potential environmental effects of marine and hydrokinetic (MHK) energy development are not well understood, and yet regulatory agencies are required to make decisions in spite of substantial uncertainty about environmental impacts and their long-term consequences. An understanding of risks associated with interactions between MHK installations and aquatic receptors, including animals, habitats, and ecosystems, can help define key uncertainties and focus regulatory actions and scientific studies on interactions of most concern. As a first step in developing the Pacific Northwest National Laboratory (PNNL) Environmental Risk Evaluation System (ERES), PNNL scientists conducted a preliminary risk screening analysis on three initial MHK cases. During FY 2011, two additional cases were added: a tidal project in the Gulf of Maine using Ocean Renewable Power Company TidGen^{TM} turbines and a wave project planned for the coast of Oregon using Aquamarine Oyster surge devices.

Through an iterative process, the screening analysis revealed that top-tier stressors in the two FY 2011 cases were the dynamic effects of the device (e.g., strike), accidents/disasters, and effects of the static physical presence of the device (e.g., habitat alteration). Receptor interactions with these stressors at the highest tiers of risk were dominated by threatened and endangered animals. Risk to the physical environment from changes in flow regime also ranked high. Peer review of this process and results will be conducted in early FY 2012.

The ERES screening analysis provides an analysis of vulnerability of environmental receptors to stressors associated with MHK installations. "Risk" has two components: (1) The likelihood, or "probability", of the occurrence of a given interaction or event, and (2) the potential "consequence" if that interaction or event were to occur. During FY 2011, the ERES screening analysis focused primarily on the second component of risk, "consequence", with focused probability analysis for interactions where data was sufficient for probability modeling. Consequence analysis provides an assessment of vulnerability of environmental receptors to stressors associated with MHK installations. Probability analysis is needed to determine specific risk levels to receptors and requires significant data inputs to drive risk models. During FY 2011, two stressor-receptor interactions were examined for the probability of occurrence. The two interactions (spill probability due to an encounter between a surface vessel and an MHK device; and toxicity from anti-biofouling paints on MHK devices) were seen to present relatively low risks to marine and freshwater receptors of greatest concern in siting and permitting MHK devices. A third probability analysis was scoped and initial steps taken to understand the risk of encounter between marine animals and rotating turbine blades. This analysis will be completed in FY 2012.

Project Overview

Energy generated from the world's oceans and rivers offers the potential to make substantial contributions to the domestic and global renewable energy supply. The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Wind and Water Power Program supports the emerging marine and hydrokinetic (MHK) energy industry. As part of an emerging industry, MHK project developers face challenges related to siting, permitting, construction, and operation of pilot- and commercial-scale facilities, as well as the need to develop robust technologies, secure financing, and gain public acceptance.

Although potential effects of MHK energy generation on the aquatic environment have been catalogued (e.g., EERE 2009 http://www1.eere.energy.gov/windandhydro/pdfs/doe_eisa_633b.pdf), the conditions under which those effects could occur and their relative significance have not been firmly established. This lack of certainty affects siting and operations decisions, the regulatory process, and the level and nature of stakeholder concerns, all of which limit the pace and scale of MHK deployment.

To unravel and address the complexity of environmental issues associated with MHK energy, Pacific Northwest National Laboratory (PNNL) is developing a program of research and development that draws on the knowledge of the industry, regulators, and stakeholders and builds on investments made by the EERE Wind and Water Power Program. The PNNL program of research and development—together with complementary efforts of other national laboratories, national marine renewable energy centers, universities, and industry—supports DOE's market acceleration activities through focused research and development on environmental effects and siting issues.

Research areas addressed include

- **Categorizing and evaluating effects of stressors** – Information on the environmental risks from MHK devices, including data obtained from in situ testing and laboratory experiments (see other tasks below) will be compiled in a knowledge management system known as *Tethys* to facilitate the creation, annotation, and exchange of information on environmental effects of MHK technologies. *Tethys* will support the Environmental Risk Evaluation System (ERES) that can be used by developers, regulators, and other stakeholders to assess relative risks associated with MHK technologies, site characteristics, waterbody characteristics, and receptors (i.e., habitat, marine mammals, and fish). Development of *Tethys* and the ERES will require focused input from various stakeholders to ensure accuracy and alignment with other needs.
- **Effects on physical systems** – Computational numerical modeling will be used to understand the effects of energy removal on water bodies from the short- and long-term operation of MHK devices and arrays. Initially, PNNL's three-dimensional coastal circulation and transport model of Puget Sound will be adapted to test and optimize simulated tidal technologies that resemble those currently in proposal, laboratory trial, or pilot study test stages. This task includes assessing changes to the physical environment (currents, waves, sediments, and water quality) and the potential effects of these changes on the aquatic food webs) resulting from operation of MHK devices at both pilot- and commercial-scale in river and ocean settings.
- **Effects on aquatic organisms** – Testing protocols and laboratory exposure experiments will be developed and implemented to evaluate the potential for adverse effects from operation of MHK

devices in the aquatic environment. Initial studies will focus on electromagnetic field effects, noise associated with construction and operation of MHK devices, and assessment of the potential risk of physical interaction of aquatic organisms with devices. A variety of fish species and invertebrates will be used as test animals, chosen due to their proximity to and potential susceptibility to MHK devices.

- **Permitting and planning** – Structured stakeholder communication and outreach activities will provide critical information to the project team to support execution of other project tasks. Input from MHK technology and project developers, regulators and natural resource management agencies, environmental groups, and other stakeholder groups will be used to develop the user interface of *Tethys*, populate the database, define the risk attributes of the ERES, and communicate results of numerical modeling and laboratory studies of exposure of test animals to MHK stressors. This task will also include activities to promote consideration of renewable ocean energy in national and local Coastal and Marine Spatial Planning activities.

The team for the Environmental Effects of Marine and Hydrokinetic Energy Development project is made up of staff, faculty, and students from

- Pacific Northwest National Laboratory
  - Marine Sciences Laboratory (Sequim and Seattle, Washington)
  - Risk and Decision Sciences (Richland, Washington)
  - Knowledge Systems (Richland, Washington)
- Oak Ridge National Laboratory (Oak Ridge, Tennessee)
- Sandia National Laboratories (Albuquerque, New Mexico; Carlsbad, California)
- Oregon State University, Northwest National Marine Renewable Energy Center (Newport, Oregon)
- University of Washington, Northwest National Marine Renewable Energy Center (Seattle, Washington)
- Pacific Energy Ventures (Portland, Oregon).

Acronyms and Abbreviations

AF	antifouling
AIS	Automatic Identification System
BCF	Biological Concentration Factor
DOE	U.S. Department of Energy
EERE	DOE Office of Energy Efficiency and Renewable Energy
EMF	electromagnetic field
ERES	Environmental Risk Evaluation System
FERC	Federal Energy Regulatory Commission
FFP	Free Flow Power Corporation
MHK	marine and hydrokinetic
NOAA	National Oceanographic and Atmospheric Administration
ORPC	Ocean Renewable Power Company
OPT	Ocean Power Technology
PNNL	Pacific Northwest National Laboratory
S–R	stressor–receptor
SnoPUD	Snohomish County Public Utility District
SQUIRT	NOAA screening quick reference tables
SRKW	Southern Resident Killer Whales
SST	Sound & Sea Technology Engineering Solutions
T&E	threatened and endangered
TSS	Traffic Separation Scheme (Puget Sound)
USCG	U.S. Coast Guard
VTS	Vessel Traffic Service

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1.0 Introduction

Responsible deployment of marine and hydrokinetic (MHK) energy devices in the marine and riverine waters of the United States requires that all appropriate regulatory requirements be met and that stakeholder concerns be taken into account. The regulatory pathways are under development and have not yet been sufficiently tested to determine whether they will prove workable and support the needs of the emerging U.S.-based MHK industry. The Pacific Northwest National Laboratory (PNNL) has been tasked by the U.S. Department of Energy (DOE) to help set appropriate regulatory priorities for responsible deployment of MHK devices, and to recommend the most pertinent and useful research that supports those priorities.

A key step in setting regulatory and research priorities is the assignment of risk to interactions between MHK installations and aquatic receptors, including animals, habitats, and ecosystem processes in the marine waters and rivers where MHK development is feasible. Risk is defined as the likelihood of a prescribed adverse outcome from an action or set of actions. Risk assessment is the process of evaluating scientific information to estimate the probability of occurrence of the action and the severity of the effect (EPA 2011; Suter 1993).

1.1 Environmental Risk Evaluation System

The Environmental Risk Evaluation System (ERES) developed by PNNL can be used to assist regulators, decision-makers, and stakeholders, including the MHK industry, to assess their tolerance toward risk, set priorities for research activities, and compare the costs and benefits of different MHK installation options. Figure 1.1 shows the steps used for management of risks in engineered and natural systems management.

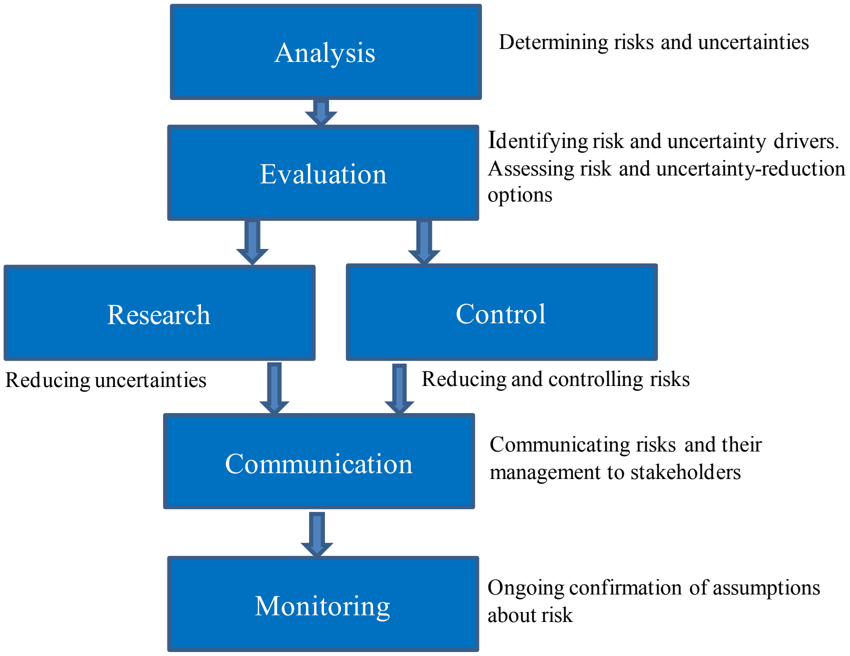

Figure 1.1. Elements of Risk Management

The risk assessment process begins with the identification and description of scenarios that result from sequences of events that lead to adverse impacts (Figure 1.2). It is useful to distinguish between scenarios that are episodic and, at the other end of the spectrum, those that are chronic. Episodic scenarios involve events that may or may not take place and are thus characterized by their likelihood or rate of occurrence. They are also characterized by the degree of impact or severity of their consequences. An example of an episodic scenario would be collision of a vessel with an MHK device or array of devices, resulting in an oil spill. The likelihood of occurrence is related to factors such as vessel traffic volume and the proximity of shipping lanes to the MHK devices. Consequences could include environmental damage due to spills and financial loss due to damaged property or loss of generation of power. In contrast, chronic risk scenarios involve events or circumstances that are continuous, so that risk characterization involves assessing only the severity of the consequences. An example of a chronic risk scenario would be toxicity due to low-level chemical releases from anti-biofouling paints and coatings used on devices. Between these two extremes, there are intermittent events, such as encounters between fish and rotating tidal turbine blades. A key feature of understanding risk is describing the uncertainty associated with the occurrence of an episodic, intermittent, or chronic event, as well as the uncertainty of the resulting consequences.

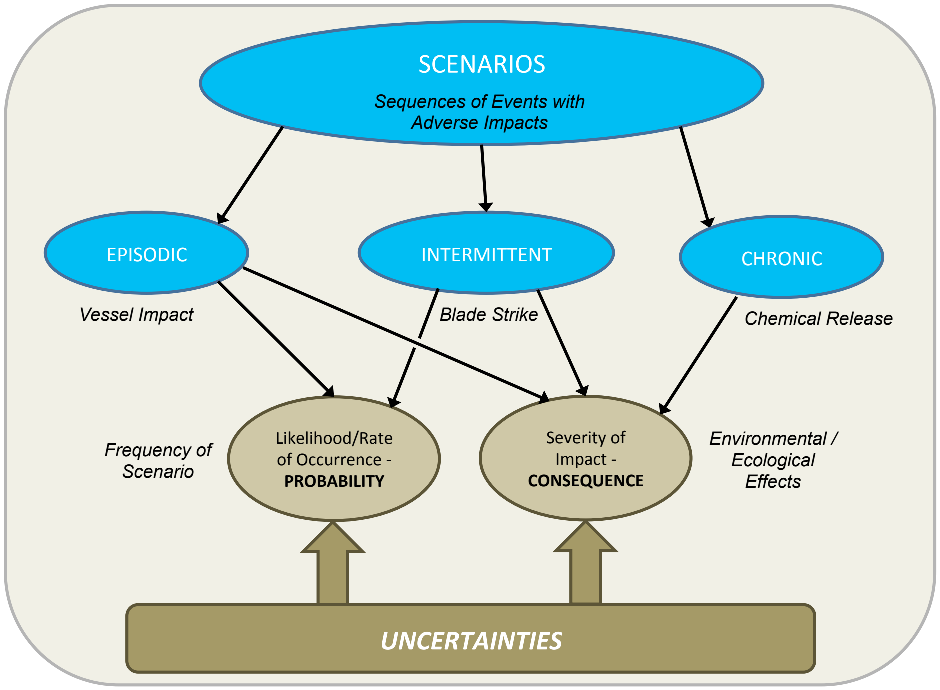

Figure 1.2. Description of Risk

In discussing risk in the context of MHK projects, it is important to separate the key types of risk:

- Environmental risk is the risk to living organisms including humans, as well as risk to physical and chemical processes that support living systems.

- Regulatory risk is the risk to MHK permitting and approvals due to regulations or their implementation.
- Investment risk is the risk to capital investment due to regulatory, legal, or market forces.

ERES addresses environmental risk; however, it is important to note that regulatory and investment risk can be driven by environmental risk. The *National Environmental Policy Act of 1969* will apply to the development of all MHK projects in waters of the United States. Although the *National Environmental Policy Act of 1969* is procedural, unlike many other standard- or threshold-driven applicable environmental laws and regulations, it has the potential to stop or significantly slow a permitting process.

Figure 1.3 shows the risk assessment process developed by PNNL. The initial steps in the process consist of a case selection process (blue box) and screening analysis (green box). This report details the process through consequence analysis on the second set of cases chosen for analysis, scoping for probability analysis, results of two probability analyses, and initial steps in a third probability analysis. During FY 2010, three initial cases were chosen: one tidal, one wave, and one river. FY 2011 cases included a second tidal and a second wave case. Probability analyses were carried out for two stressor-receptor (S-R) interactions for which sufficient data exist: 1) the risk of a spill of oil or other hazardous materials due to a tidal turbine encounter with a surface vessel on a broad variety of marine receptors; and 2) toxicity from anti-biofouling paints into the marine environment on marine receptors at highest potential consequence of harm for wave and tidal cases. A third probability analysis, focused on the encounter of a marine receptor with a very high potential consequence of harm with tidal turbine blades in a tidal case, was organized for expertise-based probability modeling in FY 2012.

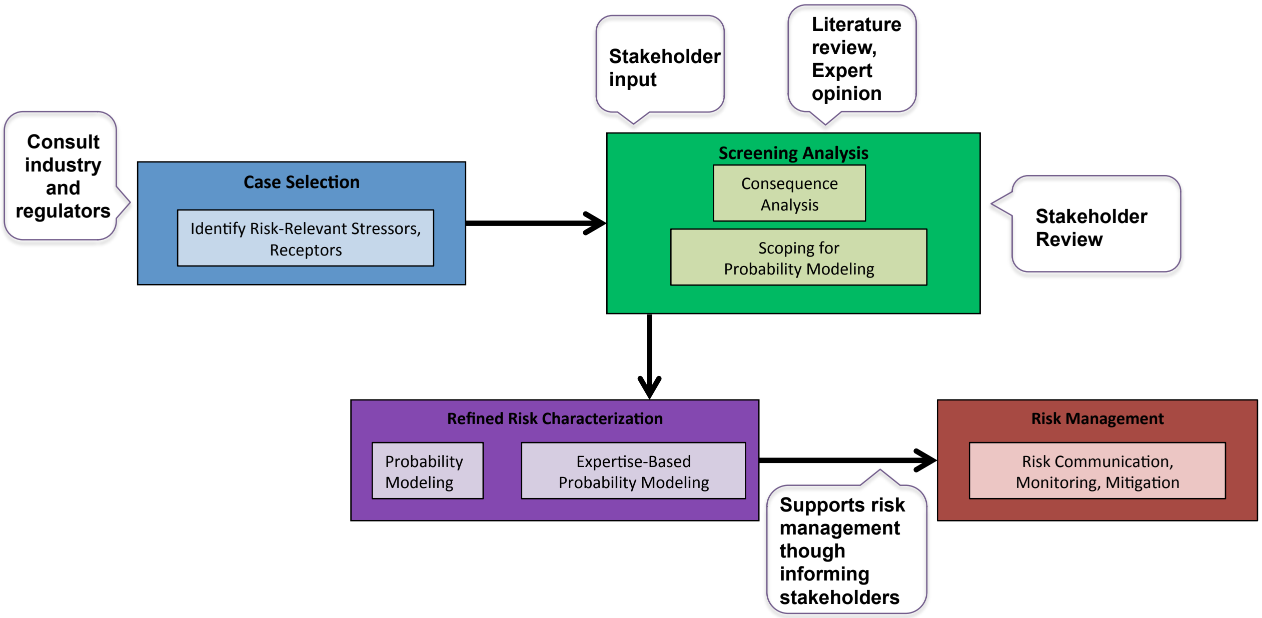

Figure 1.3. Risk-Informed Analytical Process

The initial screening analysis steps in ERES involve determining the potential effects for the highest-priority interactions between stressors (MHK systems or portions of those systems that may adversely affect aquatic receptors) and receptors (aquatic animals, habitats, and ecosystem processes), also known as *consequence analysis* (first light green box). The results of the *consequence analysis* will direct more detailed risk modeling studies. The consequence analysis methodology developed by PNNL is tailored to the unique needs of a multivariate set of interactions among many different types of stressors and a diverse group of receptors. Standardized risk assessment methodologies are not well suited to assessing and setting priorities for interactions as diverse as electromagnetic field (EMF) stress on sea turtles, the potential for blade strike on marine mammals, and the potential effect of energy removal on nearshore features.

Screening analysis also includes scoping for probability modeling (second light green box). Refined characterization of priority risks identified through consequence analysis will be further evaluated (purple box) through probability modeling (first light purple box) in cases for which environmental data are available and expertise-based evaluation (second light purple box) in cases for which data are not yet available. Probability modeling will be preferentially conducted on top-ranked S-R interactions that appear to be most highly affected by the probability of occurrence (i.e. most probability-dependent interactions) and for which sufficient data exist to carry out the analysis. Those S-R interactions include 1) the probability of an oil spill occurring from a collision between an MHK device and a surface vessel, for which the probability is extremely low but the potential consequences are high; and 2) the probability of leaching of chemicals from antifouling paints and coatings from MHK devices, for which the probability is extremely high while the potential consequences are low. With input and review from stakeholders, the outcome of the screening analysis and refined risk characterization will establish a rigorous process of evaluating risk based on real MHK development cases. ERES has been developed to ensure that new and more robust data will be incorporated into the risk modeling as they become available.

In this report, the methods used to conduct the screening analysis and initial risk modeling are detailed in Section 2. Results of the consequence analysis and initial probability modeling efforts are presented in Section 3; and the outcomes are in Section 4. Section 5 presents a summary of next steps in the risk assessment. References cited are listed in Section 6. Appendices provide additional details on the ranking process used in the consequence analysis, as well as the background for risk modeling efforts.

2.0 Methods

Methods for Consequence Analysis consist of identification and screening analyses; these are detailed in Section 2.1. Additional backup materials can be viewed in the appendices. The three steps are

- identification and description of the two cases chosen for FY 2011 (Section 2.1.1)
- identification of risk-relevant stressors and receptors and description of impact scenarios (Section 2.1.2)
- ranking of highest-priority risks for each case, taking only consequences into account (Section 2.1.3).

There are two important assumptions that underlie the development of ERES: that all S–R interactions are independent of one another, and that the most severe yet reasonable consequences are assigned to each interaction.

Methods for probability modeling addressed in FY 2011 are detailed in Section 2.2, including probability of a spill due to interaction with a surface vessel (Section 2.2.1); probability of toxicity from anti-biofouling paints (Section 2.2.2); and risk of encounter between tidal blades and marine animals (Section 2.2.3).

2.1 ERES Analysis for Consequence

2.1.1 Case Selection

Case information was collected from proposed MHK projects to provide an integrated profile of the collective risk posed by a specific MHK system (i.e., the device, moorings, anchors, surface floats, and cables) deployed in a specific body of water that supports a specific set of aquatic animals, habitats, and ecosystems. A variety of cases were selected in order to develop a sufficiently diverse knowledge base of S-R interactions. The collection of all S–R pairs for a given location and MHK installation constitutes an impact scenario that a project developer would expect to have to address to resolve regulatory and permitting requirements before deployment or operation of an MHK installation. These impact scenarios will inform discussion between the project developer and regulators to define the necessary set of monitoring and effects data collection for the project site.

