Organizing Data for Regulatory Needs

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Tidal energy data collection and analysis

Who should read this paper?

This paper should be read by the community of researchers, Marine Renewable Energy (MRE) device and project developers, regulators, and stakeholders with an interest in MRE. The nature of the data collection and analysis has strong overlap with oceanographic data collection including the interpretation of underwater active acoustics and underwater video.

Why is it important?

This paper lays out a process for dealing with data that are collected to address the potential risk of marine animals colliding with rotating tidal turbines. It seeks to make sense of the potential DRIP – data rich, information poor – aspect of many different groups collecting data of marine animals around tidal turbines and organize those data so that they are accessible and helpful for enabling the permitting process needed to deploy tidal turbines.

The tidal energy industry cannot move forward efficiently until the concern around collision risk of marine animals with turbines is settled. There are many data collection efforts underway, but the industry and regulators have no clear path forward, and the research community needs guidance to ensure their work in this area is focused on the most important questions. This paper documents the work of a large international group of scientists working on a common goal.

MRE project developers can use the results of this paper to organize and seek information they will need for permitting processes, while the regulators will become aware of the resources available to help interpret the incoming information. The research community, who work closely with the authors, will continue to have direct access to the most recent and timely information needs of the industry.

About the authors

Dr. Andrea Copping is an oceanographer and senior advisor at Pacific Northwest National Laboratory (PNNL), and a faculty member at the University of Washington. She focuses on the environmental effects of marine energy and offshore wind development and the role that these effects play in technology development and project initiation. She has led international projects that share information on environmental effects of wave and tidal (Ocean Energy Systems-Environmental) around the world. She also leads research and development for the use of marine energy devices to power Blue Economy applications, including ocean thermal energy conversion and seawater air conditioning. Dr. Copping serves as an associate editor of *Coastal Management Journal*, on the editorial board for *International Marine Energy Journal*, and as an advisor to marine energy consortia in Ireland, Chile, Australia, and France.

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PROGRESSING TIDAL ENERGY THROUGH ORGANIZED DATA APPROACHES

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ABSTRACT

As the tidal energy industry reaches commercial status in parts of Europe and pre-commercial status in North America, more environmental data are being collected, and research studies continue to address the most difficult questions around risks to marine life and environment. Collision risk of fish and marine mammals, as well as diving seabirds and sea turtles, remain the most challenging tidal turbine interactions and the focus of extensive studies in many parts of the world. At the same time, questions around animal disturbance from acoustic output of turbine or electromagnetic fields from power export cables, as well as alterations of benthic and pelagic habitats need to be addressed to achieve regulatory permission to deploy and operate tidal farms. In addition, as marine energy projects scale up to large arrays, interactions like displacement of marine animals or entanglement in mooring lines will need to be investigated.

Working with 15 other nations, Ocean Energy Systems-Environmental has developed tools and frameworks to assist in organizing and applying data and information on potential risks from tidal turbines to permitting, mitigation, and licensing. Tools have been developed that organize data to match regulatory needs including risk retirement, data transferability, management measures, and guidance documents. This paper will discuss the application of these tools and frameworks.

Keywords: Tidal energy, environmental effects, collision risk, international cooperation, organizing data and information

1. INTRODUCTION

Development of tidal energy is progressing from early demonstration projects toward commercial status in parts of Europe and pre-commercial status in North America. Despite this progress, regulatory processes continue to be prolonged and complicated by a lack of certainty around potential effects of tidal devices on marine animals, habitats, and ecosystem processes [1]. Collision risk of fish and marine mammals, as well as diving seabirds and sea turtles, remain the most challenging tidal device interactions and remain the focus of extensive studies in many parts of the world [2]. After almost two decades of deployments and demonstrations of tidal devices in the ocean, data have been collected in close proximity to at least 42 tidal devices and numerical models have been generated to explain potential interactions and deleterious effects of rotating tidal blades on marine animals [3]. Challenges of collecting data in fast moving waters in close proximity to devices, lack of knowledge about populations and behaviour of marine mammals and fish at greatest risk, and a lack of standard approaches to gathering and analyzing data combine to create a challenge for regulators who evaluate potential risks, as well as device and project developers who seek approval for development [4], [5], [6]. The research community continues to address the key questions around collision risk but has little guidance on what data are needed to describe, minimize, and eliminate the risk from tidal turbines to marine animals.

