Journal of
Marine Science and Engineering

Article

Triton Field Trials: Promoting Consistent Environmental Monitoring Methodologies for Marine Energy Sites

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Abstract: Uncertainty surrounding the potential environmental impacts of marine energy (ME) has resulted in extensive and expensive environmental monitoring requirements for ME deployments. Recently, there have been more ME deployments and associated environmental data collection efforts, but no standardized methodologies for data collection. This hinders the use of previously collected data to inform new ME project permitting efforts. Triton Field Trials (TFiT), created at the Pacific Northwest National Laboratory by the United States (U.S.) Department of Energy, explores ways to promote more consistent environmental data collection and enable data transferability across ME device types and locations. Documents from 118 previous ME projects or ME-related research studies in the U.S. and internationally were reviewed to identify the highest priority stressor–receptor relationships to be investigated and the technologies and methodologies used to address them. Thirteen potential field sites were assessed to determine suitable locations for testing the performance of relevant monitoring technologies. This introductory paper provides an overview of how priority research areas and associated promising technologies were identified as well as how testing locations were identified for TFiT activities. Through these scoping efforts, TFiT focused on four activity areas: collision risk, underwater noise, electromagnetic fields, and changes in habitat. Technologies and methodologies were tested at field sites in Alaska, Washington, California, and New Hampshire. Detailed information on the effectiveness of the identified methodologies and specific recommendations for each of the four focus areas are included in the companion papers in this Special Issue.

Keywords: marine energy; data transferability; environmental monitoring; collision risk; underwater noise; electromagnetic fields; changes in habitat

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Citation: Eaves, S.L.; Staines, G.; Harker-Klimeš, G.; Pinza, M.; Geerlofs, S. Triton Field Trials: Promoting Consistent Environmental Monitoring Methodologies for Marine Energy Sites. *J. Mar. Sci. Eng.* **2022**, *10*, 177. https://doi.org/10.3390/jmse10020177

Academic Editors: Domenico Curto and Barbara Zanuttigh

Received: 1 December 2021
Accepted: 26 January 2022
Published: 28 January 2022

1. Introduction

Marine energy (ME), which includes wave, tidal, ocean current, free-flowing river, and ocean thermal energy conversion, is an emerging renewable energy source. However, the uncertainty surrounding the potential environmental impacts of ME commonly resulted in extensive and expensive environmental monitoring requirements for the first devices to be deployed at test sites and in fully energetic wave and tidal systems [1,2]. Current aquatic environmental monitoring technologies and methods may not be sufficient to answer the questions necessary to secure permits for deployment. Traditional oceanographic monitoring technologies are not designed to function optimally in the high-energy, low-light conditions where ME devices would be sited. The adaptations of existing technologies or the development of new technologies are needed to effectively address the monitoring requirements [3,4].

In 2013, the United States (U.S.) Department of Energy (DOE), Water Power Technologies Office sponsored a workshop to examine the capabilities of and gaps in current environmental monitoring technologies for ME, and to identify potential solutions for the most prominent environmental concerns. The overarching findings of the workshop were that there is a significant need for (1) the automation of data processing and analysis, (2) the improvement of the deployment and survivability of monitoring technologies, and (3) the likely combination of instrumentation into integrated monitoring packages to collect the necessary data and cost-effectively meet the monitoring objectives [3].

Continuous monitoring to assess the environmental footprint of ME devices or detect rare events, such as the direct physical interactions between marine animals and ME devices, generates large amounts of data that are time-consuming and cost-intensive to process and analyze. Modifications are needed to reduce the total amount of data collected. Additionally, automated data-processing methods are needed to reduce the associated time and cost while improving the consistency of data analysis.

Since 2014, the DOE has devoted efforts to improving the technical performance and reducing the costs associated with environmental monitoring technologies to address the regulatory and scientific needs of the ME community. Through funding opportunities in 2014 and 2016 and work at the national laboratories, the DOE supported several environmental monitoring technology development projects. The 2014 funding opportunity provided support for the development of new instrumentation, associated processing tools, and integration of instrumentation packages for the monitoring of the environmental impacts of ME. The 2016 funding opportunity provided support for additional innovative improvements, testing, and the validation of environmental monitoring technologies and the associated data-processing software in representative field environments. The end goal of this funding opportunity was to provide the ME community with commercially available monitoring technologies.