The method for identifying cases in FY 2011 followed that used in FY 2010 (Copping et al. 2011). Cases were drawn from proposed MHK projects, focusing on those that are progressing through the permitting and development process, using criteria that have been discussed with members of the DOE Water Power Team, other national laboratories, MHK project developers, regulators, environmental organizations, and other stakeholders (Table 2.1). The criteria shown in Table 2.1 were evaluated in sequential order for each case. Cases that received *Yes* or *Sufficient* for a criterion were passed on to the next criterion for consideration. Cases that received *No* or *Insufficient* for certain criteria were removed from consideration for FY 2011 but will be reconsidered at a later date. The cases identified in FY 2010 were chosen from among projects classified as pilot or commercial projects under the Federal Energy Regulatory Commission's (FERC) regulatory framework. The FY 2010 cases (Snohomish County Public Utility District tidal project in Admiralty Inlet, Puget Sound, Washington [SnoPUD]; Ocean Power Technology wave installation off Reedsport, Oregon [OPT]; and Free Flow Power [FFP] river installation in the Mississippi River, Louisiana) represented MHK projects engaged in the FERC licensing process. Since FY 2010, two of the projects (OPT and FFP) have placed devices in the water.

Table 2.1. Criteria for Choosing MHK Projects as Cases for Initial Screening Analysis During FY 2011.

Criterion	Explanation of Criterion
1. Real/Readiness	Project is expected to be in the water within 2 years; both the technology and the project are ready.
2. Developer Willingness	Developer is willing to share technology and project data.
3. Diverse Representation	The case helps span the analytical space: a. technology type (tidal, wave, river) b. technology configuration (e.g., axial flow, horizontal flow) c. climatic zone (temperate, tropical, sub-arctic)
4. National Interest	For example, the project has received DOE funding.
5. Available Data	Environmental effects data are available.

In FY 2011, two additional cases (one tidal and one wave) were chosen to broaden the scope of technologies, waterbodies, and receptors under analysis:

- Tidal Case Study—The technology developer Ocean Renewable Power Company (ORPC) is pursuing development of a 1.2-MW pilot project using its TidGen^{TM} Power System in Cobscook Bay, Maine. The case is described as a hydrokinetic system mounted near the seafloor employing crossflow turbines to drive a magnet generator set between the turbines on a common driveshaft, designed to rotate both ways in the tidal flow direction. At this site, federally listed fish species (Gulf of Maine Distinct Population Segment of Atlantic salmon and Atlantic sturgeon) are key receptors of concern. Other receptors include diving birds, marine mammals, and nearshore habitat.
- Wave Case Study—The technology developer Aquamarine Power Ltd. is pursuing development of a project using its Oyster wave energy converter off the Oregon coast in the service areas of Central Lincoln People's Utility District and/or Tillamook People's Utility District. The case is described as an oscillating wave surge pump deployed in water depths between 24 and 48 feet, designed to capture energy from nearshore waves. Protected nearshore marine mammals (Steller sea lions, sea otters), endangered fish (Chinook salmon and green sturgeon), endangered diving birds (marbled murrelets), and sediment distribution are key receptors of concern.

In future years, as more MHK projects progress toward commercial-scale deployment, ERES results and additional cases will focus on larger arrays; risk rankings and modeling will be scaled to address differences between pilot-scale as well as small and large commercial deployments and operations.

2.1.2 Identification of Stressors and Receptors and Description of Impact Scenarios

Although each MHK technology differs in its components, configuration, and outputs, there are commonalities among them; eight stressors can be recognized that apply to MHK technologies examined to date (Table 2.2). The specific design of MHK devices and installations can eliminate certain stressors; for example a device that uses a shore-based power take off (such as the FY 2011 wave case) would not be expected to generate electromagnetic fields in the aquatic environment. Although specific species of receptors (animals, habitats, and ecosystem processes) may not be present at MHK project sites, they can usefully be described within seven major groups (Table 2.3).

Table 2.2. Stressors Associated with MHK Technology

Stressor	Explanation of Stressor
Physical presence of device (static)	Organisms may be attracted to or avoid the device, anchors, and moorings, altering ability to forage, rest, reproduce, and migrate. Habitats may be altered due to presence of the device.
Physical presence of device (dynamic)	Moving blades may threaten animals due to strike, pressure change, or shear.
Noise	Acoustic output of devices may affect organisms by interfering with communication or predator/prey detection, or through physical damage.
Electromagnetic fields (EMFs)	EMFs from generators or electrical cables may interfere with foraging or navigation, or have other effects.
Chemical leaching	Leached chemicals may have toxic effects
Energy removal	Removing energy from flowing water can alter sediment transport and water exchange/flushing, thereby affecting water quality
Changes in flow regime (wake or downstream interactions)	Structures may alter flow patterns that could alter local erosion/deposition regimes
Accidents or disasters	Accidents may include vessel collision or mooring failure resulting in floating or submerged debris or intense storms that could entangle organisms, cause damage on beaches and intertidal areas, or result in spills of petroleum or other harmful chemicals.

(a) The Wave Case Study for FY 2011 (Oyster) does not include EMF as a stressor because the power takeoff is based on land and there are no electric cables in the water.

Table 2.3. Environmental Receptors Potentially Vulnerable to MHK Technology

Receptor Group	Members of the Receptor Group
Aquatic mammals	Marine mammals (cetaceans, pinnipeds), freshwater mammals
Birds	Diving marine and aquatic birds
Reptiles	Aquatic reptiles such as sea turtles
Fish	Resident and migratory
Invertebrates	Benthic macroinvertebrates
Nearfield habitat(a)	Habitats in proximity to the MHK device that may be affected
Farfield environment(b)	Habitats within the waterbody, distant from the MHK device, that may be affected

(a) Nearfield is defined as the footprint of the device plus a distance of up to 10 meters surrounding the device. Nearfield habitat includes the footprint on the bottom of the waterbody, the volume of the device, and surrounding open water habitat.
(b) Farfield is defined as areas more than 10 meters distant from the device or array.

The significance of potential environmental impacts from ocean energy devices and systems are not well understood (DOE 2009), and only a limited number of devices have been tested in riverine or marine environments; the industry has yet to settle on a clear preferred technology for any waterbody type. As a result, the U.S. MHK industry is building on lessons learned from Europe, where MHK deployments are more advanced, from the limited number of U.S. MHK deployments to date, and from U.S.-based conventional hydropower and the domestic wind industry. There are some similarities between MHK and more mature technologies such as conventional hydropower, offshore oil and gas, and offshore wind; consequently, environmental impact and monitoring literature for these industries (e.g., Ligon et al. 1995; Carstensen et al. 2006; Poff et al. 2007; Nunneri et al. 2008) was evaluated to help develop impact scenarios for specific S-R pairs.

Recent reviews of the potential impacts of MHK technologies (e.g., Gill 2005; Devine Tarbell and Associates 2006; Michel et al. 2007; MMS 2007; Wilson et al. 2007; DOE 2009; Mangi Environmental Group 2010) were used in this study to evaluate consequences of S–R interactions. Reports from two recent scientific workshops on the environmental effects of wave energy (Boehlert et al. 2008) and tidal energy (Polagye et al. 2011) were also consulted. For the FY 2011 case studies, project- or site-specific information was gathered from environmental scoping reports (Lewis Wave Power Limited 2011; Vickery and Center for Ecological Research 2011), U.S. regulatory filings (FERC Online Elibrary), publications (Cameron et al. 2011; van der Voo 2011), industry websites, and discussions with project staff. In some cases, it was valuable to consult subject-specific references in addition to these synthesis reviews, including

- device components, including cable installation by directional drilling (Polagye and Previsic 2010)
- impact of device presence on fish behavior and abundance (Blyth et al. 2004)
- impact of wave devices on birds (Grecian et al. 2010)
- impacts to animal movement/migration, including fish and turtle aggregating behavior (Arenas and Hall 1992)
- vulnerability of marine mammals to strike, entanglement (Wilson et al. 2007; Fraenkel 2006)
- removal of hydrokinetic energy (von Arx et al. 1974; Bryden et al. 2004; Garrett and Cummins 2008; Karsten et al. 2008; Polagye et al. 2008) and change in sediment transport (Neill et al. 2009)
- effects from EMFs (Kirschvink et al. 2001; NRC 1997, Gill et al. 2005; Michel et al. 2007; Normandeau Associates, Inc. et al. 2011)
- potential acoustic impacts to marine/aquatic animals (Michel et al. 2007; NRC 2000; Southall et al. 2007).

2.1.3 Ranking Highest-Priority Consequences for Each Case

Risk is defined by both consequence of impact and probability of that impact occurring (Figure 1.2). Assigning relative risk based on consequence to each interaction between the stressors and receptors and prioritizing risks for detailed probability analysis is the essence of the screening analysis step. The process for ranking S–R pairs based on environmental consequence is outlined here. Ranked S–R pairs and interactions identified for priority probability analysis are presented in a later section. Further details on the analysis steps and risk factors, as well as tables of intermediate analysis steps, are contained in Appendix A.

For the two cases chosen for FY 2011, a list of risk-relevant S–R pairs was compiled. Each S–R pair was evaluated against a set of 14 biophysical factors to determine the vulnerability of the receptor to the stressor. Biophysical risk factors were developed to describe the biological imperatives, also known as critical life functions, that support living organisms (Odum 1977; Odum and Barrett 2004), and are listed in Table 2.4. The lack of data on interactions between stressors and receptors from MHK devices creates a high level of uncertainty; at this time, this uncertainty cannot be quantified. To address this uncertainty, a precautionary approach was used, resulting in scores and ranks for biophysical factors for S–R pair interactions that are higher than may be entirely realistic. In other words, what we show here is the most severe consequences that could be reasonably expected. As more research decreases the level of uncertainty, these scores and ranks will be reduced accordingly. This step in the evaluation resulted in a list of ranked S–R pairs across all receptor groups for each case. At this point, many of the S–R pair ranks were tied, indicating that, with the current information, these S–R pairs are equally vulnerable. As further data or information become available, these rankings will be revised appropriately.

Because the purpose of this risk assessment is to assist project developers and regulators with responsible deployment of MHK technology, it was important to consider the regulatory drivers that provide protection for the living systems supported by the aquatic environment. A second set of risk factors—regulatory risk factors—was applied to the list of S–R pairs that had been previously sorted using biophysical risk factors, resulting in a new ranking of S–R pairs for each case. Regulatory risk factors are derived from statutes or rules that pose a risk to completion of the MHK project; regulatory risks do not pose a risk to the receptors themselves. The regulatory risk factors were developed to address the regulatory authorities that apply to MHK project development and are organized into four tiers based on the stringency of each authority (Table 5). These ranks represent the vulnerability and level of regulatory protection applied to the receptors.

In carrying out the S–R pair analysis, we did not attempt to evaluate every possible receptor likely to be at risk within a project area. One or more species examples were chosen for each receptor group (e.g., fish, birds) or subgroup (e.g., cetaceans, pinnipeds, mustelids) for each case to examine interactions in the most efficient manner possible (Table 2.6). More than one species example was selected for certain receptor groups for those cases when a second (or even a third) receptor at a site represented a major variation of life history from the first species chosen. For example, Steller sea lions were chosen to represent the threatened and endangered pinniped for the wave (Oyster) case, while both Gulf of Maine Distinct Population Segment Atlantic salmon and Atlantic sturgeon were used as examples of a threatened and endangered migratory fish for the Tidal (TidGen^{TM}) case.

Table 2.4. Biophysical Risk Factors

Biophysical Risk Factor	Description
Biological Risk Factors	
Risk from small population size	Vulnerability to MHK device presence caused by critically small populations of concern
At-risk life stage	Timing and location of certain life stages vulnerable to MHK device presence that may increase risk to the population
Risk to critical prey	Decrease in available prey due to MHK device presence
Risk to critical habitat	Decrease in available habitat due to MHK device presence

Risk from predation	Changes in behavior due to MHK device presence that may result in increased predation (e.g., attraction)
Risk to ability to compete	Changes in behavior due to MHK device presence that may result in a lower competitive advantage (e.g., avoidance)
Behavior that increases risk of interaction with the device	Behavior of an animal that may increase risk of harm from an MHK device e.g., curiosity from a marine mammal)
Risk to sustaining populations	Population resilience to mitigate MHK-related stress. Vulnerability to MHK device presence due to reproductive strategy or other factors directly affecting success of reproduction (e.g., loss of suitable nesting beaches)
Physical Risk Factors, Nearfield	
Risk from size of habitat	Vulnerability to reductions in areal extent and relief of nearfield habitat due to MHK device presence
Risk from reductions in sediment quality	Nearfield changes in sediment depth, grain size, organic content, and contaminants due to MHK device presence
Physical Risk Factors, Farfield	
Circulation that affects water quality	Farfield decreases in water quality due to MHK device presence that include dissolved oxygen, nutrient, and contaminant concentrations
Circulation that affects sediment patterns	Farfield changes in sediment transport and dynamics due to MHK device presence that include rate of sedimentation, sediment quality and quantity
Circulation that affects marine/aquatic food webs	Farfield changes in primary productivity and species at the base of the food web due to MHK device presence
Circulation that affects water level	Farfield changes in height of tidal prism or river stage due to MHK device presence that may affect nearshore habitats

The final rankings of S–R pairs represent the highest vulnerabilities and represent the level of protection afforded each of the receptors for each case. It is important to note that the rankings derived from this consequence analysis are not synonymous with risk; additional steps are needed to determine the probability of occurrence for each of the ranked risks before actual risk can be calculated. For example, the rankings could change if an S–R pair demonstrating a high level of vulnerability exhibited a very low probability of occurrence.

Table 2.5. Tiered Regulatory Risk Factors Applied After Biophysical Risk Factors (Table 2.4) to Break Ties

Tier	Legislation or Regulation	Implementation of authority
First	ESA[(a)]	Strict take prohibitions
	ESA *and* MBTA[(b)]	Strict take prohibitions
	ESA *and* MMPA[(c)]	Strict take prohibitions
Second	ESA	Moderate take prohibitions; critical habitat protection
Third	Federal/state CWA[(d)]	Pollution discharge permits
	MMPA	Marine mammal take prohibitions
	MBTA	Migratory bird take prohibitions
Fourth	State/tribal protected resources	State/tribal fishery regulations/lands protection
	State listed species	Take limitations; area closures
	MSA[(e)]	Fishery management plans; essential fish habitat

(a) *Endangered Species Act of 1973*.
(b) *Migratory Bird Treaty Act of 1918*.
(c) *Marine Mammal Protection Act of 1972 As Amended*.
(d) *Clean Water Act of 1977*.
(e) *Magnuson-Stevens Fishery Conservation and Management Act*.

Table 2.6. Vulnerable Receptor Groups and the Species or Habitats Used as Representative Examples for Risk Analysis for Each Case

Receptor Group	Protection	Receptor Sub-Group	TidGen™	Oyster
Mammals	T&E[a]	Cetacean/Pinniped	None[b]	Steller sea lion
		Mustelid		Southern sea otter
	Non T&E	Cetacean	Harbor porpoise	Harbor porpoise
		Pinniped	Harbor seal	Harbor seal
Birds	T&E	T&E diving bird	None[c]	Marbled murrelet
	Non T&E	Non T&E diving bird	Black Guillemot	N/A
Invertebrates	T&E	Benthic	None	None
	Non T&E	Benthic	Cobscook sea scallop	Dungeness crab
		Shoreline		Razor clams
Reptiles	T&E		N/A[d]	Green sea turtle
Fish	T&E		GOM DPS Atl. salmon	Chinook salmon
			Atlantic sturgeon	Green sturgeon
	Non T&E		Atlantic herring	Black rockfish
	Non T&E Shark			Leopard shark
Nearfield Habitat			Rocky cobble	Sand
Farfield Habitat			Water circulation	Water circulation
			Sediment transport	Sediment transport
			Energy removal	Energy removal

(a) T&E = Threatened and endangered.
(b) No T&E species of marine mammals are expected in the proposed TidGen™ deployment area.
(c) No T&E species of diving bird has been observed in the proposed tidal (TidGen™) deployment area.
(d) No species of reptile are found in the Gulf of Maine deployment area.

2.2 Probability Analysis for Selected Risks

2.2.1 Spill Risk from Surface Vessel Collision

PNNL considered the potential risk of ship collisions with tidal turbines, using areas considered for tidal turbine deployment in Puget Sound, Washington, as a representative case study. The most relevant source of information on collision risk is a recent publication by Sound & Sea Technology (SST) Engineering Solutions (SST 2011) that evaluated the potential impact of the proposed tidal turbine installation by SnoPUD in Admiralty Inlet on the safety of vessel traffic movement.

SST pursued the risk assessment as part of the process of obtaining permits and agreements to the SnoPUD project in Admiralty Inlet. Through contact with the U.S. Coast Guard (USCG) Sector Seattle, the U.S. Army Corps of Engineers Seattle Division Navigation Station, and the Puget Sound Harbor Safety Commission, SST determined that the SnoPUD project represents an appropriate use of a commercial waterway, and that the absence of anchors, pilings, or surface-piercing structures reduces the potential for most vessel collisions. There was concern, however, that a potential collision risk might exist from the presence of slow-moving tug and barge assemblages operating outside of normal shipping lanes, as defined by the Puget Sound Traffic Separation Scheme (TSS). Strong tidal currents in parts of Puget Sound have resulted in a locally accepted practice for tugs returning from Alaska to operate east of the delineated northbound shipping lanes, placing them in the vicinity of the SnoPUD tidal turbine site. During discussions with SST, the American Waterways Organization pointed out that if the tow vessels were required to reduce speed due to other vessel traffic in this area, there was a potential for the towline catenary to sag deeply, increasing the potential for snagging or entanglement with a tidal turbine device or array. The potential encounter between the towline catenary and the tidal turbine represents the scenario examined under ERES.

Based on the tug towline encounter concerns, the SST risk assessment focused on the following questions:

- Under what situations would the presence of a tug and tow transiting Puget Sound east of the Puget Sound TSS create a collision risk with a turbine?
- How frequently would this situation be expected to occur?
- How would risk change based on specific conditions (e.g., weather, visibility, tidal stage, vessel traffic density, and direction)?
- What is the typical catenary for a towline on a vessel operating at “normal” speed?
- At what speed would the tugboat towline sag deeply enough to contact a turbine?

SST approached the risk assessment by developing an initial set of reasonable assumptions for how vessel traffic is managed in the vicinity of the SnoPUD tidal turbine site, and the capability of those piloting the vessels. The USCG Vessel Traffic Service [VTS] oversees vessel movement in Puget Sound. Professional mariners operate their vessels in accordance with international regulations designed to prevent collisions. SST used the Automatic Identification System (AIS) information for calendar year 2010 on vessel traffic in the vicinity of the tidal turbine, with the assistance of the University of Washington Northwest National Marine Renewable Energy Center.

2.2.2 Toxicity Risk from Anti-Biofouling Paints

Antifouling (AF) paints are used on boats and static structures in marine and freshwater environments to prevent the growth of attached aquatic organisms, especially algae and crustaceans such as barnacles. Control and removal of fouling organisms is important in order to reduce drag and maintenance costs. It is accomplished by the slow release of potent biocides incorporated into AF paints that are applied to these surfaces. Most biocide-containing AF paints now contain copper for its effectiveness against animals (e.g., mollusks) and herbicidal “booster” biocides for their greater effectiveness against plant growth (e.g., algae) (Lambert et al. 2006).

This risk analysis was approached in two ways:

- A standardized risk assessment that examined the likelihood of adverse outcomes to key receptors present in the study areas for the FY 2010 cases (tidal – SnoPUD deployment in Puget Sound; wave – SPT deployment off Reedsport; and river – Free Flow Power in the Mississippi River), focusing on diffusion of biocide from the AF painted surfaces of the device.

- A case study of examining other pathways, particularly through the sediments, in Puget Sound, as a result of the SnoPUD deployment in Admiralty Inlet.

2.2.2.1 Risk Assessment for FY 2010 ERES Cases

This analysis focuses on the risk to aquatic organisms that may be inadvertently exposed to AF paint biocides; the organisms examined are representative receptors for the three FY 2010 MHK cases (Anderson et al. 2010; Copping et al. 2011). Properties of the most common AF paint biocides are listed in Table 2.7.

Table 2.7. Key Properties of the Main Antifouling Biocides Currently in Use (from Table 1, Thomas and Brooks 2010)

Name	Copper Oxide	Irgarol 1051	Diuron	DCOIT SeaNine 211	Dichlofluanid	Chlorothalonil	Zinc/Copper Pyrithione
Molecular weight	143.1	253.367	233.09	282.227	253.367	265.89	317.7/315.9
Log K_{ow}		2.8	2.8	2.8	2.8	2.64–4.38	0.97
Degradation or Phase Change	<24 h	$t^{1/2}$ = 100–250 days in seawater, persistent in sediments	Persistent in seawater, $t^{½}$ = 14 days in marine sediment (biotic degradation)	<24 h (Biotic degradation)	18 h	1.8–8 days in seawater (biotic degradation)	<24 h in seawater (photolysis)

The methodology used for this risk assessment follows that of EPA (1998) and Bedford and Cooke (1996) and consists of the following steps:

- Description of the risk scenario(s) under consideration
- Characterization of the threat or hazard (stressor, source term) of concern
- Characterization of the exposure of the receptor(s) of concern to the hazard
- Calculation of the effects on the receptor(s) of concern in terms of some suitable risk measure.