With many independent research groups globally pursuing answers to collision risk and other concerns around tidal devices, as well as data collection by consultant teams at the request of device and project developers, a uniform means of collecting, collating, analyzing, interpreting, and reporting data is elusive. As tidal demonstration and commercial projects increase, there is an exponential increase in the number of datasets and outputs. This expansion has the potential to lead to DRIP – data rich, information poor – situation [7]. We have lots of data but what does it mean? Compounding this situation is the fact that almost all the data that have been collected around tidal devices comes from deployments of single devices or very small arrays [3]. Extrapolating these findings to larger arrays remains challenging, even while these large installations are under development [8].

The research community has used stressors and receptors to describe and measure interactions between marine renewable energy devices and the marine environment [9]. Stressors are those aspects of tidal energy that might cause stress, injury, or death to the receptors – marine animals, habitats, or ecosystem processes. When considering the interaction of marine animals and tidal turbines, the terms “avoid” has become commonly used to indicate that the animal can sense the turbine blade at a distance and take action to not come into close proximity, while “evade” is used when an animal does not sense the turbine until it is within a few body lengths of the blade and takes immediate evasive action.

While collision risk to marine animals remains the most difficult stressor-receptor interactions to address for tidal turbines, other key stressor-receptor interactions are also of importance in reaching regulatory permission to deploy devices. In particular, effects on marine mammals and certain fish species from the noise generated underwater by tidal devices, effects of electromagnetic fields from power export cables and energized portions of turbines, changes in benthic and/or pelagic habitats, displacement of animal populations from their normal routes or habitats, and potential changes in oceanographic conditions from the removal of energy and disruption of tidal flows must all be evaluated and assessed for risk to the marine environment [10].

International efforts to standardize engineering and power generation aspects of marine renewable energy devices are underway [11], but to date there has been no success in standardizing protocols for data collection and analysis of parameters of importance to marine animals, with the exception of the measurement of underwater noise [12]. It may not be possible to impose strict standard protocols for data collection and analysis globally in the near future, nor require the use of only certain instruments for obtaining the data; however, there is a clear need to standardize the way we look at the existing datasets, how they are used to inform regulatory processes, and how the collective tidal energy community interprets and mitigates potential risks. Numerical models are an important tool in furthering our understanding of the mechanics, the biology, and the outcomes of marine animals swimming in the vicinity of an operating turbine.

As additional environmental effects of tidal energy data have become available, there continues to be a disconnect between what the researchers and consultants collect and analyze and the inputs needed by regulators to assess risks. These risks help drive requirements for permitting, as well as mitigation conditions determined for development. These challenges remain the most difficult barriers to overcome to understand collision risk around tidal turbines and potentially retire the risk for each new project.

Ocean Energy Systems-Environmental (OES-Environmental) is a task under the International Energy Agency's Ocean Energy Systems (OES) Technology Collaboration Programme. Fifteen countries and the European Commission have signed onto OES-Environmental with the goal of understanding the potential environmental effects of marine renewable energy, including tidal energy, development, and operation, as they may affect regulatory processes for moving the marine renewable energy industry forward. OES-Environmental is led by the United States Department of Energy and implemented under the leadership of the authors of this paper at Pacific Northwest National Laboratory. OES defines the marine renewable energy industry as those devices that harvest energy from the movement of ocean water (tides, waves, persistent ocean current) or gradients in the ocean (temperature, salinity). This paper reports on the activities under OES-Environmental that have organized methods to handle data on the environmental effects of marine renewable energy development to maximize the utility and accessibility of those data to create information that informs and assists with the regulatory process. This paper focuses on those pathways and examples in support of the tidal energy industry.