In 2015, the DOE established the Triton Initiative (hereafter Triton) at the Pacific Northwest National Laboratory's (PNNL's) Marine and Coastal Research Laboratory (MCRL) to provide an objective, third-party facility at which new monitoring technologies produced by DOE-sponsored funding opportunities could be tested and evaluated. Triton provides additional resources in pre-permitted field-testing locations and field-testing support (e.g., vessels and other infrastructures). This allows funding opportunity awardees to focus their time and funds on performing technical improvements, thereby simplifying the development and testing process [5]. Since its inception, Triton has provided testing and technical support for 11 DOE-funded projects.

In 2018, the scope of Triton was expanded to find ways to promote more consistent environmental data collection and enable data transferability across ME device types and locations. While the number of ME deployments worldwide has increased in recent years and the data examining key environmental concerns has been collected, there is still a tendency for regulators to request that each new proposed development collect a wide range of data to address all environmental concerns. This can include low-level risk concerns for a device or location if regulators are unsure of how to quantify and assess potential effects when there is little other information for comparison. Data collection to address regulatory concerns adds to the time and cost of the permitting process [2]. However, consistently collected data from current projects may help to eliminate the need for extensive data collection at future deployments through data transferability (i.e., using information from one location or one device to inform the assessment of another) [6,7].

One factor preventing the transferability of data is the different ways by which data are collected, such that the results are not directly comparable across the sites or ME devices. Apart from data collected about ME-generated underwater noise [8], there are no industry standards for data collection related to the most common environmental concerns surrounding ME, and this lack of standardization has led to the use of a wide variety of instrumentation and methodologies [4,9]. In an analysis of more established renewable and offshore industries, Kramer et al. [10] noted that the formation of guidance, protocols, and siting tools helped ease environmental permitting.

A framework and online tool for the ecological risk assessment of three specific types of wave energy converters was recently developed within the context of European laws with input from European regulators [11]. Based on the characteristics of the wave energy converter and the deployment site, the tool provides an insight on the relative level of risk associated with a variety of potential stressors [11]. This could be useful during permitting negotiations to determine which environmental stressors should be monitored. Unfortunately, there are still no industry standards or even widely accepted practices for how these stressors should be monitored.

The Triton Field Trials (TFiT) project was created to address the lack of standard instrumentation and methodologies for addressing common environmental concerns faced by the ME industry. This paper serves as an introduction to TFiT, providing information on how the priority environmental concerns and promising monitoring technologies to be evaluated by TFiT activities were identified. It also details how the sites for field testing activities were chosen. Detailed evaluations of the identified monitoring technologies and methodologies, as well as recommendations for the monitoring of four common environmental concerns, are contained within the companion papers included in this Special Issue. The adoption of these recommendations by the larger ME community would enable a comparison among deployment sites and ME device types. The recommendations also consider how the data are most effectively used in models, and how the model results could be transferable between projects and verified by using targeted site-specific data collection, thereby enabling cost savings for the ME projects.

2. Materials and Methods

2.1. Identification of Environmental Concerns

Previously permitted ME and offshore wind projects around the world were identified via the Tethys knowledge base, and the categories of stressors and receptors [12–14] monitored in each project were noted. The methods and sensors used to monitor the variables within each of the categories were also noted.

A related International Energy Agency Ocean Energy Systems (OES) project led by PNNL, OES-Environmental, conducted targeted outreach efforts with U.S. regulators to determine the priority environmental concerns and develop a framework for the transferability of environmental data among projects [6,7,15]. This work identified six stressors of high concern as defined in Table 1 in Section 3.1.

Table 1. Stressors of concern for ME and relevant receptors.