We also note the following factors that will tend to minimize this risk but which need to be addressed in a systematic way:

- Many of the organisms of concern are relatively large and less susceptible to small amounts of biocide received through direct exposure than smaller organisms. This analysis did not consider the effects of toxicity to higher organisms through their diet.
- The cases all represent a small number of devices. Larger-scale deployments may represent increased risk.
- The bodies of water in which deployment is being considered are generally large and/or fast-moving, indicating a very large dilution mechanism.

2.2.2.2 Case Study of Toxicity from Biocides in Puget Sound

A first-order assessment of risk from introduction of contaminants from a point source (i.e., a submerged marine hydrokinetic energy generating device) to a water body like Puget Sound can be made from an understanding of circulation in Puget Sound, information on the rate of introduction of the contaminant, knowledge of the biogeochemical behavior of the contaminant in an aquatic system (i.e., behavior and fate), and information on the bioavailability and toxicity of the contaminant in both water and sediments.

Puget Sound is a deep fjord-type, partially mixed, two-layer estuary consisting of a series of deep basins interconnected by shallow sills at the entrance and between basins (Lavelle et al. 1991; Ebbesmeyer et al. 2002). Because the MHK devices are being planned for Admiralty Inlet, any release of contaminants will occur into the more saline bottom water that is entering Puget Sound over the sill at Admiralty Inlet. This water will then principally occupy the deep water of the main basin of Puget Sound and will primarily affect this water mass only. The average residence time for the entire main basin is 48.8 days (Babson et al 2006).

The release rate of an antifouling biocide to the environment is highly dependent on the paint formulation, the test conditions, and the test method employed (Thouvenin et al. 2002; Finnie 2006); examples of release rates are shown in Table 2.8.

An estimate of the daily or annual mass loading of antifouling paint biocide to the environment can be estimated to be

$$\textit{Mass Loading (g/day)} = [\textit{Release Rate } (\mu g\ cm^{-2}\ day^{-1})]\ [\textit{Surface Area } (m^2)][(10^4\ cm^2/m^2)(10^{-6} g/\mu g)]$$

Understanding the biogeochemical behavior of these biocides is essential to understanding and predicting their effect on the environment, including the biocides' propensity to 1) attach to particles (quantified by a particle-water partition coefficient; K_p); 2) bioaccumulate (often quantified with an octanol-water partition coefficient; K_{ow}); and 3) degrade in the environment (e.g., a photodegradation rate). These parameters allow a quantitative comparison of the behavior of the AF biocides to biogeochemical processes. The difficulty in applying this approach is that this information is often not available for the compounds of interest. For a first-order assessment, the biogeochemical behavior of individual compounds is ignored, and a maximal condition is assumed (e.g., no photodegradation or high particle reactivity) as representative of all AF biocides. The first-order assessment can then be refined for individual AF biocides where pertinent biogeochemical information is available.

Table 2.8. Selected Studies on the Release Rate of Antifouling Paint Biocides

Biocide Compound	Release Rate ($\mu g\ cm^{-2}\ day^{-1}$)	Reference
Copper (Cu_2O)	8.2 (in situ) 25-65 (laboratory study)	Valkirs et al (2003)
	1.1-3.6 (natural seawater) 7.1- 13 (artificial seawater)	Ytreberg et al. (2010)
	0.2-4.3	Schiff et al. (2004)
	0.5-2.8 (est.) (long-term test with 7 binders)	Thouvenin et al. (2002)

Zinc (ZnO)	17.3±3.7 (monocrystalline substrates) 55.6 ± 5.6 (pigments)	Yerba et al (2006)
	0.7-8.2 (natural seawater) 0.64-23 (artificial seawater)	Ytreberg et al. (2010)
XK-B1 biocide	2.5-16.7 (est.) (long term test with 7 binders)	Thouvenin et al. (2002)

2.2.3 Risk of Encounter Between Tidal Turbine Blades and Marine Animals

Endangered Southern Resident Killer Whales (SRKW) return to the inland marine waters of Washington (US) and British Columbia (CAN) annually to forage for their preferred prey, Chinook salmon. SRKWs are a species of regulatory concern to the MHK industry, due both to their listing under the Endangered Species Act and the Marine Mammal Protection Act, as well as their iconic status. Understanding the probability of a collision between an SRKW and a tidal power turbine allows regulators and project developers to focus discussions on appropriate mitigation measures.

For this preliminary probability analysis, SRKW behavior was parsed into four categories: foraging, socializing, resting, and traveling. SRKWs are known to make dives deeper than 50 m while foraging, although variables that either increase or decrease the proportion of time spent foraging also change the frequency of deep dives. Scientific literature shows that vessel presence causes whales to significantly reduce the amount of time spent foraging to favor traveling behavior (Lusseau et al. 2009; Williams et al. 2006). Because Admiralty Inlet is the ingress/egress to Puget Sound, high volumes of vessel traffic are present, potentially resulting in SRKW evasive behavior. There is some suggestion that other environmental elements such as tidal variation, seasonality, pod identity, and age have significant effects on SRKW diving behavior and movement (Baird et al. 2005; Hauser 2006; Lusseau et al. 2009; McCluskey 2006), but these variables were not considered during this study.

Data from the literature were compiled to define the relationships between variables, calculate the frequency of deep dives a SRKW makes while foraging, and determine the proportion of time the SRKWs spend foraging while in Admiralty Inlet. This model defines quantitatively how the variables influence SRKW movement in the water column.

3.0 Results

Results for screening analysis of the two FY 2011 cases are presented in Section 3.1; results of probability analyses are described in Section 3.2.

3.1 Screening Analysis Results for Two Cases

Results of the consequence ranking process are presented below, showing relative ranks of S–R pairs for biophysical risk factors only and as modified by regulatory risk factors. Risk factors are presented within tiers that represent factors that are essentially tied. These tied factors must be further elucidated through examination of the probability of the occurrence of each S–R interaction, in order to reach an estimate of risk.

3.1.1 Biophysical Risk Factors for Consequence Analysis

Tables 3.1 and 3.2 present relative biophysical rank for S–R pairs for Tidal (TidGen™) and Wave (Oyster) cases, respectively. These relative ranks reflect environmental consequence only (and not probability of occurrence). In each table, the relative ranks, or tiers, show the top issues based on scores of biophysical risk factors.

Animal receptors with small populations tended to rank high for biophysical risk factors because injury or mortality to even a single individual could threaten the survival of the population. Although these receptors are listed under the *Endangered Species Act of 1973* as threatened and endangered (T&E) species, it should be noted that the high consequence ranking of these animals results from the threat to their ability to successfully reproduce and maintain the population, not due to regulatory protection. Marine mammals also tended to rank high because they are curious and may approach MHK devices, thereby increasing their risk of injury or mortality.

The farfield environment ranked high in biophysical risk; this is largely an artifact of the risk assignment process and may not adequately reflect the actual consequences that may be expected due to the presence of MHK devices on nearfield and farfield habitats. This was particularly apparent in the case study of the Oyster technology on the Oregon coast; the substrate in that region is predominantly sand (as opposed to rock or gravel), and the effects of the nearshore wave device on sediment transport, circulation, and nearshore habitat are uncertain and pose a risk of potential negative consequence.

Among stressors, *physical presence (dynamic)* and *accidents/disasters* ranked high across the receptors.

Table 3.1. Relative Rank for Consequence of the Tidal (TidGen^{TM}) Case S–R Pairs for Biophysical Risk Factors

TidGen^{TM}	Stressor	Vulnerable Receptor
First Tier	Physical presence (dynamic)	non T&E pinniped (Harbor seal)
	Physical presence (dynamic)	non T&E cetacean (Harbor porpoise)
	Physical presence (dynamic)	non T&E diving bird (Black Guillemots)
	Physical presence (dynamic)	T&E fish (GOM DPS Atlantic salmon)
	Physical presence (dynamic)	T&E fish (Atlantic sturgeon)
	Accident/Disaster	Farfield environment
	Change in flow regime	Farfield environment
	Energy removal	Farfield environment
Second Tier	Accident/disaster	non T&E pinniped (Harbor seal)
	Physical presence (static)	T&E fish (GOM DPS Atlantic salmon)
	Noise	T&E fish (GOM DPS Atlantic salmon)
	Noise	T&E fish (Atlantic sturgeon)
	EMF	T&E fish (GOM DPS Atlantic salmon)
	EMF	T&E fish (Atlantic sturgeon)
	Accident/disaster	T&E fish (GOM DPS Atlantic salmon)
	Accident/disaster	T&E fish (Atlantic sturgeon)
Third Tier	Noise	non T&E cetacean (Harbor porpoise)
	Accident/disaster	non T&E cetacean (Harbor porpoise)
	Physical presence (static)	non T&E diving bird (Black Guillemots)
	Accident/disaster	non T&E diving bird (Black Guillemots)
	Physical presence (dynamic)	non T&E fish (Atlantic herring)
	Physical presence (static)	T&E fish (Atlantic sturgeon)
	Chemical leaching	T&E fish (GOM DPS Atlantic salmon)
	Chemical leaching	T&E fish (Atlantic sturgeon)
Fourth Tier	Physical presence (static)	non T&E pinniped (Harbor seal)
	Physical presence (static)	non T&E cetacean (Harbor porpoise)
	Noise	non T&E pinniped (Harbor seal)
	Physical presence (static)	non T&E fish (Atlantic herring)
	Noise	non T&E fish (Atlantic herring)
	EMF	non T&E fish (Atlantic herring)
	Accident/disaster	non T&E fish (Atlantic herring)
	Accident/disaster	Nearfield habitat (Rocky, cobble)
	Physical presence	Nearfield habitat (Rocky, cobble)
	Leaching of toxic chemicals	Nearfield habitat (Rocky, cobble)

Table 3.1. (contd)

TidGen^{TM}	Stressor	Vulnerable Receptor
Fifth Tier	EMF	non T&E pinniped (Harbor seal)
	EMF	non T&E cetacean (Harbor porpoise)
	Chemical leaching	non T&E pinniped (Harbor seal)
	Chemical leaching	non T&E cetacean (Harbor porpoise)
	Noise	non T&E diving bird (Black Guillemots)
	EMF	non T&E diving bird (Black Guillemots)
	Chemical leaching	non T&E diving bird (Black Guillemots)
	Physical presence (dynamic)	non T&E invertebrate (Cobscook sea scallop)
	Physical presence (static)	non T&E invertebrate (Cobscook sea scallop)
	Noise	non T&E invertebrate (Cobscook sea scallop)
	EMF	non T&E invertebrate (Cobscook sea scallop)
	Chemical leaching	non T&E invertebrate (Cobscook sea scallop)
	Accident/disaster	non T&E invertebrate (Cobscook sea scallop)
	Chemical leaching	non T&E fish (Atlantic herring)
	Changes in flow regime	Nearfield habitat (Rocky, cobble)

3.1.2 Regulatory Risk Factor Analysis for Consequence Analysis

Results of the biophysical risk ranking process modified by application of the regulatory risk factors are shown in Table 3.3. Top-tier stressors in both cases were the effects of the dynamic physical presence of the device (e.g., strike) and accidents/disasters. S–R pairs in the three highest tiers were dominated by potential effects on small populations that are afforded stringent regulatory protection under U.S. law (i.e., T&E fish, marine mammals, birds, and turtles). The effects of stressors on T&E fish are in the top tier for the TidGen^{TM} tidal case study. This is due in part to documented absence of T&E marine mammals or diving birds in the project area. The top tiers of environmental consequence for the Oyster wave case study are T&E species of nearshore marine mammals, birds, reptiles and fish. Non-T&E species of marine mammals, diving birds, and fish fell in the middle tiers. Invertebrates, nearfield habitat, and farfield environment appeared in the lower tiers in both case studies because there is much less regulatory protection for these resources than for higher biological organisms.

Table 3.2. Relative Rank for Consequence of the Wave (Oyster) Case S–R Pairs for Biophysical Risk Factors

Oyster	Stressor	Vulnerable Receptor
First Tier	Accident/disaster	Farfield environment
	Change in flow regime	Farfield environment
	Energy removal	Farfield environment
Second Tier	Physical presence (dynamic)	T&E pinniped (Steller sea lion)
	Physical presence (dynamic)	T&E mustelid (Southern sea otter)
	Accident/disaster	T&E pinniped (Steller sea lion)
	Accident/disaster	T&E mustelid (Southern sea otter)
	Physical presence (dynamic)	T&E bird (Marbled murrelet)
	Accident/disaster	T&E bird (Marbled murrelet)
	Physical presence (dynamic)	T&E fish (Green sturgeon)
Third Tier	Accident/disaster	T&E reptile (Green sea turtle)
	Physical presence (dynamic)	T&E fish (Chinook salmon)
	Physical presence (dynamic)	non T&E shark/ray (Leopard shark)
	Accident/disaster	T&E fish (Chinook salmon)
	Accident/disaster	T&E fish (Green sturgeon)
Fourth Tier	Physical presence (dynamic)	non T&E pinniped (Harbor seal)
	Physical presence (dynamic)	non T&E cetacean (Harbor porpoise)
	Noise	T&E pinniped (Steller sea lion)
	Noise	T&E mustelid (Southern sea otter)
	Chemical leaching	T&E pinniped (Steller sea lion)
	Chemical leaching	T&E mustelid (Southern Sea otter)
	Accident/disaster	non T&E pinniped (Harbor seal)
	Accident/disaster	non T&E cetacean (Harbor porpoise)
	Noise	T&E bird (Marbled murrelet)
	Chemical leaching	T&E bird (Marbled murrelet)
	Physical presence (dynamic)	T&E reptile (Green sea turtle)
	Noise	T&E reptile (Green sea turtle)
	Chemical leaching	T&E reptile (Green sea turtle)
	Noise	T&E fish (Chinook salmon)
	Noise	T&E fish (Green sturgeon)
	Chemical leaching	T&E fish (Chinook salmon)
	Chemical leaching	T&E fish (Green sturgeon)
	Accident/disaster	non T&E shark/ray (Leopard shark)
	Accident/disaster	Nearfield habitat (Sand)
	Changes in flow regime	Nearfield habitat (Sand)

Table 3.2. (contd)

Oyster	Stressor	Vulnerable Receptor
Fifth Tier	Physical presence (dynamic)	non T&E benthic invertebrate (Dungeness crab)
	Physical presence (dynamic)	non T&E shore invertebrate (Razor clams)
	Physical presence (dynamic)	resident non T&E fish (Black rockfish)
	Accident/disaster	resident non T&E fish (Black rockfish)
	Physical presence (dynamic)	Nearfield habitat (Sand)
	Leaching of toxic chemicals	Nearfield habitat (Sand)
Sixth Tier	Noise	non T&E pinniped (Harbor seal)
	Noise	non T&E cetacean (Harbor porpoise)
	Chemical leaching	non T&E pinniped (Harbor seal)
	Chemical leaching	non T&E cetacean (Harbor porpoise)
	Noise	non T&E benthic invertebrate (Dungeness crab)
	Noise	non T&E shore invertebrate (Razor clams)
	Chemical leaching	non T&E benthic invertebrate (Dungeness crab)
	Chemical leaching	non T&E shore invertebrate (Razor clams)
	Accident/disaster	non T&E benthic invertebrate (Dungeness crab)
	Accident/disaster	non T&E shore invertebrate (Razor clams)
	Noise	resident non T&E fish (Black rockfish)
	Noise	non T&E shark/ray (Leopard shark)
	Chemical leaching	resident non T&E fish (Black rockfish)
	Chemical leaching	non T&E shark/ray (Leopard shark)

Table 3.3. Top Tiers of Environmental Consequence for S–R Pairs for the Two Cases as Modified by Regulatory Risk Factors. Color gradation signifies consequence rank of S–R pairs (darker = higher consequence).

TidGen™ Stressor	TidGen™ Receptor
Tier 1	
Physical presence (dynamic)	T&E fish (GOM DPS Atlantic salmon)
Physical presence (dynamic)	T&E fish (Atlantic sturgeon)
Tier 2	
Physical presence (static)	T&E fish (GOM DPS Atlantic salmon)
Noise	T&E fish (GOM DPS Atlantic salmon)
Noise	T&E fish (Atlantic sturgeon)
EMF	T&E fish (GOM DPS Atlantic salmon)
EMF	T&E fish (Atlantic sturgeon)
Accident/disaster	T&E fish (GOM DPS Atlantic salmon)
Accident/disaster	T&E fish (Atlantic sturgeon)
Tier 3	
Physical presence (static)	T&E fish (Atlantic sturgeon)
Chemical leaching	T&E fish (GOM DPS Atlantic salmon)
Chemical leaching	T&E fish (Atlantic sturgeon)
Tier 4	
Physical presence (dynamic)	non T&E pinniped (Harbor seal)
Physical presence (dynamic)	non T&E cetacean (Harbor porpoise)
Physical presence (dynamic)	non T&E diving bird (Black Guillemots)
Accident/disaster	Farfield environment
Accident/disaster	non T&E pinniped (Harbor seal)
Noise	non T&E cetacean (Harbor porpoise)
Accident/disaster	non T&E cetacean (Harbor porpoise)
Physical presence (static)	non T&E diving bird (Black Guillemots)
Accident/disaster	non T&E diving bird (Black Guillemots)
Physical presence (static)	non T&E pinniped (Harbor seal)
Physical presence (static)	non T&E cetacean (Harbor porpoise)
Noise	non T&E pinniped (Harbor seal)
Accident/disaster	Nearfield habitat (Rocky, cobble)
Leaching of toxic chemicals	Nearfield habitat (Rocky, cobble)
EMF	non T&E pinniped (Harbor seal)

Oyster Stressor	Oyster Receptor
Tier 1	
Physical presence (dynamic)	T&E pinniped (Steller sea lion)
Physical presence (dynamic)	T&E mustelid (Southern sea otter)
Accident/disaster	T&E pinniped (Steller sea lion)
Accident/disaster	T&E mustelid (Southern sea otter)
Physical presence (dynamic)	T&E bird (Marbled murrelet)
Accident/disaster	T&E bird (Marbled murrelet)
Tier 2	
Accident/disaster	T&E reptile (Green sea turtle)
Tier 3	
Physical presence (dynamic)	T&E fish (Green sturgeon)
Physical presence (dynamic)	T&E fish (Chinook salmon)
Accident/disaster	T&E fish (Chinook salmon)
Accident/disaster	T&E fish (Green sturgeon)
Noise	T&E fish (Chinook salmon)
Noise	T&E fish (Green sturgeon)
Chemical leaching	T&E fish (Chinook salmon)
Chemical leaching	T&E fish (Green sturgeon)
Tier 4	
Noise	T&E pinniped (Steller sea lion)
Noise	T&E mustelid (Southern sea otter)
Chemical leaching	T&E pinniped (Steller sea lion)
Chemical leaching	T&E mustelid (Southern sea otter)
Noise	T&E bird (Marbled murrelet)
Chemical leaching	T&E bird (Marbled murrelet)
Physical presence (dynamic)	T&E reptile (Green sea turtle)
Noise	T&E reptile (Green sea turtle)
Chemical leaching	T&E reptile (Green sea turtle)
Tier 5	
Accident/disaster	Farfield environment
Physical presence (dynamic	non T&E pinniped (Harbor seal)
Physical presence (dynamic)	non T&E cetacean (Harbor porpoise)

Table 3.3. (contd)

TidGen^{TM} Stressor	TidGen^{TM} Receptor
EMF	non T&E cetacean (Harbor porpoise)
Chemical leaching	non T&E pinniped (Harbor seal)
Chemical leaching	non T&E cetacean (Harbor porpoise)
Noise	non T&E diving bird (Black Guillemots)
EMF	non T&E diving bird (Black Guillemots)
Chemical leaching	non T&E diving bird (Black Guillemots)
Tier 5	
Change in flow regime	Farfield environment
Energy removal	Farfield environment
Physical presence (dynamic)	non T&E fish (Atlantic herring)
Physical presence (static)	non T&E fish (Atlantic herring)
Noise	non T&E fish (Atlantic herring)
EMF	non T&E fish (Atlantic herring)
Accident/disaster	non T&E fish (Atlantic herring)
Physical presence	Nearfield habitat (Rocky, cobble)
Physical presence (dynamic)	non T&E invertebrate (Cobscook sea scallop)
Physical presence (static)	non T&E invertebrate (Cobscook sea scallop)
Noise	non T&E invertebrate (Cobscook sea scallop)
EMF	non T&E invertebrate (Cobscook sea scallop)
Chemical leaching	non T&E invertebrate (Cobscook sea scallop)
Accident/disaster	non T&E invertebrate (Cobscook sea scallop)
Chemical leaching	non T&E fish (Atlantic herring)
Changes in flow regime	Nearfield habitat (Rocky, cobble)

Oyster Stressor	Oyster Receptor
Accident/disaster	non T&E pinniped (Harbor seal)
Accident/disaster	non T&E cetacean (Harbor porpoise)
Accident/disaster (oil spills)	Nearfield habitat (Sand)
Leaching of toxic chemicals	Nearfield habitat (Sand)
Noise	non T&E pinniped (Harbor seal)
Noise	non T&E cetacean (Harbor porpoise)
Chemical leaching	non T&E pinniped (Harbor seal)
Chemical leaching	non T&E cetacean (Harbor porpoise)
Tier 6	
Change in flow regime	Farfield environment
Energy removal	Farfield environment
Physical presence (dynamic)	resident shark/ray (Leopard shark)
Accident/disaster	resident shark/ray (Leopard shark)
Changes in flow regime	Nearfield habitat (Sand)
Physical presence (dynamic)	non T&E invertebrate (Dungeness crab)
Physical presence (dynamic)	non T&E shore invertebrate (Razor clams)
Physical presence (dynamic)	resident non T&E fish (Black rockfish)
Accident/disaster	resident non T&E fish (Black rockfish)
Physical presence	Nearfield habitat (Sand)
Noise	non T&E invertebrate (Dungeness crab)
Noise	non T&E shore invertebrate (Razor clams)
Chemical leaching	non T&E invertebrate (Dungeness crab)
Chemical leaching	non T&E shore invertebrate (Razor clams)
Accident/disaster	non T&E invertebrate (Dungeness crab)
Accident/disaster	non T&E shore invertebrate (Razor clams)
Noise	resident non T&E fish (Black rockfish)
Noise	resident shark/ray (Leopard shark)
Chemical leaching	resident non T&E fish (Black rockfish)
Chemical leaching	resident shark/ray (Leopard shark)

3.2 Probability Analysis Results

Probabilistic analysis results for spill risk from surface vessel collisions and for anti-biofouling paints are presented below.