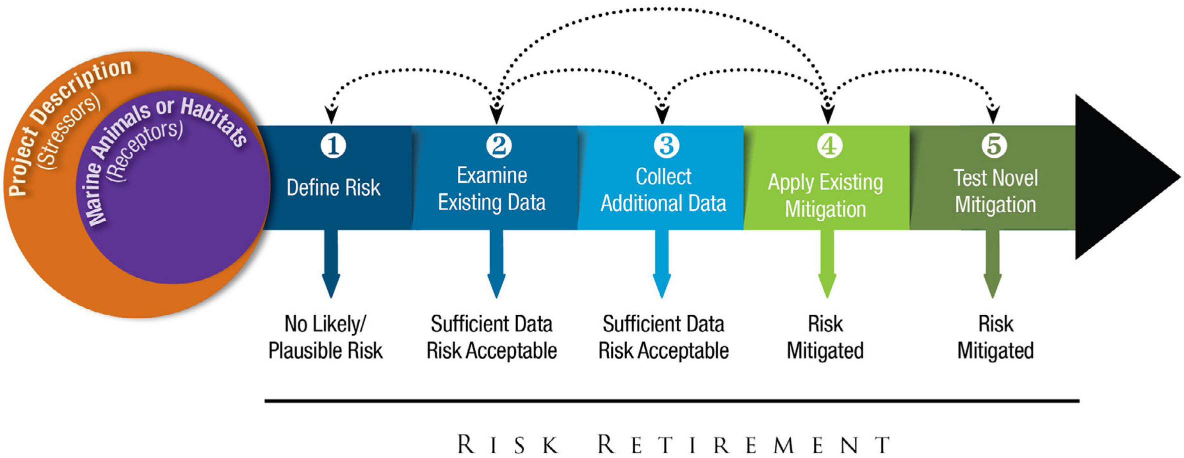

Figure 1: Schematic of the steps in the risk retirement process. Developed by OES-Environmental.

2. OES-ENVIRONMENTAL'S ORGANIZED DATA APPROACHES

In order to address the need for information for permitting marine renewable energy devices, OES-Environmental has developed the risk retirement process [13]. This process applies existing and newly collected data in an organized manner that will be useful for developers interacting with the regulatory process (Figure 1). This process is useful only as far as the data are accessible, of high quality, and consistent.

The approach that has been developed by OES-Environmental revolves around examining potential effects that may occur from the interaction of specific portions of a tidal energy system, as well as deployment, operation, or maintenance procedures that might affect the risk of collision with marine animals, notably marine mammals, fish, diving seabirds, and sea turtles. The interactions detail the stressor (that aspect of tidal energy that might cause stress, injury, or death to an animal) and receptors (the specific animal species), commonly known as stressor-receptor interactions.

The system of interlocking methods that has been developed by OES-Environmental fits into a framework of risk retirement – the concept that, for all new tidal projects, not all stressor-receptor interactions must be fully investigated, but should rely on information from existing permitted projects, surrogate industries, and research studies. The risk retirement process was described in [14]. The process assists developers in determining what data they might need to present for regulatory purposes, where they might find those data (existing data or data that must be collected), and how existing data might be applied.

Evaluating the relative risk of each stressor-receptor interaction within the risk retirement process requires the best available knowledge generated by other projects or studies. OES-Environmental has assembled the most relevant high-quality papers and reports for each of the stressor-receptor interactions and made them available as evidence bases (https://tethys.pnnl.gov/risk-retirement-evidence-bases). OES-Environmental adds to these evidence bases annually as new studies are completed and datasets become available. The

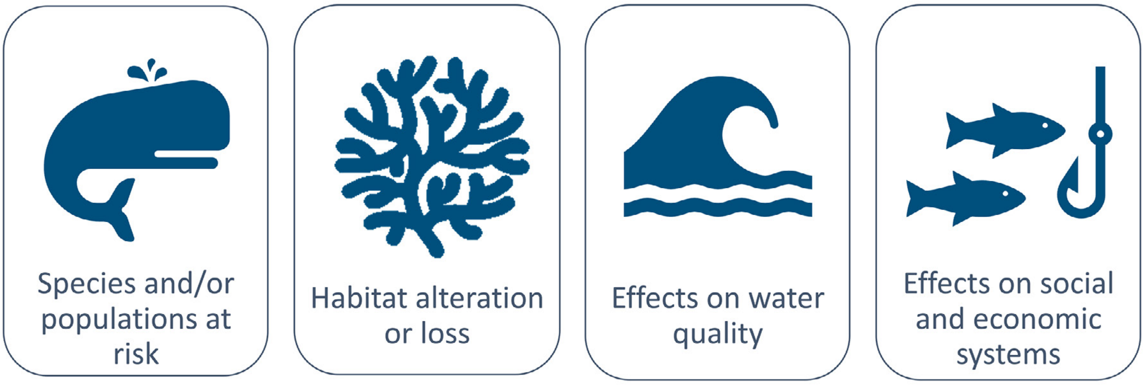

Figure 2: Four categories of legal and regulatory focus for permitting and licensing of tidal projects. Developed by OES-Environmental.

collision risk evidence base consists of 40 peer-reviewed journal papers, conference papers, and reports (https://tethys.pnnl.gov/collision-risk-evidence-base).

Coupled with the evidence bases for key stressor-receptor interactions is the need to determine effective mitigation measures, should they be needed. The management measures tool developed by OES-Environmental (https://tethys.pnnl.gov/management-measures) documents over 300 mitigation measures that have been required, tested, or suggested for permitting tidal or wave energy projects. These studies, field trials, and models are applied to the steps in the risk retirement process that indicates risk is still present after collection and analysis of data and comparisons with existing marine renewable energy projects.

OES-Environmental has addressed the disconnect between the data needed for tidal energy permitting and what is being collected in many monitoring programs through the development of guidance documents that relate the stressor-receptor interactions of marine energy (including tidal) devices to groupings of laws and regulations that govern permitting and licensing. Through an assessment within OES-Environmental member countries, it was determined that all regulations pertaining to marine energy fall into one of four groupings (Figure 2). All OES nations protect marine species and populations through a series of laws and regulations, most often focused on endangered species or species at risk. Habitat alteration or loss is often associated with determining the aerial extent and location of seabed leases or shoreline cable landings. Water quality effects are not as commonly used for marine energy permitting, but with the increased interest in using ocean temperature and salinity gradients for energy, as well as the application of antifouling coatings and paints to marine energy devices, water quality risks are being increasingly scrutinized. The potential effects and benefits of marine renewable energy development on local and regional communities is also taken into account in the regulatory process in most nations.

Guidance documents were created based on these groupings and consist of pathways that are useful internationally (Figure 3). In addition to the generalized guidance documents, stressor-specific guidance documents are available, as well as a series of