3.2.1 Spill Risk from Surface Vessel Collision

The AIS data collected by SST indicate that approximately 113 vessels per year transit the area within a 200-m radius of the SnoPUD project site. Using this information, SST focused its risk analysis on the probability of tug and tow vessel encounters near the turbine site under specific circumstances or activities that could lead to an adverse outcome (e.g., tow cables or chains striking a tidal turbine). The "activity of interest" with respect to the SnoPUD turbine site was related to the presence of southbound tugs returning from Alaska east of the northbound shipping lanes, which places them near the tidal turbine site. Contributing factors to risk such as additional vessel traffic, the potential for head-to-head encounters with vessels traveling in the opposite direction, and weather and tide variation were also factored into the analysis. As noted in SST (2011), barges operating in the vicinity of the SnoPUD turbine site are, in some instances, carrying hazardous chemicals, and tidal stage and other vessel traffic in the area can significantly slow southbound progress, decreasing maneuverability and increasing the potential risk of collision or entanglement with turbines. Risk-related factors addressed in the SST assessment include

- situations where a southbound tug and tow encounters a northbound tug and tow in the vicinity of the turbine site, with an additional risk factor associated with the presence of a car ferry operating across Admiralty Inlet between Coupeville and Port Townsend
- the presence of northbound vessel traffic in the TSS lanes, resulting in restricted maneuvering room for tug and tow vessels
- the presence of strong tidal currents affecting vessel maneuverability
- reduced visibility due to inclement weather or darkness.

Consultation with the American Waterways Organization and Western Tug and Barge indicated that the most critical element of these risk factors was the potential for a head-to-head meeting between two vessels restricted in their ability to maneuver. The subsequent risk analyses assessed a variety of situational categories related to vessel traffic near the tidal turbine site, potential safety issues that could contribute to an adverse outcome, the potential severity of the outcome, and a review of hazards associated with tug and tow operations. This process led to a "what if" analysis that included the following components:

1. definition of the functions or events included in the analysis, and bounding assumptions
2. delineation of known or potential hazards that may contribute to accidents
3. examination of the potential consequences of accidents occurring
4. identification of appropriate safeguards that already exist to reduce hazard
5. development of specific recommendations to reduce hazards.

Based on the risk analyses, the frequency of head-to-head meetings between two towing vessels near the SnoPUD tidal turbine site is expected to be less than one occurrence per month. As stated in the SST report,

> Given the presence in Puget Sound of USCG's VTS, a unit with an exceptional record of safety, it is difficult to envision a scenario in which advance coordination between VTS and towing vessels moving through the test site could not easily accomplish a safe passage with sea room to spare.

The probability of an adverse outcome is further reduced, given the expected sag in the cable under slow-speed conditions of approximately 23 m compared to the designed overhead clearance between the top of the SnoPUD tidal turbine and the water surface under lowest astronomical tide conditions of 43 m. This provides a reasonable margin of safety even if the tug and barge trajectory resulted in a course directly over a tidal turbine. SST (2011) stated a further margin of safety could be achieved through the identification of a Regulated Navigation Area by the USCG that would ensure tug and tow arrays were safely routed away from the tidal turbine site.

3.2.2 Toxicity Risk from Anti-Biofouling Paints

A toxic biocide may leach into the aquatic environment and remain dissolved, decaying at some rate, or in the case of metals such as copper, changing phase. The biocide may become bioavailable in its original form for some period, then in the form of one or more transformation products. Alternatively, it may settle and bind to the sediments, where it may be less available to certain organisms. If it persists in the environment in sufficient concentration, where new leachate must be added to any pre-existing levels (Konstantinou and Albanis 2004) to determine totals, then it may pose a risk to all exposed organisms through direct absorption or to upper trophic level organisms through bioaccumulation.

Key properties that control the fate of biocides in terms of their phase partitioning and biological and photochemical degradation are listed in Table 2.7. For the purposes of this analysis, Irgarol 1051 was chosen as a model because it is relatively persistent in seawater with a degradation half-life of 100–250 days and has a high bioaccumulation factor (ranging from 240 for freshwater sheepshead minnow (Bard et al. 1994) to 30,000 for freshwater macrophytes (Toth et al. 1996)).

Using industry data, the maximum aqueous concentration of biocide at the MHK device was estimated to be approximately 10 pg/L; this value constitutes a bounding condition for environmental concentrations aquatic species could experience.

Little or no toxicity data are available for specific species that are receptors of concern for MHK devices. Available toxicity benchmarks were assembled by Mochida and Fujii (2009), representing experimental tests of aqueous concentrations that resulted in lowest-observed effects (periphyton community), 50% reduction in growth rates after 3-5 days exposure (algae), or 50% mortality after 3-4 days exposure (fish). These constituted the benchmark exposure levels of concern (Figure 3.1).

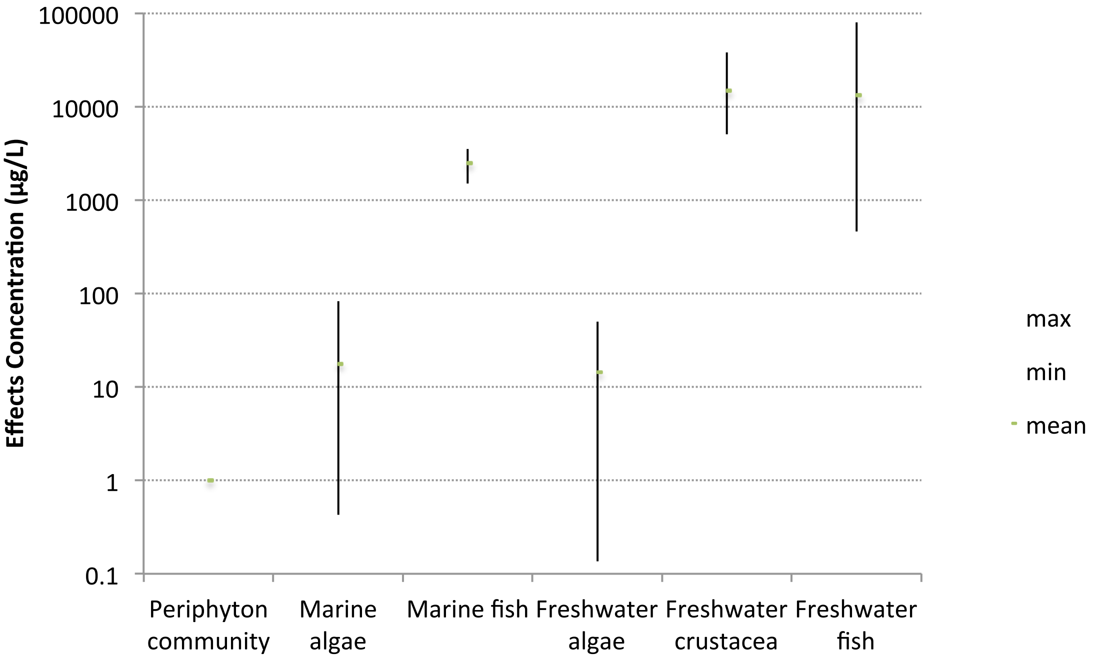

Figure 3.1. Concentrations of Irgarol 1051 Affecting Growth or Mortality in 50% of Experimentally-Exposed Organisms (after Mochida and Fujii 2009)

Comparing bounding condition water concentrations to the lowest toxicity benchmarks for each taxonomic group, the highest risk quotient for marine cases would be for algae (including periphyton) of between 10^{-2} and 10^{-4}. Risk quotients for marine fish are below 10^{-5}. Risk quotients for freshwater species also are dominated by alga (between 10^{-1} and 10^{-4}), while fish and crustaceans (invertebrates) range from 10^{-5} to 10^{-7}. All are well below levels of concern.

3.2.3 Risk of Encounter Between Tidal Turbine Blades and Marine Animals

The conceptual model (Figure 3.2) of SRKW behavior indicates that the variables of greatest influence on dive rates are the proportion of time spent in foraging behavior, the presence of shipping, and the presence of SRKW prey. Primary variables (those that influence the frequency of 50-m dives by the SRKWs) and secondary variables (those that directly influence the primary variables) were determined from the published scientific literature. Tertiary and quaternary variables (those that determine the amount of time that the SRKWs spend in each behavior mode) could not be quantified from existing information.

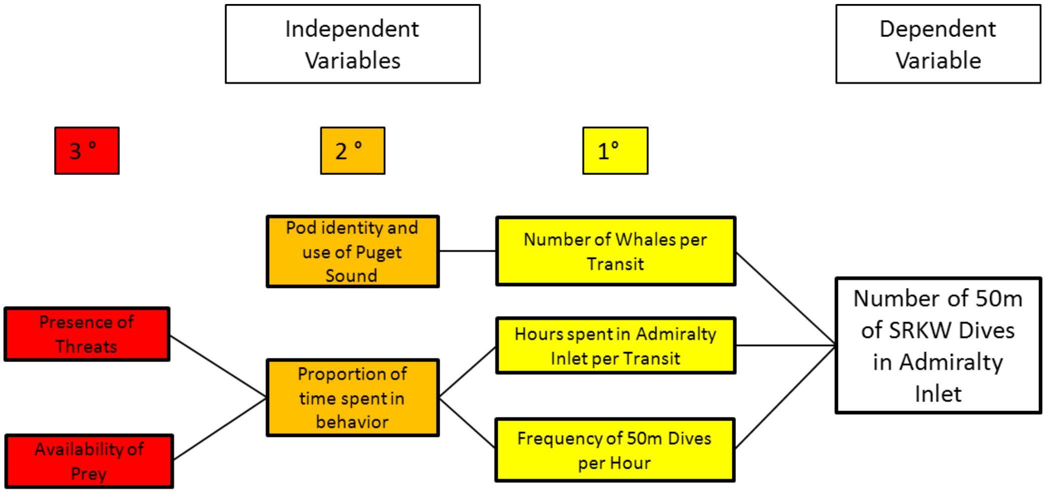

Figure 3.2. Conceptual Model of SRKW Diving Behavior in Admiralty Inlet, Showing Relationship of the Input Variables to the Number of 50-m Dives

Drawing from the published literature and using risk analysis software (@Risk), the mean number of SRKW dives per hour was determined (Figure 3.3). Insufficient data exist to assign dive rates to SRKWs only in Admiralty Inlet; the dataset also took into account behavior of the animals inside Puget Sound and outside in the Straits of Juan du Fuca.

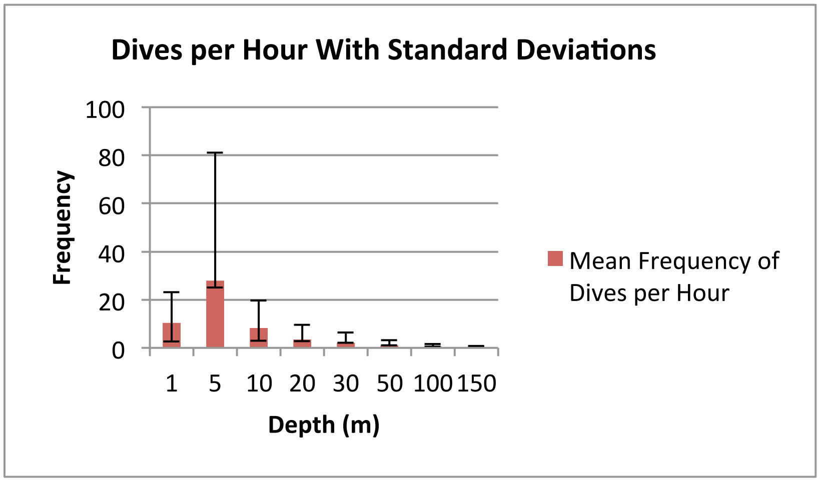

Figure 3.3. Average Dives per Hour for SRKWs in the Waters Surrounding Admiralty Inlet

4.0 Discussion

Responsible deployment of MHK devices requires compliance with all applicable laws and regulations; at the same time, the regulatory burden should not overwhelm the beneficial value of providing carbon-free renewable energy to meet the needs of the nation. By determining the highest-priority risks for stressors from MHK devices and associated installations with vulnerable receptors in the marine and freshwater environment, project proponents, regulators, and stakeholders can engage in the most efficient and effective siting and permitting pathways.

4.1 Consequence Analysis for FY 2011 Case Studies

S-R interactions for the proposed MHK projects that ended up ranked in the top tiers of this analysis did so for one of two reasons: either the interaction is a true impact to the receptor in question, or so little is known about the interaction that the resulting uncertainty—assuming a precautionary approach—raises the apparent risk level. Tables 3.1 and 3.2 rank the S–R pairs for each case study based on biophysical factors; Table 3.3 ranks the most important S–R interactions for both case studies, reflecting consequences of highest priority for a project developer from both the biophysical and U.S. regulatory environments.

For the tidal case study, the biophysical risk analysis (Table 3.1) shows that interactions with the dynamic physical presence (i.e., blade strike) with marine mammals, diving birds, and threatened or endangered fish are relatively the highest concern for the project, along with effects of the tidal turbine to the farfield environment (including effects stemming from an accident or disaster, change in flow regime, or energy removal from the system). All of these potential consequences have a high degree of uncertainty and are issues requiring additional scientific study. After regulatory risk factors were applied (Table 3.3), the highest ranked (Tier 1) issues narrow to include the impact dynamic physical presence of the device with threatened or endangered fish, followed by (Tier 2) other environmental stressors on threatened or endangered fish. This second layering underscores that at this point in time, the project developer, OPRC must address the potential interactions of the TidGen^{TM} device on threatened or endangered fish species in the deployment area in order to satisfy the legal mandates imposed on environmental regulators in the permitting process. The permitting pathway that ORPC is following in the Gulf of Maine (Cobscook Bay) is underscored by the finding of this consequence analysis.

For the wave case study, the biophysical risk analysis (Table 3.2) shows the potential consequences to the physical environment (changes in flow regime, energy removal, and the impact of an accident or disaster) as the highest relative risk, followed by the potential consequence of the dynamic physical presence of the device or an accident/disaster on T&E species of nearshore marine mammals, birds, reptiles, and fish. Effects on the physical environment rank particularly high in this wave case study because of the uncertainties about the siting of this nearshore project on a predominantly soft bottom substrate. Threatened and endangered receptors also rank high on the biophysical risk analysis because of the impact that a potential consequence may have on species with small population sizes. These S–R pairs in these top relative biophysical tiers are all issues needing additional scientific study. Combining biophysical and regulatory risk factors (Table 3.3), the highest relative ranks (Tiers 1 and 2) include the potential consequence of the dynamic physical presence or an accident/disaster on T&E species of nearshore marine mammals, birds, reptiles, and fish. This second analysis shows that Aquamarine needs to first address the potential impacts of the wave device on all T&E species in the deployment region in order to advance the deployment of a device in Oregon waters. The MHK projects represented by each case require that the probability of occurrence of the potential risk be evaluated, including the real potential for T&E species to occur in the vicinity of the devices. The need to evaluate the presence of animals of concern is perhaps most acute in the Oyster case. Results from European deployments of the Oyster show no signs of animals being directly affected by the devices; potential deployment in the United States may hinge on rapidly identifying the presence of T&E animals at risk. While the nature of this analysis does not assign high rank to changes in sediment transport and soft bottom habitat from the action of the Oyster, it is likely that if T&E species are not found to frequent the depths and location of the project, movement of sediment due to device operation will emerge as the most likely concern for regulators and stakeholders.

As additional information about S–R interactions becomes available through research studies and monitoring of MHK projects, S–R interactions that are in the top tiers based on uncertainty may drop farther down the ranked list. Alternatively, consequences to marine organisms and the physical environment may be lowered by changes in engineering or operational design or alternative siting; these S–R interactions will also drop down the ranked list. Eventually the remaining top-tier interactions will form the basis for post-installation monitoring and mitigation.

The U.S. regulatory system and the environmental protections afforded to key species is a genuine hurdle for any project developer in U.S. waters. The regulatory power of the *Endangered Species Act of 1973* "no take" provision, especially if combined with the *Marine Mammal Protection Act of 1972 As Amended* or the *Migratory Bird Treaty Act of 1918*, ensures that all threatened and endangered turtles, marine mammals, and migratory birds will rank as the greatest risk from a regulatory perspective, regardless of whether they are the most vulnerable biological receptors to each specific stressor. The FY 2011 tidal case study (TidGen^{TM}) shows that animals not listed under the *Endangered Species Act of 1973* or those *Endangered Species Act of 1973*-listed species where limited take is allowed (i.e., GOM DPS Atlantic salmon and Atlantic sturgeon) become top-tier concerns after scientific research shows that other highly protected species are not present in the deployment area or at significant risk.

The two FY 2011 case studies are early-stage MHK developments, considered as pilots or demonstration projects under FERC's regulatory framework. The small number of devices proposed for deployment may present certain risks to receptors from specific device–receptor interactions. As larger arrays of MHK devices are deployed, these direct-proximity risks may increase in some fashion, and cumulative impacts of devices operating over long time-frames may create effects not visible at the pilot level. This consequence analysis is the first step in the ERES risk assessment process. Analysis of the probability of top-tier S–R interactions will take place in the next phase.

4.2 Probability Analyses Undertaken in FY 2011

During FY 2010, two areas of encounter between MHK stressors and marine stressors were identified as likely candidates for probability analysis, based on stressor information directly applicable from other industrial interactions in the marine environment: 1) the likelihood of a collision between a surface vessel and a bottom-mounted tidal turbine; and 2) the likelihood of harm caused to the receptors of concern from MHK devices due to leaching of chemicals applied to the devices to retard biofouling.

The probability analysis for collision between a tidal device and a surface vessel was undertaken by SST at the request of SnoPUD. PNNL staff examined this interaction in the context of the probability aspect of risk from a tidal device (Section 4.2.1). PNNL staff carried out a probability modeling analysis for the toxicity from anti-biofouling paints on key marine receptors; based on bounding case analyses for single-unit deployments, significant harm to biota is highly unlikely at any distance from the source through water-column exposures. The potential for sediment accumulation and its associated exposure pathway has not yet been evaluated.

Although appropriate analogues were not found to exist for other industries, PNNL determined that the encounter of tidal turbine blades with endangered marine mammals was of sufficient importance to getting tidal projects (SnoPUD in particular) in the water to warrant undertaking the initial steps in an expert-driven probability analysis. Discussion of the results is in Section 4.2.3; the full report is in Appendix C.

4.2.1 Probability Analysis for Spills from Surface Vessel Collision

Although the SST analysis could not provide a probability outcome of high fidelity, the results of the USCG-approved analysis strongly indicates that vessel encounters with tidal turbine arrays at depths similar to those of the SnoPUD project are unlikely for vessels operating within the Puget Sound USCG VTS. The SST report did conclude, however, that interactions of recreational vessels trolling fishing gear with tidal turbines was more possible and would be less likely to be detected by the VTS. SST concludes that marine radio broadcasts by the VTS at regular intervals would significantly contribute to public safety.

PNNL staff has evaluated the SST report and determined that the analysis is sound and indicates the potential for harm from such an encounter to be unquantified but extremely small. Although the SST analysis is explicit to shipping through Admiralty Inlet in Puget Sound, similar analyses in areas of moderate to heavy shipping are likely to yield similar results. This assumption is based in large part on the depths at which tidal devices are located (with a significant overhead clearance to allow for shipping and boating), the specific and unusual circumstances under which portions of a surface vessel (e.g., a tow vessel catenary) are likely to encounter a tidal device, and the unlikely occurrence of a cable hooking a tidal device; the latter likelihood was not addressed in the SST report.

Other MHK projects such as wave farms will require a similar analysis for encounter with surface vessels to similarly determine the likelihood of such encounters occurring, leading to an adverse outcome. Surface-mounted wave energy converters increase the probability of an adverse outcome with a surface vessel encounter as compared to a subsurface tidal device. However, USCG vessel traffic measures, exclusion zones, Notes to Mariners, and other preventive measures will greatly reduce the potential adverse outcomes in the same manner that navigation buoys and ocean observation buoys are seldom the cause of surface vessel impacts and spills.

4.2.2 Risk of Toxicity from Anti-Biofouling Paints

Through the application of two risk modeling approaches to examining toxicity of AF paints to marine and riverine organisms from MHK devices, a picture begins to emerge that, while there are insufficient data to predict effects on the animals of greatest concern in the case study systems, the levels of toxicity from AF paints are very low close to the devices and are further diluted at a distance from the installations. Based on chemical leaching alone, there appears to be little cause for concern from exposure to AF paints on higher-level organisms such as marine mammals, birds, and fish. Lower-level organisms, particularly early developmental phases, are at higher risk; however, the high-energy environments in which MHK devices are placed preclude the persistence of embryos and planktonic developmental forms in the zone of maximum toxicity for extended periods, thereby reducing their exposure.