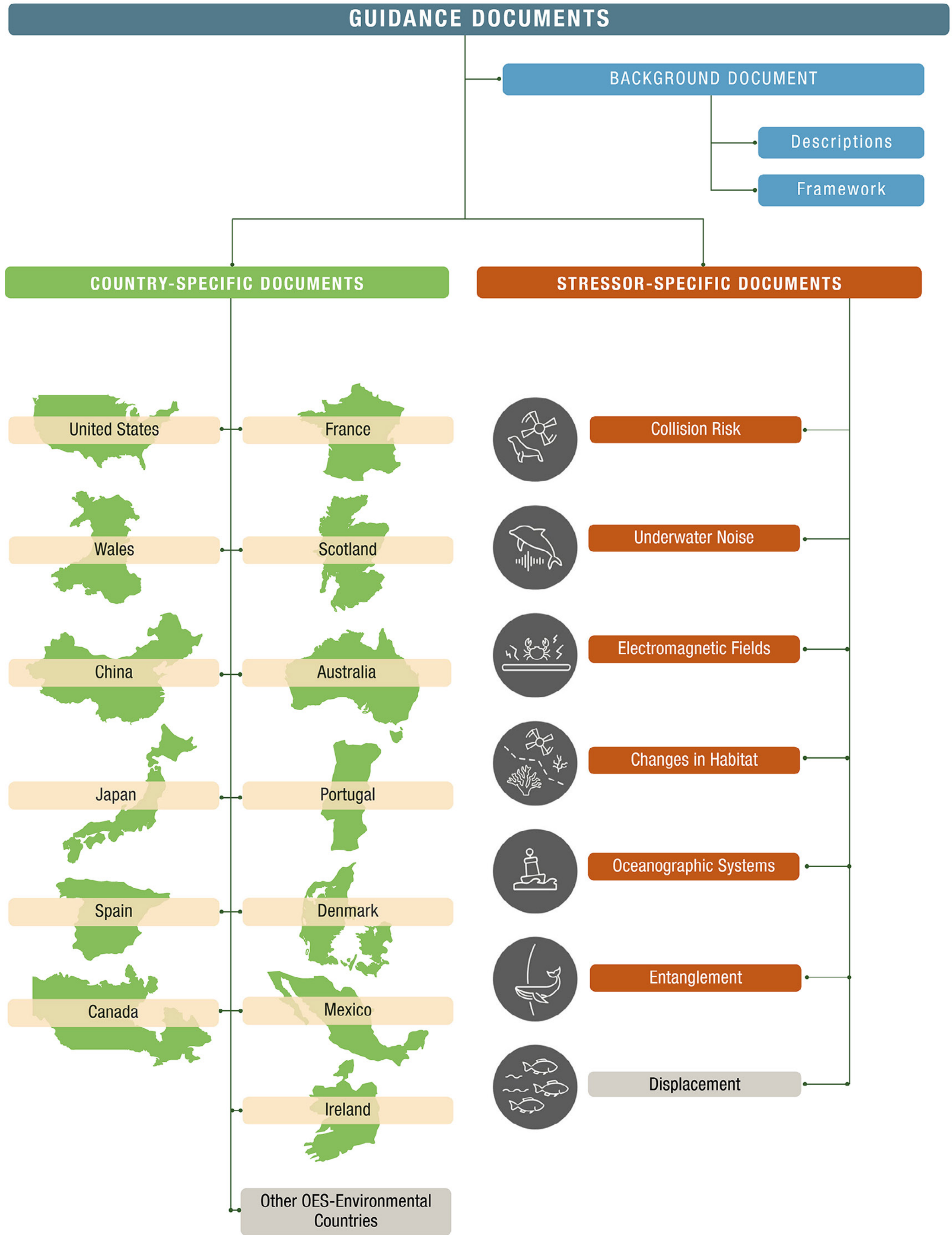

Figure 3: Guidance documents that help organize scientific information for use in permitting applications for marine (including tidal) energy. The background documents describe the process, while the stressor-specific documents bring together information that addresses each part of a tidal system. The country-specific documents provide more detail that is particular to the nation, while the best management practices for risk retirement help guide the user through the process. Developed by OES-Environmental.

country-specific guidance documents that demonstrate the nuances of regulation in each of the OES-Environmental nations (Figure 3). More detailed information is found at https://tethys.pnnl.gov/guidance-documents.

The final step in making data available and accessible was developed as a set of Best Management Practices (BMPs) for applying the risk retirement methods and models. The BMPs consist of guidelines for handling data and assessing data sufficiency and are written in a manner that is accessible and actionable for the marine renewable energy industry, regulators and advisors, and other stakeholders.

A use case consisting of a tidal turbine deployed in the Bay of Fundy, Canada, is analyzed using the risk retirement process and the results reported here. This process, as outlined in this paper, will be most useful to a device or project developer who seeks to gain regulatory permission to deploy a tidal device in the Bay of Fundy.

3. APPLICATION OF APPROACHES THROUGH A USE CASE

The risk retirement process developed by OES-Environmental consists of six steps: defining the risk; examining existing data; collecting additional data as needed; applying existing mitigation measures; testing novel mitigation measures; and finally, determining what can be done if residual unacceptable risk remains.