The choice of AF paint for MHK devices and foundations should take into account the specific biocide in use, as well as the aquatic receptors of concern in the immediate environment. Should organic biocides be used in the vicinity of aquatic invertebrates that are afforded special protection, or in situations where higher-level organisms of concern can accumulate toxins from a benthic food source in proximity to MHK devices, additional studies may be needed to determine the exposure and effects of the biocide.

4.2.3 Risk of Encounter Between Tidal Turbine Blades and Marine Animals

SRKW feed almost exclusively on one species of fish, and have been shown to favor certain areas for foraging, which is the behavior identified to have the most risk of tidal turbine interactions. The results of this study show that insufficient data exist in the scientific literature to parameterize a quantitative behavioral model for SRKW in Admiralty Inlet. Although the data available can support a conceptual model of diving behavior, they lack the information needed to clearly define the relationships between these variables and the event of a 50-m dive. Drawing from the available data, it is clear that the time spent by SRKWs in the deep waters are limited to between 2 and 3% of their time in Admiralty Inlet, posing a very limited risk of encounter with the two tidal turbines placed on the bottom of the inlet.

The analysis undertaken by PNNL to determine the behavior of SRKWs in Admiralty Inlet is very specific to one highly endangered species, in one location, with a single MHK technology; whether the analytical results will be useful for other scenarios is unknown. The probability analysis undertaken for the SRKWs in Puget Sound through expert input is far from complete. This analysis was undertaken to shed light on a potential S–R encounter that is of extremely high regulatory and stakeholder concern for the SnoPUD project; in addition, we hope that this analysis may prove useful for evaluating other S–R encounters of concern for which sufficient data do not exist.

5.0 Next Steps in ERES Risk Assessment

The consequence analysis for the two cases undertaken in FY 2011 was developed through review of the scientific literature and reports and with input from a number of subject matter experts. However, we intend to further gauge the validity of the ERES approach for the two cases through a peer review process that will take place early in FY 2012.

The results of risk analysis for encounter of SRKW in Puget Sound with tidal turbine blades, as represented by the proposed OpenHydro devices planned for deployment by SnoPUD in Admiralty Inlet, will be pursued in FY 2012. Peer review will be sought on the results of the conceptual model and associated data for SRKW behavior. The results of the reviewed analysis will be taken to a group of experts, convened with assistance from NOAA Fisheries, to carry out an expert elicitation. The purpose of the elicitation is to bring expert opinion together in a consensus-driven highly structured process, with the desired outcome being a probabilistic model of SRKW encounter with tidal turbine blades.

6.0 References

Arenas P and M Hall. 1992. "The association of sea turtles and other pelagic fauna with floating objects in the eastern tropical Pacific Ocean." In *Proceedings of the Eleventh Annual Workshop on Sea Turtle Biology and Conservation*, M Salmon and J Wyneken (compilers), pp. 7–10. NOAA Technical Memorandum NMFS-SEFSC-302, National Marine Fisheries Service, Southeast Fisheries Center, Miami Laboratory, Miami, Florida.

Anderson, R.M., S.D. Unwin, and F.B. Van Cleve. 2010. Identification and prioritization of analysis cases for marine and hydrokinetic energy risk screening. PNNL-19535, Pacific Northwest National Laboratory, Richland, Washington.

Babson, A. L., M. Kawase and P. MacCready (2006). Seasonal and Interannual Variability in the Circulation of Puget Sound, Washington: A Box Model Study. *Atmosphere-Ocean*, 44(1): 29-45.

Baird RW, MB Hanson, and LM Dill. 2005. "Factors influencing the diving behaviour of fish-eating killer whales: sex differences and diel and interannual variation in diving rates." *Canadian Journal of Zoology* 83:257–267.

Bard, J., A. Pedersen, and E. Tiberg. 1994. Scientific documentation and research; KEMI National Chemicals Inspectorate, Solna, Sweden.

Bedford, T. and R. Cooke. 2001. Probabilistic risk analysis: Foundations and methods. Cambridge University Press.

Blyth RE, MJ Kaiser, G Edwards-Jones, and PJB Hart. 2004. "Implications of a zoned fishery management system for marine benthic communities." *Journal of Applied Ecology* 41:951–961.

Boehlert GW, GR McMurray, and CE Tortorici (eds). 2008. *Ecological Effects of Wave Energy Development in the Pacific Northwest*. NOAA Technical Memorandum NMFS-F/SPO-92, Northwest Fisheries Science Center, National Marine Fisheries Service, National Oceanic and Aeronautic Administration, Seattle, Washington.

Bryden IG, T Grinstead, and GT Melville. 2004. "Assessing the potential of a simple tidal channel to deliver useful energy." *Applied Ocean Research* 26:198–204.

Cameron L, R Doherty, A Henry, K Doherty, J Van't Hoff, D Kaye, D Naylor, S Bourdier, and T Whittaker. 2010. "Design of the Next Generation of the Oyster Wave Energy Converter." *3rd International Conference on Ocean Energy*, Aquamarine Power Ltd., Edinburgh, United Kingdom. Available from http://www.aquamarinepower.com/resource-library/ (September 2, 2011).

Carstensen J, OD Henrikson, and J Teimann. 2006. "Impacts of offshore wind farm construction on harbor porpoises: acoustic monitoring of echolocation activity using propose detectors (T-PODs)." *Marine Ecology Progress Series* 321:295–308.

Chapra, S.C. 1997. Surface water-quality modeling. McGraw-Hill.

Clean Water Act of 1977. 1977. Public Law 95-217, as amended, 33 USC 1251 et seq.

Copping, A.E., F.B. Van Cleve, and R.M. Anderson. 2011. Screening analysis for the Environmental Risk Evaluation System Task 2.1.1: Evaluating effects of stressors. PNNL-20196. Pacific Northwest National Laboratory, Richland, Washington.

Devine Tarbell and Associates, Inc. 2006. *Instream Tidal Power in North America: Environmental and Permitting Issues.* EPRI-TP-007-NA, Electric Power Research Institute, Palo Alto, California.

DOE – U.S. Department of Energy. 2009. *Report to Congress on the Potential Environmental Effects of Marine and Hydrokinetic Energy Technologies: Prepared in Response to the Energy Independence and Security Act of 2007, Section 633(B).* Wind and Hydropower Technologies Program, Office of Energy Efficiency and Renewable Energy, Washington, D.C.

Ebbesmeyer, C.C., G.A. Cannon, B.J. Nairn, M. Kawase and W.P. Fox, 2002. Puget Sound physical oceanography related to the Triple Junction region. Final Report for King County Department of Natural Resources and Parks, November 2002. 167 pp, appendices A-L, CD appendices A-E. Report available at: http://your.kingcounty.gov/dnrp/library/2002/kcr2052/Report.pdf

Endangered Species Act of 1973. 1973. Public Law 93-205, as amended, 16 USC 1531 et seq.

EPA—U.S. Environmental Protection Agency. 1998. Guidelines for ecological risk assessment. EPA/630/R-95/002F, Washington D.C.

EPA – U.S. Environmental Protection Agency. 2011. *Integrated Risk Information System (IRIS)*. Washington, D.C. Available from http://www.epa.gov/iris/index.html (January 25, 2011).

Finnie, A.A. 2006. "Improved estimates of environmental copper release rates from antifouling products." *Biofouling* 22: 279-291.

Fraenkel PL. 2006. "Tidal current energy technologies." *Ibis* 148:145–151.

Garrett C and P Cummins. 2008. "Limits to tidal current power." *Renewable Energy* 33:2485–2490.

Gill AB. 2005. "Offshore renewable energy: ecological implications of generating electricity in the coastal zone." *Journal of Applied Ecology* 42(4):605–615.

Gill, A.B.; Gloyne-Phillips, I.; Neal, K.J.; Kimber. J.A. 2005. The potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electrically and magnetically sensitive marine organisms-a review. COWRIE.

Gulf of Maine Aquarium. 2001. *Coastal Fishery Research Priorities: Sea Scallops(Plactopecten magellanicus)*. Maine Department of Marine Resources, Maine. Available from http://www.maine.gov/dmr/research/sea_scallops.htm (September 2, 2011).

Grecian WJ, R Inger, MJ Attrill, S Bearhop, B Goodley, MJ Witt, and SC Votier. 2010. "Potential impacts of wave-powered marine renewable energy installations on marine birds." *Ibis* 152:683–697.

Hauser DDW. 2006. "Summer space use of Southern Resident killer whales (*Orcinus orca*) within Washington and British Columbia." Master of Science, School of Aquatic and Fishery Science, University of Washington, Seattle.

Karsten R, M McMillan, M Lickley, and R Haynes. 2008. "Assessment of tidal current energy in the Minas Passage, Bay of Fundy." *Proceedings of the Institution of Mechanical Engineers, Part: Journal of Power and Energy* 22(5):493–507.
Kirschvink, J.L., Walker, M.M., Diebel, C.E. 2001. Magnetite-based magnetoreception. *Current Opinion in Neurobiology* 11: 462-467.

Konstantinou, I. K. and T. A. Albanis. 2004. "Worldwide occurrence and effects of antifouling paint booster biocides in the aquatic environment: a review." *Environment International* 30(2): 235-248.

Lambert, S.J., K.V. Thomas, and A.J. Davy. 2006. "Assessment of the risk posed by antifouling booster biocides Irgarol 1051 and diuron to freshwater macrophytes." *Chemosphere* 63: 734-743.

Langton R, IM Davies, and BE Scott. 2011. "Seabird conservation and tidal stream and wave power generation: Information needs for predicting and managing potential impacts." *Marine Policy* 35(2011):623–630. Lavelle, J.W., E.D. Cokelet, and G.A. Cannon. 1991. "A model study of density intrusions into and circulation within a deep, silled estuary: Puget Sound." *Journal of Geophysical Research.* 96(C9): 16779-16800.

Lewis Wave Power Limited. 2011. *Lewis Wave Power Environmental Scoping Report, 40MW Oyster Wave Array, West Coast Lewis, UK*. Report Reference Number: LWP-SD.PR.EU.UK.LEW.06-REP-001. Available from http://www.aquamarinepower.com/resource-library/ (September 2, 2011).

Ligon FK, WE Dietrich, and WJ Trush. 1995. "Downstream ecological effects of dams." *Bioscience* 45:183–192.

Lusseau D, DE Bain, R Williams, and JC Smith. 2009. "Vessel traffic disrupts the foraging behavior of southern resident killer whales *Orcinus orca*." *Endangered Species Research* 6:221–221.

Magnuson-Stevens Fishery Conservation and Management Act. 16 U.S.C. 1801-1882, April 13, 1976, as amended 1978-1980, 1982-1984, 1986-1990, 1992-1994, and 1996.

Mangi Environmental Group. 2010. *Updated Summary of Knowledge: Selected Areas of the Pacific Coast*. BOEMRE 2010-014, Bureau of Ocean Energy, Regulation and Enforcement, U.S. Department of the Interior, Herndon, Virginia.

Marine Mammal Protection Act of 1972 as Amended. 2007. 16 USC 1361 et seq.

McCluskey SM. 2006. "Space Use Patterns and Population Trends of Southern Resident Killer Whales (*Orcinus orca*) in Relation to Distribution and Abundance of Pacific Salmon (*Oncorhynchus* spp.) in the Inland Marine Waters of Washington State and British Columbia." School of Aquatic and Fishery Science, Masters of Science, University of Washington, Seattle.

Michel J, H Dunagan, C Boring, E Healy, W Evans, JM Dean, A McGillis, and J Hain. 2007. *Worldwide Synthesis and Analysis of Existing Information Regarding Environmental Effects of Alternative Energy*

Uses on the Outer Continental Shelf. MMS OCS Report 2007-038, Minerals Management Service, U.S. Department of the Interior, Herndon, Virginia.

Migratory Bird Treaty Act of 1918. 1918. 40 Stat. 755, as amended, 16 USC 710.

MMS – Minerals Management Service. 2007. *Programmatic Environmental Impact Statement for Alternative Energy Development and Production and Alternate Use of Facilities on the Outer Continental Shelf.* OCS EIS/EA MMS 2007-046, U.S. Department of the Interior, Herndon, Virginia.

Mochida, K., and K. Fujii. 2009. Toxicity in plankton and fish. In: Takaomi, A., H. Harino, O. Madoka, and W.J. Langson, editors. Ecotoxicology of antifouling biocides. Tokyo: Springer, pp. 365-393.

National Environmental Policy Act of 1969. 1969. Public Law 91-190, as amended, 42 USC 4321 et seq.

National Marine Fisheries Service. 2010. Letter to HDR|DTA providing list of Rare, Threatened, and Endangered Species near the Project Area. Accession Number: 20110518-5003. November 2010. Available from FERC Online Elibrary: http://www.FERC.gov/docs-filing/elibrary.asp (September 19, 2011).

Normandeau Associates, Inc., Exponent, Inc., T Tricas, and A Gill. 2011. *Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species*. OCS Study BOEMRE 2011-09, U.S. Department of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo, California.

NRC – National Research Council. 1997. *Possible Health Effects of Exposure to Residential Electric and Magnetic Fields.* The National Academies Press, Washington, D.C.

NRC – National Research Council. 2000. *Marine Mammals and Low Frequency Sound.* The National Academies Press, Washington, D.C.

Neill SP, EJ Litt, SJ Couch, and AG Davies. 2009. “The impacts of tidal stream turbines on large-scale sediment dynamics.” *Renewable Energy* 34(12):2803–2812.

Nunneri C, HJ Lenhart, B Burkhard, and W Windhorst. 2008. “Ecological risk as a tool for evaluating the effects of offshore wind farm construction in the North Sea.” *Regional Environmental Change* 8(1):31–43.

Odum EP. 1977. “The emergence of ecology as a new integrative discipline.” *Science* 195:1289–1293.

Odum EP and GW Barrett. 2004. *Fundamentals of Ecology*. 5th edition. Brooks/Cole Publishing, Cengage Learning, Stamford, Connecticut.

ORPC Maine, LLC. 2011. FERC public filing: Responses to Requests for Additional Information. Cobscook Bay Tidal Energy Project, FERC Project No. 12711. Accession Number: 20110518-5003. Ocean Renewable Power Company, LLC, Portland, Maine. Available from FERC Online Elibrary: http://www.FERC.gov/docs-filing/elibrary.asp (September 19, 2011).

ORPC Maine, LLC. 2011. FERC public filing: Appendix A: ORPC Cobscook Bay and western Passage bird and marine mammal species checklist. Accession Number: 20110518-5003. Ocean Renewable Power Company, LLC, Portland, Maine. Available from FERC Online Elibrary: http://www.FERC.gov/docs-filing/elibrary.asp (September 19, 2011). [

Poff NL, JD Olden, DM Merritt, and DM Pepin. 2007. "Homogenization of regional river dynamics by dams and global diversity implications." *Proceedings of the National Academy of Sciences of the United States of America* 104: 5732–5737.

Polagye B and M Previsic. 2010. *Scenario Based Analysis of Environmental and Navigation Impacts: Tidal Energy Scenarios*. RE Vision DE-002, RE Vision Consulting, LLC, Sacramento, California. Available from http://www.re-vision.net/index.html (February 15, 2011).

Polagye B, P Malte, M Kawase, and D Durran. 2008. "Effect of large-scale kinetic power extraction on time–dependent estuaries." *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy* 222(5):471–484.

Polagye B, FB Van Cleve, A Copping, and K Kirkendall (eds). 2011. *Environmental Effects of Tidal Energy Development: Proceedings of a Scientific Workshop*, March 22–25, 2010. National Marine Fisheries Service, National Oceanic and Atmospheric Administration, Portland, Oregon.

Schiff K., D. Diehl, A. Valkirs. 2004. "Copper emission from antifouling paint on recreational vessels." *Marine Pollution Bulletin*, 48: 371-377.

Shields MA, DK Woolf, EPM Grist, SA Kerr, AC Jackson, RE Harris, MC Bell, R Beharie, A Want, E Osalusi, SW Gibb, J Side. 2010. "Marine renewable energy: The ecological implications of altering the hydrodynamics of the marine environment." *Ocean & Costal Management* 54(2011):2–9. Simmonds MP, and VC Brown. 2010. Is there a conflict between cetacean conservation and marine renewable-energy developments? *Wildlife Research* 37: 688-694.

Southhall, B.R., A.E. Bowles, W.T. Wllison, J.J. Finneran, R.L. Gentry, C.R. Greene Jr., D. Kastak, D.R. Ketten, J.H. Miller, P.E. Nachtigall, W.J. Richardson, J.A. Thomas, & P.R. Tyack. 2007. "Marine Mammal Noise Exposure Criteria: Initial Scientific Recommendations." *Aquatic Mammals* 33(4): 411-521.

SST – Sound & Sea Technology Engineering Solutions. 2011. *Assessment of Potential Puget Sound Marine Safety Risk Resulting from Installation of the Admiralty Inlet Tidal Energy Project: Defining a Risk Management Strategy for the Admiralty Inlet Tidal Energy Project*. Prepared for Snohomish Public Utility District #1.

Suter, GW. 1993. Ecological Risk Assessment. Lewis Publishers, Boca Raton.

Thouvenin, M., J.J. Pron, C. Charreteur, P. Guerin, J.Y Langlois, and J Vallee-Rehel. 2002. "A study of the biocide release from antifouling paints." *Progress in Organic Coatings*. 44: 75-83.

Thomas, K.V., S. Brooks. 2010. "MINI Review: The environmental fate and effects of antifouling paint biocides." *Biofouling*. 26(1): 73-88.

Toth, S., K. Becker-van Slooten, L. Spack, L.F. de alencastro, and J. Tarradellas. 1996. "Irgarol 1051, an antifouling compound in freshwater, sediment, and biota of Lake Geneva." *Bulletin of Environmental Contamination and Technology* 57(3): 426-433.

U.S. Fish and Wildlife Service. 2009. FERC public filing: ORPC tidal power, Western Passage, Eastport, Maine. Accession Number: 20110518-5003. U.S. Fish and Wildlife Service Maine field office, Orono, Maine. Available from FERC Online Elibrary: http://www.FERC.gov/docs-filing/elibrary.asp (September 19, 2011).

Valkirs, A.O., P.F. Seligman, E. Haslbeck. 2003. "Measurement of copper relase rates from antifouling paint under laboratory and in situ conditions: implications for loading estimation to marine water bodies." *Marine Pollution Bulletin* 46(6): 763-779.

van der Voo L. 2011 . *Waiting for Wave Energy*. Oregon Business: 1-5. Available from http://www.oregonbusiness.com/articles/99-may-2011/5162-waiting-for-wave-energy (September 19, 2011).

Vickery P. 2010. *Survey Protocol for Censusing Seabirds in Cobscook Bay*. The Center for Ecological Research, Richmond, Maine.

Vickery PD and Center for Ecological Research. 2011. *First Interim Report to ORPC on Bird Studies in Cobscook Bay, Maine Period of Investigation*. Accession Number: 20110518-5003, Ocean Renewable Power Company, LLC, Portland, Maine. Available from FERC Online Elibrary: http://www.FERC.gov/docs-filing/elibrary.asp (September 19, 2011).

von Arx WS, HB Stewart Jr, and JR Apel. 1974. "The Florida current as a potential source of useable energy." In *Proceedings of the MacArthur Workshop on the Feasibility of Extracting Useable Energy from the Florida Current*, HB Stewart (ed.), February 27–March 1, 1974, Palm Beach Shores, Florida.

Williams R, D Lusseau, and PS Hammond. 2006. "Estimating relative energetic costs of human disturbance to killer whales (Orcinus orca)." *Biological Conservation* 133:301–311.

Wilson B, RS Batty, F Daunt, and C Carter. 2007. *Collision Risks Between Marine Renewable Energy Devices and Mammals, Fish and Diving Birds.* Report to the Scottish Executive, Scottish Association for Marine Science, Oban, Scotland.

Yebra, D.M., S. Kiil, C.E. Weinell, and K. Dam-Johansen. 2006. "Dissolution rate measurements of sea water soluble pigments for antifouling paints: ZnO." *Progress in Organic Coatings* 56: 327-337.

Ytreberg, E., J. Karlsson, B. Eklund. 2010. "Comparison of toxicity and release rates of Cu and Zn from anti-fouling paints leached in natural and artificial brackish seawater." *Science of the Total Environment* 408(12): 2459-2466.

Appendix A

Details of the Consequence Ranking Process and Intermediate Results Tables

Appendix A

Details of the Consequence Ranking Process and Intermediate Results Tables

A.1 Preparation for Screening Analysis

Screening analysis preparation consists of developing a list of stressor–receptor (S–R) pairs. This was done following the steps below:

1. Identify the major groups of receptors of concern (Table 2.3). Subdivide receptor groups to reflect life history (e.g., cetaceans versus pinnipeds within aquatic mammals; migratory versus resident marine fish). Within each of those subdivisions, identify one or more example species for risk analysis that is broadly representative. The species or habitats used as examples for each receptor group are listed in Table 2.6.
2. Identify the major stressors of concern. These are listed in Table 2.2.
3. Produce the complete list of risk-relevant S–R pairs for each of the two cases. These S–R pairs are the basis for screening analysis for each case.

A.2 Procedure for Ranking Impact Scenarios for Each Case

Preliminary assessment of the relative risk associated with stressor–receptor pairs for each case was conducted by Pacific Northwest National Laboratory staff for subsequent review by subject matter experts. The purpose of this assessment is to develop a ranked list of relative consequence across receptor groups for each case. This assessment is subdivided into three steps to allow for transparency. The transparency serves two purposes: 1) to clearly show how risk has been assigned and 2) to allow for replacing each outcome as new data or information become available. The five steps follow an iterative process to assign relative risk using a series of risk factors.