To demonstrate how the risk retirement process comes together to support the development of tidal energy, a realistic but not real-world tidal project in the Bay of Fundy was used in this paper to apply the risk retirement process to collision risk. Information that should be collected at each of these steps is applied to the tidal project. We begin by describing the project and identifying the animals and habitats potentially at risk. Here we use a floating tidal turbine anchored in 40 m of water. The floating body is held in place with three anchor lines, two lines at the bow and one at the stern. The floating body supports three two-bladed turbines that can be lowered for energy generation and raised for maintenance. Each rotor is 16 m in diameter; when lowered, the rotor swept area reaches a depth of approximately 22 m. Key receptors of concern in the area of the Bay of Fundy include Atlantic salmon, striped bass, white sharks, and harbour porpoise [15]. The risk retirement pathway was applied for the use case by examining each step in the process.

3.1 Define the Risk

For Atlantic salmon, striped bass, white sharks, and harbour porpoise in the Bay of Fundy, a collision with the rotating blades clearly defines a plausible risk as each species frequents the water column where the blades are deployed during energy generation [15]. Regulators may request additional baseline data collection to verify that the marine animals of concern are present at the planned tidal deployment location. Deploying at test sites and other well-characterized sites may help lessen this baseline collection need.

By comparing similar potential encounters found in the collision risk evidence base (https://tethys.pnnl.gov/collision-risk-evidence-base), this risk must be considered plausible rather than likely as many additional factors must align for a collision to occur, as discussed in the following section [2]. Based on the potential risk, the developer must continue to gather information to evaluate the risk of collision.

3.2 Examine Existing Data

The additional factors that must be considered for a collision to occur include the need for the fish (salmon, bass, and shark) or marine mammal (porpoise) to be swimming at the particular depths of the turbine, in order to be struck while the blades are rotating, which only occurs during part of each tidal cycle. In addition, the animals must have little to no ability to detect and avoid or evade the blades. Existing data from laboratory studies, field observations, and numerical models demonstrate a reasonable likelihood that many species of fish will pass close to or even through the rotor swept area of a turbine without harm [16], [17], [18], [19]. Some fish species appear to avoid or evade an underwater device such as a tidal turbine, while others may be subject to hydrodynamic forces that prevent them from being struck by the blades [20]. Similar studies support the ability of marine mammals, including harbour porpoise, to detect and avoid/evade a collision [5], [6], [21]. Existing datasets from the United Kingdom and elsewhere could help provide insight into the likelihood of collision with the tidal turbine blades for fish and marine mammals in the Bay of Fundy. These datasets can be gleaned from the data transferability process, through providing the key parameters of the project (e.g., tidal device, depth envelope, channel width; https://tethys.pnnl.gov/monitoring-datasets-discoverability-matrix).

While there are considerable indications in published literature that the risk of collision with a tidal turbine blade is likely to be very low, this risk cannot be ruled out. Hence, the developer must consider the need to collect additional data.

3.3 Collect Additional Data

The goal of open communication between researchers and developers in the tidal energy community is to ensure that sufficient information is developed to meet the needs of permitting specific tidal projects. This should include sufficient information to understand and mitigate effects of collision risk universally, but must also be tailored to different deployment sites, water bodies, and species, as well as the specific tidal device proposed for deployment. However, variable ocean conditions, differing latitudes and weather conditions, and regional differences in species distributions will require that local conditions be considered, most commonly with the collection of additional data.

Regulators in the Bay of Fundy region are likely to require that site-specific information be compiled to determine the level of risk that will guide their decisions on permitting and licensing the tidal project. The tidal developers and their consultants can anticipate this need by examining the guidance document that pertains to collision risk [22]. While standardized collection and analysis methods continue to evade the marine renewable energy research community, the data transferability process provides the first steps in designing an effective field effort to collect those data through the data collection consistency table (https://tethys.pnnl.gov/data-transferability).

The developer and their consultants should be prepared to design and implement a monitoring campaign that consists of sufficient data collection before deployment to ensure that the presence, movement, behaviour, and seasonality of the marine animals of concern are known for the planned deployment area. In addition, a post-deployment collision risk monitoring campaign may be required for the operational phase of the project, which can best be designed using information from other tidal projects and research studies (e.g., [5], [23], [21]) as well as the results of numerical models that simulate encounters of marine animals with turbines (e.g., [16], [24]).

Despite these data collection efforts, regulators and stakeholders may continue to be concerned about potential collisions and may require investigations into mitigation measures. Collision risk cannot be considered "retired" or set aside, unlike other stressor-receptor risks for single devices [10] (such as underwater noise and electromagnetic fields).

3.4 Apply Existing Mitigation

As tidal energy projects continue to expand in the UK and Europe, there have been investigations into how any remaining risk of collision might be lessened for marine animals by implementing mitigation measures. The management measures tool developed by OES-Environmental (https://tethys.pnnl.gov/management-measures) is a searchable database that will allow a tidal developer to examine the range of proposed or implemented measures, filtering by the project phase (installation, operation, maintenance, decommissioning), and the receptor group (fish, marine mammals, etc.). It is important to note that many of these mitigation measures have never been enacted, largely because they were found to be unnecessary or unfeasible. Some of the mitigations that might make sense in the Bay of Fundy include the use of acoustic deterrent devices that create a sound that alerts marine mammals and fish with hearing capabilities to the presence of the turbine, enhancing their ability to avoid or evade the blades. This has been proposed in the UK, drawing on experience with keeping seals away from aquaculture pens [25] [26]. Coloured blades have been used successfully in shallow water applications at the European Marine Energy Centre to assist marine animals in seeing the turbine [27]. Soft start procedures for slowly bringing the turbine up to speed have also been suggested as a way to make the animals aware of the turbine and move out of the area before it reaches full operational speed [27].

Should mitigation be considered necessary, and existing measures not be deemed sufficient, the development and testing of new mitigation measures may become the purview of the research community.

3.5 Test Novel Mitigation

There is room for new and different collision risk mitigation measures to be tested either as a direct obligation under a regulatory process or in forward-thinking research. Mitigation measures that have been discussed as part of permitting and licensing procedures in the UK, Europe, Australia, Canada, and the US but never tested include decreasing the tip speed of the turbine blades to make the reaction time for animals less urgent, and the ability to stop the turbine in real time with a detection system, triggered when sensitive species are present.

3.6 Changes to Tidal Project

Eventually, if the tidal developer, working with the regulators, determines that the risk retirement process steps (i.e., examining existing data, collecting new data, evaluating existing mitigation strategies, and testing novel mitigation strategies) are not sufficient to avoid significant risk to the marine animals of concern, there is cause to re-examine the tidal project itself. Modifications to the design of the project might include changing the planned deployment location, making alterations in the design and/or operation of the turbine, or modifying the installation or maintenance procedures. If none of these actions can reduce the risk sufficiently, the project in its proposed form may need to be abandoned.

4. DATA COLLECTION, ANALYSIS, STORAGE, AND ACCESSIBILITY

True standardization and universally accepted protocols for collecting data on animal behaviour and tidal blade encounter around tidal energy projects is challenging. These fast-moving and often turbid environments have been the location of an increasing number of research studies. The use of underwater cameras and video, as well as a range of active acoustic instruments, appears to provide the best data [3], [10]. Underwater still and video cameras are limited to shallow, clear water for the most part, although the use of strobe lights triggered by the movement of animals can extend their use into deeper water and/or nighttime. Acoustic cameras, echosounders, and a series of other sonar devices all provide useful data about nearfield encounters and potential collisions with tidal turbines [28]. In addition to the challenges of collecting the data, video and acoustic instruments collect vast amounts of data that must be analyzed, often slowing or requiring frequent subsampling, and needing vast human and financial resources [8]. The best professional judgement gathered by OES-Environmental recommends the development of more open-source data collection approaches as a community [10]. These approaches should include:

- A means to lower the "data mortgage" with smart systems that record data only when movement of marine animals occurs around a turbine.
- Increased use of existing video and acoustic datasets near turbines to understand the movement and mechanisms of potential harm to animals.
- Improvements to our ability to recognize species using acoustic data.
- Use of animal-mounted tracking devices to gather data, where feasible.
- Use of numerical model outputs to design and interpret field data.
- Improvements to understanding marine animal use of an area before a tidal project is initiated.