1. *Identify S–R pairs by receptor group*. Separate the complete listing of S–R pairs by receptor into the seven receptor groups identified in Table 2.3.
2. *Apply biophysical risk factors to rank ALL S–R pairs for each case study*. Biophysical risk factors are used to order the stressor–receptor pairs in their receptor group by relative consequence risk. Biophysical risk factors are described in Table 2.4. A score of "1" was used to indicate potential consequence ("a noticeable impact/destabilized system") for each S–R pair and across the eight applicable biophysical risk factors, a score of 0.5 was used to indicate an intermediate consequence ("noticeable effect, but not destabilizing"), and "0" was used to indicate no probable consequence ("no noticeable effect"). *Once risk factor scores were assigned, potential risk count was summed f*or each S–R pair. Stressor–receptor pairs with the highest sums were considered the highest rank. These are considered "first-tier" S–R pairs at this stage. Second-, third-, and fourth- highest sums also were assigned corresponding relative rank values (i.e., 2 or second tier, and so on) based on their biophysical risk factor sums.

This step resulted in a master list for each case comprised of all the S-R interactions broken down into tiers derived from the application of biophysical risk factor scores (Table 3.1 and 3.2). Table A.1 shows the biophysical risk factor score for each ranked S–R pair.

3. *For each case, apply regulatory risk factors to S–R pairs, starting with tier 1 S–R pairs*. A second set of risk factors, regulatory risk factors, is used to rank S–R pairs within tiers based on their regulatory consequence. Regulatory risk factors are described in Table 2.5 and divided into four levels to reflect the level of protection provided by the law or combination of laws. Level 1 law combinations that apply to S–R pairs are assigned a score of 1 to signify the highest risk. Level 2 laws are assigned a score of 2, and level 3 a score of 3, etc.

   S–R pairs that were considered to be tier 1 in step 2 are re-ranked into new tiers based on regulatory risk factors. This was done by applying regulatory risk scores to tier 1 S–R pairs and then re-sorting the tier 1 S–R pairs by regulatory risk factor. The output of this step is a new, shorter list of tier-1 S–R pairs that collectively have the highest risk for biophysical and regulatory risk factors. This short list of tier-1 S–R pairs is set aside while remaining S–R pairs receive further risk screening with the second-tier S–R pairs from step 3 (i.e., second tier S–R pairs for biophysical risk factors).

   Regulatory risk factors risk factors are sequentially applied to biophysical risk tier 2 S–R pairs and then re-ranked. Top-tier S–R pairs are set aside while remaining S–R pairs receive further risk screening with the third-tier S–R pairs from step 3. This process is repeated until the top risks from each of the tiers are determined for each of the three cases. Table 3.3 shows the final relative ranking for each tier of risk for each case. Regulatory risks assigned to each S–R pair are shown in Table A.2.

Table A.1. Outcome of the Application of Biophysical Risk Factors to Each Stressor—Receptor Pair for Receptor Group

Mammal Receptor Group

Technology	Stressor	Vulnerable receptor	Risk from small population size	At risk life stage	Risk to critical prey	Risk to critical habitat	Risk from predation	Risk from competition	Behavior that increases risk	Risk to sustaining populations	Sum
TidGen™	Physical Presence (Dynamic)	non T&E pinniped (Harbor seal)	0	0	0	0	0	0	1	1	2
TidGen™	Physical Presence (Dynamic)	non T&E cetacean (Harbor porpoise)	0	0	0	0	0	0	1	1	2
TidGen™	Physical Presence (Static)	non T&E pinniped (Harbor seal)	0	0	0	0	0	0	0.5	0	0.5
TidGen™	Physical Presence (Static)	non T&E cetacean (Harbor porpoise)	0	0	0	0	0	0	0.5	0	0.5
TidGen™	Noise	non T&E pinniped (Harbor seal)	0	0	0	0	0	0	0.5	0	0.5
TidGen™	Noise	non T&E cetacean (Harbor porpoise)	0	0	0	0	0	0	1	0	1
TidGen™	EMF	non T&E pinniped (Harbor seal)	0	0	0	0	0	0	0	0	0
TidGen™	EMF	non T&E cetacean (Harbor porpoise)	0	0	0	0	0	0	0	0	0
TidGen™	Chemical Leaching	non T&E pinniped (Harbor seal)	0	0	0	0	0	0	0	0	0
TidGen™	Chemical Leaching	non T&E cetacean (Harbor porpoise)	0	0	0	0	0	0	0	0	0
TidGen™	Accidents and Disasters	non T&E pinniped (Harbor seal)	0	1	0	0	0	0	0	0.5	1.5
TidGen™	Accidents and Disasters	non T&E cetacean (Harbor porpoise)	0	0.5	0	0	0	0	0	0.5	1
Oyster	Physical Presence (Dynamic)	T&E pinniped (Steller sea lion)	1	0	0	0	0	0	0.5	0.5	2
Oyster	Physical Presence (Dynamic)	T&E mustelid (Southern Sea otter)	1	0	0	0	0	0	0.5	0.5	2
Oyster	Physical Presence (Dynamic	non T&E pinniped (Harbor seal)	0	0	0	0	0	0	0.5	0.5	1
Oyster	Physical Presence (Dynamic)	non T&E cetacean (Harbor porpoise)	0	0	0	0	0	0	0.5	0.5	1
Oyster	Noise	T&E pinniped (Steller sea lion)	1	0	0	0	0	0	0	0	1
Oyster	Noise	T&E mustelid (Southern Sea otter)	1	0	0	0	0	0	0	0	1
Oyster	Noise	non T&E pinniped (Harbor seal)	0	0	0	0	0	0	0	0	0
Oyster	Noise	non T&E cetacean (Harbor porpoise)	0	0	0	0	0	0	0	0	0
Oyster	Chemical Leaching	T&E pinniped (Steller sea lion)	1	0	0	0	0	0	0	0	1
Oyster	Chemical Leaching	T&E mustelid (Southern Sea otter)	1	0	0	0	0	0	0	0	1
Oyster	Chemical Leaching	non T&E pinniped (Harbor seal)	0	0	0	0	0	0	0	0	0
Oyster	Chemical Leaching	non T&E cetacean (Harbor porpoise)	0	0	0	0	0	0	0	0	0
Oyster	Accident/Disaster	T&E pinniped (Steller sea lion)	1	0.5	0	0	0	0	0	0.5	2
Oyster	Accident/Disaster	T&E mustelid (Southern Sea otter)	1	0.5	0	0	0	0	0	0.5	2
Oyster	Accident/Disaster	non T&E pinniped (Harbor seal)	0	0.5	0	0	0	0	0	0.5	1
Oyster	Accident/Disaster	non T&E cetacean (Harbor porpoise)	0	0.5	0	0	0	0	0	0.5	1

Table A.1. (contd)

Bird Receptor Group

Technology	Stressor	Vulnerable receptor	Risk from small population size	At risk life stage	Risk to critical prey	Risk to critical habitat	Risk from predation	Risk from competition	Behavior that increases risk	Risk to sustaining populations	Sum
TidGen™	Physical Presence (Dynamic)	non T&E diving bird (Black Guillemots)	0	0	0	0	0	0	1	1	2
TidGen™	Physical Presence (Static)	non T&E diving bird (Black Guillemots)	0	0	0	0	0	0	0	1	1
TidGen™	Noise	non T&E diving bird (Black Guillemots)	0	0	0	0	0	0	0	0	0
TidGen™	Cables/EMF	non T&E diving bird (Black Guillemots)	0	0	0	0	0	0	0	0	0
TidGen™	Chemical Leaching	non T&E diving bird (Black Guillemots)	0	0	0	0	0	0	0	0	0
TidGen™	Accidents and Disasters	non T&E diving bird (Black Guillemots)	0	0.5	0	0	0	0	0	0.5	1
Oyster	Physical Presence (Dynamic)	T&E bird (Marbled murrelet)	1	0	0	0	0	0	0	1	2
Oyster	Noise	T&E bird (Marbled murrelet)	1	0	0	0	0	0	0	0	1
Oyster	Chemical Leaching	T&E bird (Marbled murrelet)	1	0	0	0	0	0	0	0	1
Oyster	Accidents and Disasters	T&E bird (Marbled murrelet)	1	0	0	0	0	0	0	1	2

Table A.1. (contd)

Invertebrate Receptor Group

Technology	**Stressor**	**Vulnerable receptor**	**Risk from small population size**	**At risk life stage**	**Risk to critical prey**	**Risk to critical habitat**	**Risk from predation**	**Risk from competition**	**Behavior that increases risk**	**Risk to sustaining populations**	**Sum**
TidGen™	Physical Presence (Dynamic)	non T&E benthic invertebrate (Cobscook Sea Scallop)	0	0	0	0	0	0	0	0	0
TidGen™	Physical Presence (Dynamic)	non T&E benthic invertebrate (Green Urchin)	0	0	0	0	0	0	0	0	0
TidGen™	Physical Presence (Static)	non T&E benthic invertebrate (Cobscook Sea Scallop)	0	0	0	0	0	0	0	0	0
TidGen™	Physical Presence (Static)	non T&E benthic invertebrate (Green Urchin)	0	0	0	0	0	0	0	0	0
TidGen™	Noise	non T&E benthic invertebrate (Cobscook Sea Scallop)	0	0	0	0	0	0	0	0	0
TidGen™	Noise	non T&E benthic invertebrate (Green Urchin)	0	0	0	0	0	0	0	0	0
TidGen™	Cables/EMF	non T&E benthic invertebrate (Cobscook Sea Scallop)	0	0	0	0	0	0	0	0	0
TidGen™	Cables/EMF	non T&E benthic invertebrate (Green Urchin)	0	0	0	0	0	0	0	0	0
TidGen™	Chemical Leaching	non T&E benthic invertebrate (Cobscook Sea Scallop)	0	0	0	0	0	0	0	0	0
TidGen™	Chemical Leaching	non T&E benthic invertebrate (Green Urchin)	0	0	0	0	0	0	0	0	0
TidGen™	Accidents and Disasters	non T&E benthic invertebrate (Cobscook Sea Scallop)	0	0	0	0	0	0	0	0	0
TidGen™	Accidents and Disasters	non T&E benthic invertebrate (Green Urchin)	0	0	0	0	0	0	0	0	0
Oyster	Physical Presence (Dynamic)	non T&E benthic invertebrate (Dungeness Crab)	0	0.5	0	0	0	0	0	0	0.5
Oyster	Physical Presence (Dynamic)	non T&E shore invertebrate (Razor clams)	0	0.5	0	0	0	0	0	0	0.5
Oyster	Noise	non T&E benthic invertebrate (Dungeness Crab)	0	0	0	0	0	0	0	0	0
Oyster	Noise	non T&E shore invertebrate (Razor clams)	0	0	0	0	0	0	0	0	0
Oyster	Chemical Leaching	non T&E benthic invertebrate (Dungeness Crab)	0	0	0	0	0	0	0	0	0
Oyster	Chemical Leaching	non T&E shore invertebrate (Razor clams)	0	0	0	0	0	0	0	0	0
Oyster	Accidents and Disasters	non T&E benthic invertebrate (Dungeness Crab)	0	0	0	0	0	0	0	0	0
Oyster	Accidents and Disasters	non T&E shore invertebrate (Razor clams)	0	0	0	0	0	0	0	0	0

Table A.1. (contd)

Reptile Receptor Group

Technology	Stressor	Vulnerable receptor	Risk from small population size	At risk life stage	Risk to critical prey	Risk to critical habitat	Risk from predation	Risk from competition	Behavior that increases risk	Risk to sustaining populations	Sum
Oyster	Accident/Disaster	T&E reptile (Green Sea Turtle)	1	0.5	0	0	0	0	0	0	1.5
Oyster	Physical Presence (Dynamic)	T&E reptile (Green Sea Turtle)	1	0	0	0	0	0	0	0	1
Oyster	Noise	T&E reptile (Green Sea Turtle)	1	0	0	0	0	0	0	0	1
Oyster	Chemical Leaching	T&E reptile (Green Sea Turtle)	1	0	0	0	0	0	0	0	1

Table A.1. (contd)

Fish Receptor Group

Technology	Stressor	Vulnerable receptor	Risk from small population size	At risk life stage	Risk to critical prey	Risk to critical habitat	Risk from predation	Risk from competition	Behavior that increases risk	Risk to sustaining populations	Sum
TidGen™	Physical Presence (Dynamic)	migratory T&E fish (GOM DPS Atlantic Salmon)	1	0	0	0	0	0	1	0	2
TidGen™	Physical Presence (Dynamic)	migratory T&E fish (Atlantic sturgeon)	1	0	0	0	0	0	1	0	2
TidGen™	Physical Presence (Dynamic)	non T&E fish (Atlantic herring)	0	0	0	0	0	0	1	0	1
TidGen™	Physical Presence (Static)	migratory T&E fish (GOM DPS Atlantic Salmon)	1	0	0	0	1	0	0	0	1.5
TidGen™	Physical Presence (Static)	migratory T&E fish (Atlantic sturgeon)	1	0	0	0	0	0	0	0	1
TidGen™	Physical Presence (Static)	non T&E fish (Atlantic herring)	0	0	0	0	1	0	0	0	0.5
TidGen™	Noise	migratory T&E fish (GOM DPS Atlantic Salmon)	1	0	0	0	0	0	0.5	0	1.5
TidGen™	Noise	migratory T&E fish (Atlantic sturgeon)	1	0	0	0	0	0	0.5	0	1.5
TidGen™	Noise	non T&E fish (Atlantic herring)	0	0	0	0	0	0	0.5	0	0.5
TidGen™	Cables/EMF	migratory T&E fish (GOM DPS Atlantic Salmon)	1	0	0	0	0	0	0.5	0	1.5
TidGen™	Cables/EMF	migratory T&E fish (Atlantic sturgeon)	1	0	0	0	0	0	0.5	0	1.5
TidGen™	Cables/EMF	non T&E fish (Atlantic herring)	0	0	0	0	0	0	0.5	0	0.5
TidGen™	Chemical Leaching	migratory T&E fish (GOM DPS Atlantic Salmon)	1	0	0	0	0	0	0	0	1
TidGen™	Chemical Leaching	migratory T&E fish (Atlantic sturgeon)	1	0	0	0	0	0	0	0	1
TidGen™	Chemical Leaching	non T&E fish (Atlantic herring)	0	0	0	0	0	0	0	0	0
TidGen™	Accidents and Disasters	migratory T&E fish (GOM DPS Atlantic Salmon)	1	0.5	0	0	0	0	0	0	1.5
TidGen™	Accidents and Disasters	migratory T&E fish (Atlantic sturgeon)	1	0.5	0	0	0	0	0	0	1.5
TidGen™	Accidents and Disasters	non T&E fish (Atlantic herring)	0	0.5	0	0	0	0	0	0	0.5
Oyster	Physical Presence (Dynamic)	migratory T&E fish (Chinook Salmon)	1	0	0	0	1	0	0	0	1.5
Oyster	Physical Presence (Dynamic)	migratory T&E fish (Green sturgeon)	1	1	0	0	0	0	0	0	2
Oyster	Physical Presence (Dynamic)	resident non T&E fish (Black rockfish)	0	0	0	0	1	0	0	0	0.5
Oyster	Physical Presence (Dynamic)	resident shark/ray (Leopard Shark)	0	1	0	0	0	0	0	0.5	1.5
Oyster	Noise	migratory T&E fish (Chinook Salmon)	1	0	0	0	0	0	0	0	1
Oyster	Noise	migratory T&E fish (Green sturgeon)	1	0	0	0	0	0	0	0	1
Oyster	Noise	resident non T&E fish (Black rockfish)	0	0	0	0	0	0	0	0	0
Oyster	Noise	resident shark/ray (Leopard Shark)	0	0	0	0	0	0	0	0	0

Table A.1. (contd)

Technology	Stressor	Vulnerable receptor	Risk from small population size	At risk life stage	Risk to critical prey	Risk to critical habitat	Risk from predation	Risk from competition	Behavior that increases risk	Risk to sustaining populations	Sum
Oyster	Chemical Leaching	migratory T&E fish (Chinook Salmon)	1	0	0	0	0	0	0	0	1
Oyster	Chemical Leaching	migratory T&E fish (Green sturgeon)	1	0	0	0	0	0	0	0	1
Oyster	Chemical Leaching	resident non T&E fish (Black rockfish)	0	0	0	0	0	0	0	0	0
Oyster	Chemical Leaching	resident shark/ray (Leopard Shark)	0	0	0	0	0	0	0	0	0
Oyster	Accidents and Disasters	migratory T&E fish (Chinook Salmon)	1	0.5	0	0	0	0	0	0	1.5
Oyster	Accidents and Disasters	migratory T&E fish (Green sturgeon)	1	0.5	0	0	0	0	0	0	1.5
Oyster	Accidents and Disasters	resident non T&E fish (Black rockfish)	0	0.5	0	0	0	0	0	0	0.5
Oyster	Accidents and Disasters	resident shark/ray (Leopard Shark)	0	0.5	0	0	0	0	0	0.5	1

Table A.1. (contd)

Near Field Receptor Group

Technology	Stressor	Vulnerable receptor	Risk from size of habitat	Risk from reductions in sediment quality	sum
TidGen™	Accident/disaster (oil spills, blade break)	Nearfield habitat (Rocky, cobble)	0	0.5	0.5
TidGen™	Physical presence	Nearfield habitat (Rocky, cobble)	0.5	0	0.5
TidGen™	Changes in flow regime	Nearfield habitat (Rocky, cobble)	0	0	0
TidGen™	Leaching of toxic chemicals	Nearfield habitat (Rocky, cobble)	0	0.5	0.5
Oyster	Accident/disaster (oil spills)	Nearfield habitat (Sand)	0	1	1
Oyster	Physical presence	Nearfield habitat (Sand)	0.5	0	0.5
Oyster	Changes in flow regime	Nearfield habitat (Sand)	0	1	1
Oyster	Leaching of toxic chemicals	Nearfield habitat (Sand)	0	0.5	0.5

Table A.1. (contd)

Farfield Receptor Group

Technology	Stressor	Vulnerable receptor	Circulation that affects water quality	Circulation that affects sediment patterns	Circulation that affects food web	Circulation that affects water level	nearshore habitat	sum
TidGen™	Accident/disaster (oil spills, lost gear)	Farfield environment	1	0	0.5	0	0.5	2
TidGen™	Change in flow regime	Farfield environment	0.5	0.5	0.5	0	0.5	2
TidGen™	Energy removal	Farfield environment	0.5	0.5	0.5	0	0.5	2
Oyster	Accident/disaster (oil spills, lost gear)	Farfield environment	1	0	1	0	1	3
Oyster	Change in flow regime	Farfield environment	0	1	1	0	1	3
Oyster	Energy removal	Farfield environment	0	1	1	0	1	3

Table A.2. Biophysical Rank as Modified by Regulatory Rank

Tidal Case (TidGen™)

Technology	Stressor	Vulnerable receptor	Regulatory Risk Rank	Biophysical Relative Rank
Tier 1				
TidGen™	Physical Presence (Dynamic)	migratory T&E fish (GOM DPS Atlantic Salmon)	2	1
TidGen™	Physical Presence (Dynamic)	migratory T&E fish (Atlantic sturgeon)	2	1
Tier 2				
TidGen™	Physical Presence (Static)	migratory T&E fish (GOM DPS Atlantic Salmon)	2	2
TidGen™	Noise	migratory T&E fish (GOM DPS Atlantic Salmon)	2	2
TidGen™	Noise	migratory T&E fish (Atlantic sturgeon)	2	2
TidGen™	Cables/EMF	migratory T&E fish (GOM DPS Atlantic Salmon)	2	2
TidGen™	Cables/EMF	migratory T&E fish (Atlantic sturgeon)	2	2
TidGen™	Accidents and Disasters	migratory T&E fish (GOM DPS Atlantic Salmon)	2	2
TidGen™	Accidents and Disasters	migratory T&E fish (Atlantic sturgeon)	2	2
Tier 3				
TidGen™	Physical Presence (Static)	migratory T&E fish (Atlantic sturgeon)	2	3
TidGen™	Chemical Leaching	migratory T&E fish (GOM DPS Atlantic Salmon)	2	3
TidGen™	Chemical Leaching	migratory T&E fish (Atlantic sturgeon)	2	3
Tier 4				
TidGen™	Physical Presence (Dynamic)	non T&E pinniped (Harbor seal)	3	1
TidGen™	Physical Presence (Dynamic)	non T&E cetacean (Harbor porpoise)	3	1
TidGen™	Physical Presence (Dynamic)	non T&E diving bird (Black Guillemots)	3	1
TidGen™	Accident/disaster (oil spills, lost gear)	Farfield environment	3	1
TidGen™	Accidents and Disasters	non T&E pinniped (Harbor seal)	3	2
TidGen™	Noise	non T&E cetacean (Harbor porpoise)	3	3
TidGen™	Accidents and Disasters	non T&E cetacean (Harbor porpoise)	3	3
TidGen™	Physical Presence (Static)	non T&E diving bird (Black Guillemots)	3	3
TidGen™	Accidents and Disasters	non T&E diving bird (Black Guillemots)	3	3
TidGen™	Physical Presence (Static)	non T&E pinniped (Harbor seal)	3	4
TidGen™	Physical Presence (Static)	non T&E cetacean (Harbor porpoise)	3	4
TidGen™	Noise	non T&E pinniped (Harbor seal)	3	4
TidGen™	Accident/disaster (oil spills, blade break)	Nearfield habitat (Rocky, cobble)	3	4
TidGen™	Leaching of toxic chemicals	Nearfield habitat (Rocky, cobble)	3	4
TidGen™	EMF	non T&E pinniped (Harbor seal)	3	5
TidGen™	EMF	non T&E cetacean (Harbor porpoise)	3	5
TidGen™	Chemical Leaching	non T&E pinniped (Harbor seal)	3	5
TidGen™	Chemical Leaching	non T&E cetacean (Harbor porpoise)	3	5
TidGen™	Noise	non T&E diving bird (Black Guillemots)	3	5
TidGen™	Cables/EMF	non T&E diving bird (Black Guillemots)	3	5
TidGen™	Chemical Leaching	non T&E diving bird (Black Guillemots)	3	5

Table B.1. (contd)

Technology	**Stressor**	**Vulnerable receptor**	**Regulatory Risk Rank**	**Biophysical Relative Rank**
Tier 5				
TidGen^{TM}	Change in flow regime	Farfield environment	4	1
TidGen^{TM}	Energy removal	Farfield environment	4	1
TidGen^{TM}	Physical Presence (Dynamic)	non T&E fish (Atlantic herring)	4	3
TidGen^{TM}	Physical Presence (Static)	non T&E fish (Atlantic herring)	4	4
TidGen^{TM}	Noise	non T&E fish (Atlantic herring)	4	4
TidGen^{TM}	Cables/EMF	non T&E fish (Atlantic herring)	4	4
TidGen^{TM}	Accidents and Disasters	non T&E fish (Atlantic herring)	4	4
TidGen^{TM}	Physical presence	Nearfield habitat (Rocky, cobble)	4	4
TidGen^{TM}	Physical Presence (Dynamic)	non T&E benthic invertebrate (Cobscook Sea Scallop)	4	5
TidGen^{TM}	Physical Presence (Dynamic)	non T&E benthic invertebrate (Green Urchin)	4	5
TidGen^{TM}	Physical Presence (Static)	non T&E benthic invertebrate (Cobscook Sea Scallop)	4	5
TidGen^{TM}	Physical Presence (Static)	non T&E benthic invertebrate (Green Urchin)	4	5
TidGen^{TM}	Noise	non T&E benthic invertebrate (Cobscook Sea Scallop)	4	5
TidGen^{TM}	Noise	non T&E benthic invertebrate (Green Urchin)	4	5
TidGen^{TM}	Cables/EMF	non T&E benthic invertebrate (Cobscook Sea Scallop)	4	5
TidGen^{TM}	Cables/EMF	non T&E benthic invertebrate (Green Urchin)	4	5
TidGen^{TM}	Chemical Leaching	non T&E benthic invertebrate (Cobscook Sea Scallop)	4	5
TidGen^{TM}	Chemical Leaching	non T&E benthic invertebrate (Green Urchin)	4	5
TidGen^{TM}	Accidents and Disasters	non T&E benthic invertebrate (Cobscook Sea Scallop)	4	5
TidGen^{TM}	Accidents and Disasters	non T&E benthic invertebrate (Green Urchin)	4	5
TidGen^{TM}	Chemical Leaching	non T&E fish (Atlantic herring)	4	5
TidGen^{TM}	Changes in flow regime	Nearfield habitat (Rocky, cobble)	4	5

Table B.1. (contd)

Wave Case (Oyster)

Technology	Stressor	Vulnerable receptor	Regulatory Risk Rank	Biophysical Relative Rank
Tier 1				
Oyster	Physical Presence (Dynamic)	T&E pinniped (Steller sea lion)	1	3
Oyster	Physical Presence (Dynamic)	T&E mustelid (Southern Sea otter)	1	3
Oyster	Accident/Disaster	T&E pinniped (Steller sea lion)	1	3
Oyster	Accident/Disaster	T&E mustelid (Southern Sea otter)	1	3
Oyster	Physical Presence (Dynamic)	T&E bird (Marbled murrelet)	1	3
Oyster	Accidents and Disasters	T&E bird (Marbled murrelet)	1	3
Tier 2				
Oyster	Accidents and Disasters	T&E reptile (Green Sea Turtle)	1	4
Tier 3				
Oyster	Noise	T&E pinniped (Steller sea lion)	1	5
Oyster	Noise	T&E mustelid (Southern Sea otter)	1	5
Oyster	Chemical Leaching	T&E pinniped (Steller sea lion)	1	5
Oyster	Chemical Leaching	T&E mustelid (Southern Sea otter)	1	5
Oyster	Noise	T&E bird (Marbled murrelet)	1	5
Oyster	Chemical Leaching	T&E bird (Marbled murrelet)	1	5
Oyster	Physical Presence (Dynamic)	T&E reptile (Green Sea Turtle)	1	5
Oyster	Noise	T&E reptile (Green Sea Turtle)	1	5
Oyster	Chemical Leaching	T&E reptile (Green Sea Turtle)	1	5
Tier 4				
Oyster	Physical Presence (Dynamic)	migratory T&E fish (Green sturgeon)	2	3
Oyster	Physical Presence (Dynamic)	migratory T&E fish (Chinook Salmon)	2	4
Oyster	Accidents and Disasters	migratory T&E fish (Chinook Salmon)	2	4
Oyster	Accidents and Disasters	migratory T&E fish (Green sturgeon)	2	4
Oyster	Noise	migratory T&E fish (Chinook Salmon)	2	5
Oyster	Noise	migratory T&E fish (Green sturgeon)	2	5
Oyster	Chemical Leaching	migratory T&E fish (Chinook Salmon)	2	5
Oyster	Chemical Leaching	migratory T&E fish (Green sturgeon)	2	5

Table B.1. (contd)

Technology	Stressor	Vulnerable receptor	Regulatory Risk Rank	Biophysical Relative Rank
Tier 5				
Oyster	Accident/disaster (oil spills, lost gear)	Farfield environment	3	1
Oyster	Physical Presence (Dynamic	non T&E pinniped (Harbor seal)	3	5
Oyster	Physical Presence (Dynamic)	non T&E cetacean (Harbor porpoise)	3	5
Oyster	Accident/Disaster	non T&E pinniped (Harbor seal)	3	5
Oyster	Accident/Disaster	non T&E cetacean (Harbor porpoise)	3	5
Oyster	Accident/disaster (oil spills)	Nearfield habitat (Sand)	3	5
Oyster	Leaching of toxic chemicals	Nearfield habitat (Sand)	3	6
Oyster	Noise	non T&E pinniped (Harbor seal)	3	7
Oyster	Noise	non T&E cetacean (Harbor porpoise)	3	7
Oyster	Chemical Leaching	non T&E pinniped (Harbor seal)	3	7
Oyster	Chemical Leaching	non T&E cetacean (Harbor porpoise)	3	7
Tier 6				
Oyster	Change in flow regime	Farfield environment	4	1
Oyster	Energy removal	Farfield environment	4	1
Oyster	Physical Presence (Dynamic)	resident shark/ray (Leopard Shark)	4	4
Oyster	Accidents and Disasters	resident shark/ray (Leopard Shark)	4	5
Oyster	Changes in flow regime	Nearfield habitat (Sand)	4	5
Oyster	Physical Presence (Dynamic)	non T&E benthic invertebrate (Dungeness Crab)	4	6
Oyster	Physical Presence (Dynamic)	non T&E shore invertebrate (Razor clams)	4	6
Oyster	Physical Presence (Dynamic)	resident non T&E fish (Black rockfish)	4	6
Oyster	Accidents and Disasters	resident non T&E fish (Black rockfish)	4	6
Oyster	Physical presence	Nearfield habitat (Sand)	4	6
Oyster	Noise	non T&E benthic invertebrate (Dungeness Crab)	4	7
Oyster	Noise	non T&E shore invertebrate (Razor clams)	4	7
Oyster	Chemical Leaching	non T&E benthic invertebrate (Dungeness Crab)	4	7
Oyster	Chemical Leaching	non T&E shore invertebrate (Razor clams)	4	7
Oyster	Accidents and Disasters	non T&E benthic invertebrate (Dungeness Crab)	4	7
Oyster	Accidents and Disasters	non T&E shore invertebrate (Razor clams)	4	7
Oyster	Noise	resident non T&E fish (Black rockfish)	4	7
Oyster	Noise	resident shark/ray (Leopard Shark)	4	7
Oyster	Chemical Leaching	resident non T&E fish (Black rockfish)	4	7
Oyster	Chemical Leaching	resident shark/ray (Leopard Shark)	4	7

Appendix B

Risk of Encounter Between Tidal Turbine Blades and Marine Animals

Determining Risk to Southern Resident Killer Whales from Tidal Turbines

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Abstract

The endangered Southern Resident Killer Whales (SRKW) annually return to the inland marine waters of Washington (US) and British Columbia (CAN) to forage for their preferred prey of Chinook salmon. SRKW behavior has been parsed into four categories: foraging, socializing, resting, and traveling. Characteristics that include dive depth, dive frequency, directional or non-directional movement, and swimming define each behavior. SRKW are known to make dives deeper than 50m while foraging, although they spend the majority of their time in the upper 30m of the water column. Due to this diving behavior, the SRKW may be at risk for interactions with the planned installation of tidal turbines in Admiralty Inlet, WA. The tidal turbines will sit on the seafloor, at approximately 60m deep, and use the energy in the movement of water from tidal changes to generate electricity. These devices do not cause the degree of environmental impact of conventional hydropower, and still hold the other benefits of reliable, clean energy generation. SRKW are listed under the Endangered Species Act and their safety post-installation of the tidal turbines must be assessed. Since there is little information that can be used to predict the risk of SRKW interaction due to difficulties associated with data collection, a conceptual behavioral model was developed to describe SRKW diving behavior and to quantify the frequency of dives in Admiralty Inlet to 50m. While there was insufficient data to parameterize the necessary variables quantitatively, the conceptual model has specified areas for future research so that a mathematical behavioral model can be created in the future.

Introduction

Emerging as an alternative energy source, marine and hydrokinetic (MHK) devices use the energy in waves and tides to generate electricity. The Snohomish Public Utilities District No. 1 (SnoPUD) wishes to install two OpenHydro tidal energy conversion turbines at a depth of approximately 60m in Admiralty Inlet at the mouth of Puget Sound as part of their energy source diversification [1]. Admiralty Inlet experiences mixed semidiurnal tides—where water flows in and out of the Sound as the tide shifts between two daily highs and low tides that can be used to generate electricity with bi-directional turbines [2]. Even though the turbine installation is likely to not cause significant environmental changes, like those associated with hydroelectric dams, there is concern that the turbines' presence might affect marine populations including the endangered Southern Resident Killer Whale (SRKW) (Wood, Tollit et al. 2009). Admiralty Inlet provides the only access to Puget Sound for the SRKW and potential risks to the transiting SRKW from the installation of tidal turbines must be evaluated.

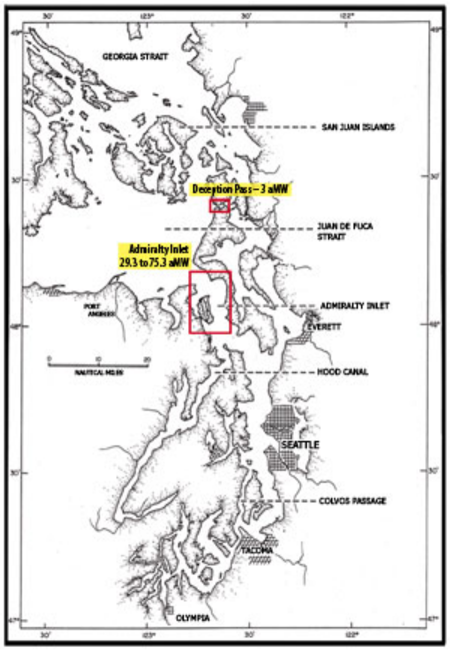

Fig. 1 Location of Admiralty Inlet, in the larger red square [3].

The purpose of this study is to quantitatively determine the probability of interaction between the SRKW and turbines by assessing the available data in the literature, creating a conceptual behavioral model, and processing the information in a mathematical simulation. Tasks were the following:

- SRKW behavior was informed by published studies, contributing to a conceptual model that describes the common behaviors in which the whales engage;
- Published values for the proportion of time that SRKWs spend in each behavior informed the conceptual model, and the power of a mathematical interpretation of the model was tested; and
- Using the software @Risk, the potential for creating a mathematical model was explored.

SRKW Background

The SRKW, a community of 80-90 orcas, annually returns to the inland marine waters of Washington (US) and British Columbia (CAN) [4]. SRKW are frequently found in these waters between April and November for the spring and fall runs of their preferred food, Chinook salmon [5]. SRKW stay in matriarchal pods, share kills while foraging, and spend time communicating with one another through whistles and clicks [6-9]. As an apex predator, killer whales can be significantly affected by changes to the quality of the environment where they live and hunt. Compounding biological effects of existing stressors and decreased food availability has reduced the whales' ability to adjust to new environmental pressures [10]. These pressures may have resulted in the population instability that led them to be classified as endangered under the US Endangered Species Act in 2005 after the population fell below 80 whales [4, 10].

Salmon and SRKW

Killer whale movements through the Straits of Juan de Fuca and Puget Sound are correlated with the overall population of multiple salmon species, Chinook salmon population, and timing of runs [5]. In years of less productive summer runs, whales have been found to travel greater distances to find Chinook salmon rather than prey on a different species [5]. Chinook tend to be larger than other salmon, sometimes reaching 100 pounds, and often mature later in life [11]. The SRKW prefer fish age four years or older that have gained considerable size over the years, but also have accumulated bio-toxins including persistent organic pollutants (POPs) which transfer to the SRKW upon consumption [7, 12, 13]. All SRKW carry an unsafe level of POPs that can cause immunosuppression and infertility[10]. The far reaching effects of this chemical body burden in the SRKW have been cited as a possible influence on whale health, population stability, and bioenergetics [10]. SRKW traveling and foraging behavior is intimately correlated with salmon availability and is important for the creation of behavioral models as the dynamics of SRKW activity may depend on the availability of prey.

Dive Rates

Data from time-depth recorder (TDR) tags temporarily deployed on SRKW in the Straits between 1993 and 2002 were used to explore influences on diving and foraging behavior, particularly their location in the water column [6]. While whales make deep dives to forage, they most often bring their prey to the surface to feed [7, 14]. Frequently, whales share kills within the pod[7]. Furthermore, whales dive deeper than 50m only 2.6% of the time, or approximately one dive per hour [14]. SRKW dive rates significantly vary depending on the time of day (night vs. day) and have exhibited different diving habits depending on their age and sex [14].

Killer Whale Behavior

SRKW behavior has been parsed into four categories: foraging, socializing, resting, and traveling. Two time intensive investigations to categorize whale behavior were published by Osborne and Heimlich-Boran in the late 1980s, each logging almost 1000 hours of observation time. In the time since these observations were conducted, the SRKW population dropped during the 1990s to fewer than 80 whales, prompting their listing under the Endangered Species Act [4]. Even though factors including food availability contributed to their decline, there has been no comprehensive investigation on how environmental factors may affect the whales' behavior, foraging habits, social structure, and health. It is likely that SRKW declines may be due to a combination of pressures including food availability and increases in commercial shipping and whale watching boats [15-19]. Subtle changes may have not only impacted the SRKW population stability, but also the behavior of the whales over time.

Effects of Human Activities

Vessel Proximity

Boat traffic causes whales to expend more energy without increasing foraging time in both the SRKW community and similar Northern Resident Killer Whale community [15, 17-20]. Researchers compared the activities of killer whales within a marine protected area (MPA), where boats are prohibited, and whale activities in an area with boats present. SRKW exhibit evasive behavior when in the proximity of boaters [17]. One study found human boating activities may cause an approximate net energy intake reduction of 18% as whales spend more time fleeing and less time foraging [19]. These evasive tactics can differ depending on the number of boats and their proximity to the whales [17]. Not only can the presence of watercraft pose as a predatory threat, the noise from boat propellers may also mask sounds the whales make, including echolocation clicks used for foraging [19, 21]. Admiralty Inlet is the main ingress/ egress for Puget Sound, supporting large numbers of commercial shipping vessels bound for the Ports of Seattle and Tacoma, as well as military, recreational, fishing vessels, and public ferries [2]. Extrapolating from the studies on whale watch vessels, it can be assumed that the SRKW are aware and likely reactive to the vessel traffic.

Methods

The development of a conceptual model to describe the relationships and influences between external variables and the SRKW was needed before beginning mathematical modeling. SRKW occasionally dive to depths greater than 50m which puts them at risk for potential interactions with the proposed OpenHydro tidal turbines in Admiralty Inlet. The purpose of the conceptual model was to identify and isolate variables that would cause a SRKW to make a deep dive by defining relationships between behavior states.

The Conceptual Model

SRKW on average only make one dive deeper than 50m per hour during the day, most likely while foraging [14]. Assuming SRKWs' 50m dives are directly associated with foraging, then variables that either increase or decrease the proportion of time spent foraging also change the frequency of deep dives. The literature shows that vessel presence causes whales to significantly reduce the amount of time spent foraging to favor traveling behavior [19, 20]. Since Admiralty Inlet is the only shipping channel to Puget Sound, high volumes of vessel traffic are present, potentially resulting in SRKW evasive behavior. There is some suggestion that other environmental elements such as tidal variation, seasonality, pod identity, and age have significant effects on SRKW diving behavior and movement, but these variables were not considered during this study [5, 14, 20, 22]. This conceptual model shows that the variables of greatest influence on dive rate are the proportion of time spent in foraging behavior, the presence of shipping, and the presence of SRKW prey.

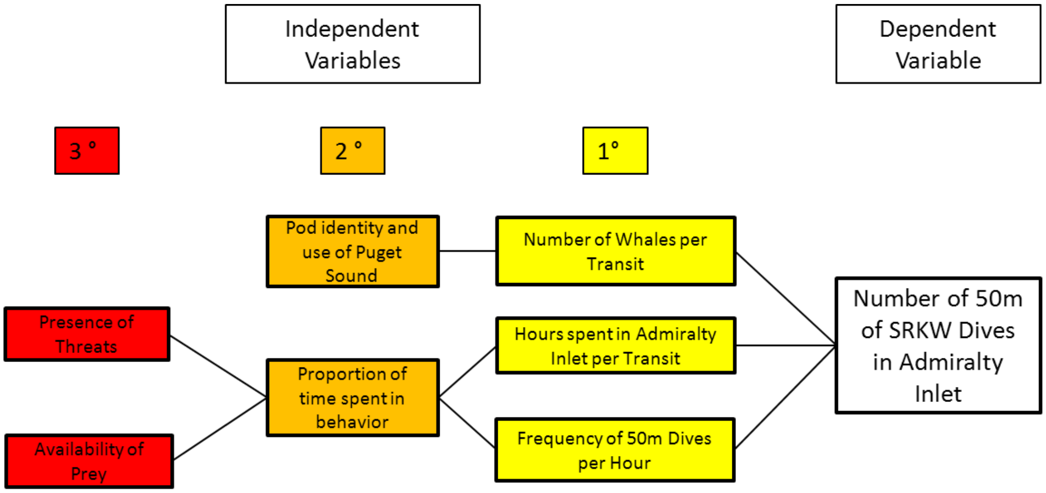

Fig. 2 Conceptual model showing the variables (primary, secondary, and tertiary) as well as their relation to the number of 50m dives.

Definition of Variables

Further description SRKW diving behavior by classifying various external factors into primary, secondary, and tertiary independent variables is a precursor to mathematical modeling of the number of times SRKW made a 50m dive in Admiralty Inlet. This model requires the definition of variables that influence SRKW movement through the water column

Primary Variables

The primary variables determine the frequency of 50m dives for whales transiting Admiralty Inlet. 'Number of whales present' and 'Hours spent in Admiralty Inlet' were both reported in preliminary assessments of risk to SRKW [1, 23, 24]. A separate study on diving rates of SRKW was used to determine frequency of 50m dives [14]. Using the primary variables to calculate dive frequency does not account for sources of uncertainty or externalities.

$$[(Frequency\ of\ 50m\ Dives\ per\ Hour) * (Hours\ per\ Transit\ of\ Admiralty\ Inlet) * (Number\ of\ whales\ per\ transit\ of\ Admiralty\ Inlet)] = Number\ of\ 50m\ dives\ made\ by\ whales$$

Fig. 2 Primary Variables used to define the number of dives to 50m

Secondary Variables

Secondary variables directly influence the quantitative value of the primary variables (Fig 2). Secondary variables affecting the number of whales present in each transit and the length of time spent in transit are defined and accounted for in separate studies [1, 24, 25].

An additional secondary variable requiring definition is the proportion of time SRKWs spent in each behavior. Characterized by different rates of water column use, resting, socializing, and traveling occur in the top 20-30m of the water column almost exclusively, while foraging behavior tends to occur deeper [14]. Additionally, whales move at different speeds depending on behavior; foraging is characterized by rapid swimming and frequent dives, often is non-directional, and does not expedite transit [6-8, 14].

Tertiary and Quaternary Variables

Direct influences on the amount of time whales spend in particular behaviors were classified as tertiary variables (Figure 2). From the literature, the greatest influences on SRKW behavior are the presence of prey and threats to the whales. SRKW travel great distances in search of Chinook salmon; it is assumed that they would be less likely to forage if Chinook are not present in an area. Additionally, in the presence of boats and ships and other perceived threats, SRKW significantly reduce their forage time in favor of travel time [19, 20]. Changes in the time spent in each behavior alter both the frequency of deep dives and the speed at which the pod moves [17, 19].

Quaternary variables were not examined in this study but should include the timing of Chinook salmon migrations, frequency that whales are confronted with threatening stimuli, and seasonal and diurnal timing of the observations.

Model Parameters

Data from the literature were compiled to define the relationships between variables, calculate the frequency of deep dives a SRKW makes while foraging, and determine the proportion of time the SRKWs spend foraging while in Admiralty Inlet. This model defines quantitatively how the variables influence SRKW movement in the water column.