In addition, ensuring that collision risk studies and associated data are made accessible to all users is key to solving the collision risk puzzle. Researchers must be responsible for quality assurance of their data, but common repositories with strong capabilities for curation and long-term storage as well as active outreach to ensure accessibility are necessary. One such example is the integrated PRIMRE system in the US that houses data and information on all aspects of marine renewable energy development (https://openei.org/wiki/PRIMRE), allowing for comparison and integration of environmental information and data that are stored in the environmental knowledge hub Tethys (https://tethys.pnnl.gov/) with engineering, modelling, geospatial, and guidance data that can be used to assist in understanding and mitigating potential harm to marine animals [29].

5. USE OF MODELS IN COLLISION RISK

Collision risk and encounter risk models have been in use for more than a decade [16], [30], [31], although many have been adapted from collision and encounter risks for birds around wind turbines and continue to need refinement and parameterization that is more appropriate for tidal turbines and marine animals. Newer modelling approaches include agent-based models that are organized around individual animals [32]. While there is general consensus that there is a need to improve the working of all the existing models, the greatest need is for more field data for calibration and validation that will increase the realism of the models [24], [10]. As these models improve and are validated with additional data, they can be used to plan field campaigns by optimizing sampling locations and timing. The goal of these models is to ensure that they are sufficiently robust to use in most tidal energy locations and begin to replace most, if not all, monitoring of interactions between marine animals and tidal turbines. However, that time has yet to come.

6. SCALING UP TIDAL ARRAYS

The knowledge that has been gained on the potential for marine animals to collide with rotating tidal turbine blades comes largely from monitoring around single deployed devices, small arrays such as those of Ampeak Energy, formerly SAE Renewables, (MeyGen, in Pentland Firth, Scotland) and Nova Innovations (Blue Mull Sound, in the Shetland Islands, Scotland), as well as from models and research studies. As the tidal energy industry seeks to scale up to larger commercial arrays, much of what has been learned at the smaller scale will be applicable but how those potential effects will extrapolate is not clear [34]. Monitoring around multiple tidal devices will be needed to ensure that our understanding of collision risk scales as anticipated, and, in some locations, additional site-specific monitoring may be needed as well.

7. CONCLUSION

In order for the tidal energy industry to become firmly established as a renewable energy source, the risk of collision with marine animals must be well understood and the information must be made widely available to regulators and stakeholders. The state of our knowledge is not yet there, and the circular problem of not having enough permitted tidal turbines in the water around which to gather data to improve our state of knowledge remains as a considerable barrier. The tidal energy community as a whole – developers, researchers, regulators and advisors, and other stakeholders – must collectively push for more research to narrow the uncertainty around collision risk [10]. That research can only move forward efficiently if there are deployed devices around which monitoring can take place.

Frameworks such as OES-Environmental's risk retirement process and associated tools can help organize and increase the value from data and information that is available, help identify the gaps in knowledge that will drive research studies toward decreasing the uncertainty, and anticipate the use of new information.

The tidal energy industry continues to be most affected by the lack of comprehensive knowledge about collision risk, and the research community seeks to focus available public funds on answering the most pressing questions. Regulators suffer from this uncertainty as well, torn between the need for reliable renewable energy sources and their mandates to protect natural resources. Other stressor-receptor interactions also feature in the regulatory processes and must be shown to be acceptable. Through the risk retirement process, questions around animal disturbance from acoustic output of turbines and electromagnetic fields from power export cables as well as alterations of benthic and pelagic habitats have been "retired" for small tidal deployments [14], [33]. As new information becomes available with an increase in deployed arrays, this information will need to be revisited. In addition, as tidal energy projects scale up to large arrays, interactions like displacement of marine animals or entanglement in mooring lines will need to be investigated [8], [4].

The use of strategies such as the risk retirement process outlined here will not completely solve the DRIP problem nor settle all concerns about collision risk to marine animals from rotating tidal blades. However, with continued open communication, sharing of data, and broad accessibility of information among the marine renewable energy community, collision should become a manageable risk for device and project developers, regulators and advisors, and stakeholders.

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Authors' Declaration

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- Competing interests: The authors declare that they have no competing interests.
- Availability of data and materials: Datasets used and/or analyzed during the current

study are available from the corresponding author upon reasonable request.
- Artificial intelligence was not used in this work.

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