Primary

50m Dives per Hour

The dive rate primary variable was defined from published data to predict the probability and frequency of SRKW dives. The data used are presented in the form of average dives per hour to particular depths and associated standard deviations. To create a probability distribution, the data were converted to cumulative probabilities from the average frequencies. To define a distribution for frequency of dives, the data were rescaled by logarithmic transformation. Due to software limitations of @Risk, the modeling software used, the standard deviations could not be accounted for in the final distributions. The following charts are histograms illustrating the distributions of dive depth frequency, with (Fig 3) and without (Fig 4) standard deviation.

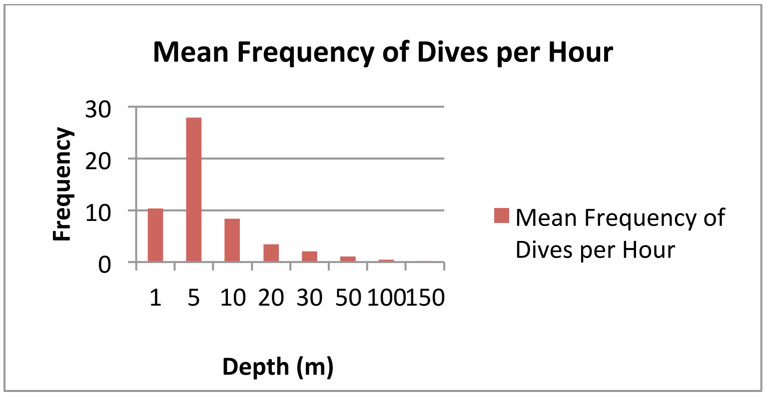

Fig. 3 Average number of dives per hour to depth, in meters [14] This data set was used to define the cumulative probability distribution and frequency distribution.

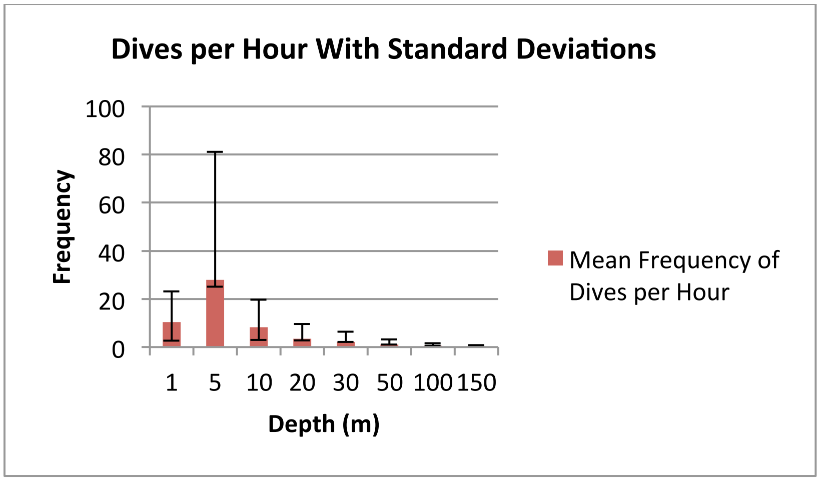

Fig. 4 Average dives per hour with standard deviations

Transit Time and Number of Whales

An assessment of the presence of SRKW in Admiralty Inlet and the frequency of acoustically active behaviors was used in the development of a passive acoustic monitoring system to determine the interaction of the whales with proposed tidal turbines [23, 25]. Researchers calculated the average length of time whales spent transiting Admiralty Inlet using observational, historical, and published data on whale transiting speeds [24, 25]. Additionally, researchers determined the number of crossings whales made in a year[1, 24, 25]. These reported values were used to define the number of whales per crossing and time required for transit.

Secondary Variables

Proportion of Time Spent in Behavior

Published data from studies conducted by Beam Reach, Ford, Heimlich-Boran, Osborne, and SnoPUD provides estimates of the proportion of time that the SRKW population spends in each of the four behavioral states[25]. To test the applicability of these data to support a behavioral model, data normalized by hours of observation were evaluated using a Chi-square test of homogeneity. This test was used to establish whether variations in the reported proportions of time spent in specific behaviors were significant, and if so, which studies provided the most sensitive data. Of the five studies presented, only one [23] conducted observations within Admiralty Inlet exclusively. The chi-square test determined if there was significant variation between the studies overall, not specifically caused by the limited time and region of observations in Admiralty Inlet.

Behavior	**Osborne (1986)**	**Heimlich-Boran (1988)**	**Ford (1989)**	**Beam Reach (2011)**	**SMRU (2011)**	**Total Obs. Time (Hrs)**
Foraging						
Proportion	0.46	0.47	0.67	0.28	0.21	
Observation Time	445	463	277	11	2	1198
Resting						
Proportion	0.12	0.13	0.13	0.11	0.00	
Observation Time	116	128	55	4	0	303
Socializing						
Proportion	0.15	0.15	0.12	0.09	0.05	
Observation Time	145	148	48	4	1	345
Traveling						
Proportion	0.27	0.25	0.04	0.52	0.74	
Observation Time	261	246	17	21	9	554
Total Observation Time (Hours)	967	985	397	41	12	2401

Table 1 Published behavioral proportions and total observation hours per study [25]The observation time for each behavior within each study was calculated (e.g. the number of hours of observed foraging behavior).

Tertiary

Prey and Threats

Tertiary variables were not included in the quantitative analysis. Significant changes in behavior may have direct influence on a behavioral model that attempts to calculate the number of dives per hour and transit speed, assuming that different behaviors are characterized by different dive rates and directional movement. A whale attempting evasive tactics may reduce foraging time, increase path tortuosity, traveling time, and behave erratically in order to “throw off” a predator [17, 18]. It is assumed that if prey is unavailable, the amount of time spent foraging would decrease. The relationship between dive rate and behavior, whether evasive or otherwise, must be determined before accounting for these variables

Results

The variables outlined by the literature assessment were quantitatively defined to determine utility in a mathematical simulation. The software @RISK uses a Monte Carlo simulation, allowing for the flexibility of input data to be defined as probability or frequency distributions if an absolute value is unknown. @Risk can also define distributions for collected data and quantify sensitivity in mathematical models [26].

Transit Time and Number of Whales per Transit

The definition of transit time and number of whales per transits were calculated in a previous report summarizing SRKW presence in Admiralty Inlet.

Primary Variable	Quantitative Value
Transit Time	6.5 hrs
Number of Whales per Transit	42

Table 2. Primary variables' quantitative values taken from the 2011 Final SRKW Assessment [25]

50m Dives per Hour

The distribution of dive frequencies was defined by two methods using the @Risk modeling software to produce a cumulative probability distribution and a logarithmic transformation frequency distribution, then using RMS error to determine fit. Ideally, the RMS should equal zero to indicate a perfect fit.

Depth (≥m)	log(Depth+1)	Mean/ Hr (Day)	Cumulative Probability
1	0.30	10.29	0.191
5	0.78	27.96	0.710
10	1.04	8.32	0.864
20	1.32	3.45	0.928
30	1.49	2.12	0.968
50	1.71	1.04	0.987
100	2.00	0.5	0.996
150	2.18	0.2	1
	Total Dives/ Hr	53.88	

Table 3. Results of the cumulative probability calculation and logarithmic transformation

Logarithmic Transformation

The data reported by Baird et al. have considerable skew to the right with significantly more observations made for the top 30 m than the total 150m analyzed (Fig. 3 and 4) which required a logarithmic transformation to define the distribution. The distribution produced by @Risk is a poor fit for the data set, as it shows a considerable proportion of depths to be at a 0 frequency; the software did not provide any better-fitting alternatives. This distribution was not included in assessments due to the high RMS value and visual discrepancy between the data and fitted line.

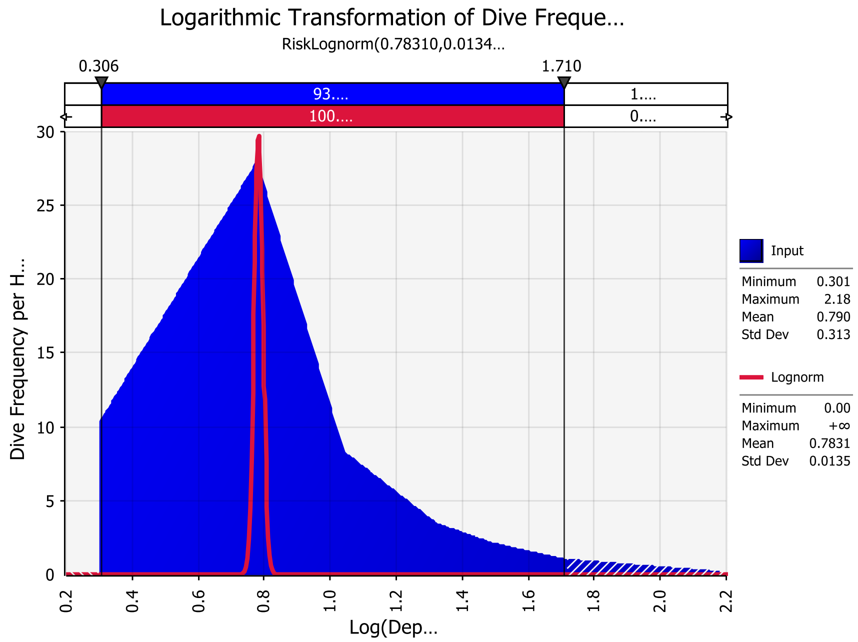

Fig. 5 Frequency distribution of published dive rates (in blue) with computer generated best fit distribution (red). The shaded area shows the frequency distribution, with a maximum of 27 dives per hour for 5m or 0.78 on this chart. @Risk found that a lognormal function to be the best fit line for this distribution with a Root Mean Square value of 4.9101.

Cumulative Probability

The cumulative probability distribution is considered to be an accurate representation of the data (RMS=0.0064). This distribution shows that as depth increases, the probability of occurrence approaches 1. The data are shown in blue, and the model in Red. The cumulative probability is expressed as a log-logistic equation. 98.4% of dives occur between 0 -50m and 1.6% occur at depths greater than 50m.

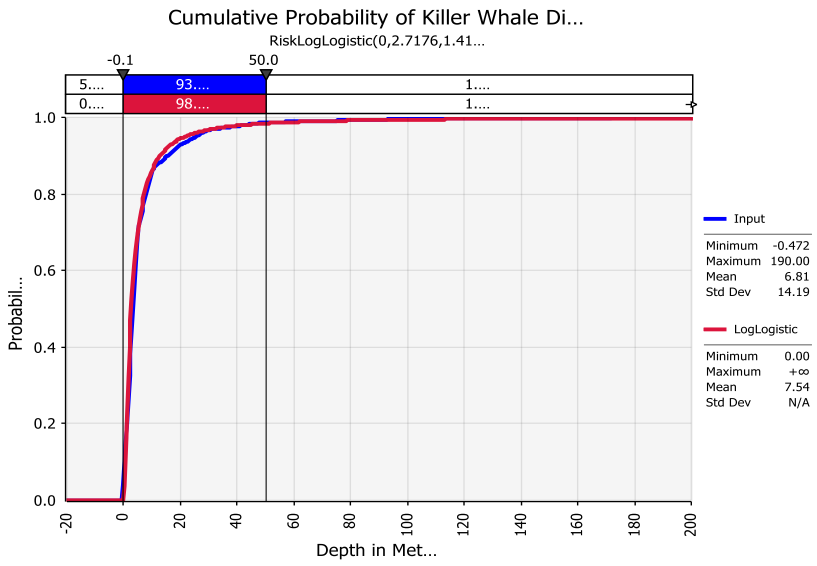

Fig. 6 Cumulative Probability graph showing calculated cumulative probabilities from Table 3 (Blue) and curve fit by @Risk Professional (Red) Fit determined by root mean of squares (RMS for RISKLoglogistic fit= 0.0064). Diving in excess of 50m is p=0.016.

Behavior

Chi-Square Analysis

The chi-square test showed significant differences between the reported behavioral proportions, with particularly large chi-square sensitivities in traveling behavior (chi-sq: 145.9, df= 12, p-value= 0.00). The data from the Ford 1989 study significantly affected the chi-square value. There were also significant differences between all of the studies in both the traveling and foraging categories. This test indicates that the published behavioral proportions are inconsistent. Observations that exceeded 800 hours (Osborne, 1986 and Heimlich-Boran, 1988) had the lowest chi-square contribution; however, the two studies with less than 50 hours of observation (Beam Reach 2011 and SMRU 2011) had lower chi-square contributions than the Ford study, which had 400 hours of observation. In preliminary investigations, SRKW dive rates were assessed in Admiralty Inlet through the use of passive acoustics. This method does not offer the same precision as collection by TDRs [23]. The information collected in the assessment of Admiralty Inlet found all measurements of SRKW behavior and dive rates to be significantly different from values published in the literature, which is supported by the Chi-square test of homogeneity for behavior rates [23].

Behavior	Osborne	Heimlich-Boran	Ford	Beam	SnoPud	Total Chi-Sq
Foraging	2.91	1.65	31.44	4.02	2.66	42.68
Resting	0.30	0.11	0.48	0.22	1.51	2.62
Socializing	0.23	0.26	1.48	0.54	0.31	2.82
Traveling	6.43	1.54	60.76	15.01	14.02	97.77
Total Chi-Square	9.87	3.56	94.16	19.79	18.50	145.88

Chi-Sq	**145.88**
DF	**12**
P-value	**0**

Table 4 Chi Square Contributions for various behaviors and studies. Highlighted values show significant chi-square contributions from the Ford study. Any individual contribution greater than 5 was considered significant. (Critical chi-square test value= 5.226, p-value= 0.05

Discussion

The model developed for this study illustrates how the unique behavioral and feeding ecology of SRKW directly affects their risk of interaction with the tidal turbine. The SRKW feed almost exclusively on one species of fish, and have been shown to favor certain areas for foraging, which is the behavior identified to have the most risk of tidal turbine interactions. The results of this study show that insufficient data in the literature to parameterize a quantitative behavioral model for SRKW in Admiralty Inlet. While the data available can support the generation of a conceptual model of diving behavior, it lacks the information needed to clearly define the relationships between these variables and the event of a 50m dive.

The fidelity to both geographic location and prey type causes unique problems for SRKW modeling and behavioral assessments. The SRKW annual return to specific areas at specific times of the year has resulted in researchers focusing observational efforts to those particular areas, often in the San Juan Islands. There appears to be an assumption in the literature that SRKW behavior in this area adequately represents SRKW behavior in the region. Such an assumption requires further verification. Numerous studies, including those focusing on Admiralty Inlet, show that SRKWs can be influenced by many externalities such as geographic location, time of day, and human activities. A mathematical model created from the limited quantitative data in the literature suggests that all whales behave the same way throughout the region because insufficient information exists to define the relationship between environmental variables and whale behavior.

Modeling software, like @Risk, works using a Monte Carlo method and requires a combination of quantitative values and distributions to simulate numerous scenarios. The specificity of the parameters available allows this software to narrow input distributions to produce a more powerful result. The software has limited flexibility to amplify the power of a model through simulation of data sets given the proper definition of input distributions. The probability of 50m SRKW dives while foraging in Admiralty Inlet cannot be determined by a Monte Carlo simulation as the published data are presented as summary statistics and proportions. Data in this form represent summarized trends and are presented without the degree of detail and quantity needed to parameterize a mathematical model. Inadequate amounts of data result in poorly defined distributions and any relationship between simulated input distributions will be insufficiently powerful for modeling risk.

Recommendation

Future research investigating the relationship between water column use and surface behavior of SRKW would reduce uncertainty in behavioral modeling. The data available are not sufficiently robust to quantify the relationships between variables that influence whale diving behavior. Due to physical limitations, behavioral observation and dive studies are difficult to conduct and limited in rigor. More studies into environmental influences on whale behavior will reduce uncertainty for surface behavior and geographic location; however, without dive data, they cannot incorporate water column use.

To model dive rates in Admiralty Inlet using the primary and secondary variables of the conceptual model, more studies are needed to increase the understanding of:

- Frequency of SRKW dives in specific behavior states
- Behaviors of SRKW within Admiralty Inlet
- SRKW use of the water column (similar to Baird and Hanson’s studies [14]) in varying bathymetry

Bibliography

[1] D. Tollit*, et al.*, "Admiralty Inlet Pilot Project marine Mammal Pre-Installation Field Studies Final Report," Snohomish PUD2010.

[2] WA-DOE, "Admiralty Inlet/ Hood Canal Geographic Response Plan," W. D. o. Ecology, Ed., ed. Olympia: Washington Department of Ecology, 2003.

[3] S. C. P. N. SnoPUD, "Tidal Study Sites Power Supply," vol. 2011, ed. Everett, 2011.

[4] NMFS, "Recovery Plan for Southern Resident Killer Whales (*Orcinus orca*)," N. M. F. Service, Ed., ed. Seattle, WA: Northwest Region, 2008.

[5] S. M. McCluskey, "Space Use Patterns and Population Trends of Southern Resident Killer Whales (*Orcinus orca*) in Relation to Distribution and Abundance of Pacific Salmon (*Oncorhynchus* spp.) in the Inland Marine Waters of Washington State and British Columbia," School of Aquatic and Fishery Science, Masters of Science, University of Washington, Seattle, 2006.

[6] R. W. Baird and B. M. Hanson, "Diet Studies of "Southern Resident" Killer Whales: Prey Sampling and Behavioral Cues of Predation," November 13, 2004 2004.

[7] J. K. B. Ford and G. M. Ellis, "Selective foraging by fish-eating killer whales Orcinus orca in British Columbia," *Marine Ecology-Progress Series,* vol. 316, pp. 185-199, 2006.

[8] B. M. Hanson*, et al.*, "Focal behavioral observations and fish-eating killer whales: Improving our understanding of foraging behaviors and prey selection," presented at the 16th Biennial Conference on the Biology of Marine Mammals, San Diego, California, 2005.

[9] A. R. Hoelzel, "Foraging behaviour and social group dynamics in Puget Sound killer whales," *Animal Behaviour,* vol. 45, pp. 581-591, 1993.

[10] M. M. Krahn*, et al.*, "Persistent organic pollutants and stable isotopes in biopsy samples (2004/2006) from Southern Resident killer whales," *Marine Pollution Bulletin,* vol. 54, pp. 1903-1911, 2007.

[11] NMFS, "Puget Sound Salmon Recovery Plan," vol. 2011, N. M. F. Service, Ed., ed. Seattle: National Marine Fisheries Service (NMFS), 2007.

[12] J. K. B. Ford*, et al.*, "Dietary specialization in two sympatric populations of killer whales (*Orcinus orca*) in coastal British Columbia and adjacent waters," *Canadian Journal of Zoology,* vol. 76, pp. 1456-1471, Aug 1998 1998.

[13] B. M. Hanson*, et al.*, "Species and stock identification of prey consumed by endangered southern resident killer whales intheir summer range," *Endangered Species Research,* vol. 11, pp. 69-82, 2010.

[14] R. W. Baird*, et al.*, "Factors influencing the diving behaviour of fish-eating killer whales: sex differences and diel and interannual variation in diving rates," *Canadian Journal of Zoology,* vol. 83, pp. 257-267, 2005.

[15] E. Ashe*, et al.*, "Animal behaviour and marine protected areas: incorporating behavioural data into the selection of marine protected areas for an endangered killer whale population
" *Animal Conservation,* vol. 1-8, 2009 2009.

[16] K. M. Parsons*, et al.*, "The social dynamics of southern resident killer whales and conservation implications for this endangered population," *Animal Behaviour,* vol. 77, pp. 963-971, 2009.

[17] R. Williams and E. Ashe, "Killer Whale Evasive Tactics vary with Boat Number," *Journal of Zoology,* pp. 390-397, 2007 2007.

[18] R. Williams*, et al.*, "Behavioral responses of male killer whales to a 'leapfrogging' vessel," *Journal of Cetacean Research and Management,* vol. 4, pp. 305-210, 2002 2002.

[19] R. Williams*, et al.*, "Estimating relative energetic costs of human disturbance to killer whales (Orcinus orca)," *Biological Conservation,* vol. 133, pp. 301-311, 2006.

[20] D. Lusseau*, et al.*, "Vessel traffic disrupts the foraging behavior of southern resident killer whales *Orcinus orca*," *Endangered Species Research,* vol. 6, pp. 221-221, March 2009 2009.

[21] W. W. L. Au*, et al.*, "Echolocation signals of free-ranging killer whales (*Orcinus orca*) and modeling of foraging for chinook salmon (*Onchorhynchus tshawytscha*)," *Journal of the Acoustical Society of America,* vol. 115, p. 9, 2004.

[22] D. D. W. Hauser, "Summer space use of Southern Resident killer whales (*Orcinus orca*) within Washington and British Columbia," Master of Science, School of Aquatic and Fishery Science, University of Washington, Seattle, 2006.

[23] D. Tollit and J. Wood, "SRKW PAM Protection Plan Draft Report," SMRUMarch 18, 2011 2011.

[24] J. Wood*, et al.*, "Review of Historical Information and Site-Specific Synthesis," The Whale Museum

SMRU Ltd.

Orca Network2009.

[25] S. P. n. SnoPUD, "Admiralty Inlet Pilot Tidal Project; Orca Passive Acoustic MOPP Analysis discussion draft," Snohomish PUD No. 1, Everett2011.

[26] PalisadeCorporation. (2011, 8/12/2011). *@Risk:Risk Analysis Software using Monte Carlo Simulation for Excel* [business webpage]. Available: http://www.palisade.com/risk/

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