Stressor of Concern	Description	Relevant Receptor Categories
Collision Risk	The potential for marine animals to collide with tidal or river turbine blades, resulting in injury or death. There is a high degree of uncertainty about the probability or consequence of collision, especially for populations afforded special protection.	Marine Mammals and Sea Turtles, Fish, Birds
Underwater Noise	The potential for acoustic outputs from wave or tidal devices to interfere with marine mammal, sea turtle, and fish communication or navigation, alter behavior, or cause physical harm remains uncertain. This risk is focused on the longer-term operational sound of devices.	Essential Fish Habitat, Fish, Marine Mammals and Sea Turtles, Birds

Table 1. *Cont.*

Stressor of Concern	Description	Relevant Receptor Categories
Electromagnetic Fields (EMFs)	EMFs emitted from power export cables and energized portions of ME devices may affect EMF-sensitive species by interrupting their orientation, navigation, or hunting abilities. Cables have been deployed in the ocean for many decades, yet concerns about the effects of the cables associated with ME devices persist.	Benthic Resources, Fish, Essential Fish Habitat, Marine Mammals and Sea Turtles
Changes in Habitat	Placement of ME devices may alter or eliminate the surrounding habitat, which can affect the behavior of marine organisms. The relatively small footprint of ME devices is unlikely to affect animals or habitats differently than other, well-studied industries, but regulators and stakeholders continue to express concern.	Physical Oceanography, Geologic Resources, Benthic Resources, Fish, Essential Fish Habitat, Marine Mammals and Sea Turtles, Birds
Displacement of Marine Animal Populations	The placement of a single ME device is unlikely to cause the displacement of marine animal populations, but there are concerns that larger arrays could displace animals from critical foraging, mating, rearing, or resting habitats. There are also concerns that large arrays might create a barrier to movement or migration.	Fish, Essential Fish Habitat, Marine Mammals and Sea Turtles, Birds
Changes in Physical Systems	ME devices may alter natural water flows and remove energy from physical systems, which could result in changes in sediment transport or water quality. Models indicate that the impacts from single devices are too small to be measured, but should be revisited once large arrays of ME devices are deployed.	Physical Oceanography, Geologic Resources, Water Quality, Benthic Resources, Fish, Essential Fish Habitat, Marine Mammals and Sea Turtles, Cultural Resources, Marine Uses

2.2. Identification of Suitable Field Sites

To produce environmental monitoring methodology recommendations that would be useful to the larger ME community, TFiT strove to field test instrumentation at multiple sites that featured different biological and physical characteristics. Data collection under diverse conditions would enable TFiT to provide recommendations about the extent of data collection consistency and a summary of the effective methodologies.

The focus was on identifying sites in the U.S. with different conditions that would be suitable for ME development. The geographic area was initially limited to the states of Oregon (OR), Washington (WA), and Alaska (AK) to address logistical limitations. The U.S. Federal Energy Regulatory Commission (FERC) docket provides locations for hundreds of proposed ME projects that have completed the preliminary permit process. A complete list of preliminary permit submittal records compiled by O'Neil et al. [16] was used to filter the FERC docket library for proposed sites located in or near Oregon, Washington, and Alaska. Forty-seven project dockets were found and filtered for accessible road access, ease of research vessel launching, distance from PNNL's MCRL, and their likelihood to be affected by other ocean users (e.g., shipping). The refined list had nine sites. Further internal discussion added 4 more for a total of 13 (Table 2). No preliminary permit has been submitted for Sequim Bay, but it is a currently permitted location for field operations at MCRL. This location does not have a substantial wave, tidal, or in-river resource, but the Sequim Bay channel has moderate energy levels and provides a good interim site where the wet-testing of sensors can be performed in the absence of a high-energy environment, and the channel site can provide a meaningful transition from bench testing to energetic site testing. Furthermore, there was no preliminary permit for Marrowstone Island (tidal site), Clallam Bay (wave site), or Neah Bay (wave site). However, based on the published literature [17], the knowledge of these sites, their potential tidal and wave resources, and proximity to MCRL, they were added as potential test sites.

Table 2. Five categories were assessed and assigned a score of good (green (2)), neutral (yellow (1)), or challenging (red (0)). A cumulative score was determined for each site, with higher scores indicating a better site. NA = no significant resource. * indicates the finalists considered for TFiT testing sites based on parameter evaluation.

	Resource Type	**Resource Potential**	**Accessibility**	**Other Users**	**Permitting and Threatened Species**	**Known Physical and Biological Characteristics**	**Site Cumulative Score**
Admiralty Inlet, WA	Tidal	2	2	0	0	2	6
Cook Inlet, AK	Tidal	2	0	1	1	1	5
Deception Pass, WA	Tidal	1	2	1	1	1	6
Marrowstone Island, WA *	Tidal	2	2	2	1	1	8
San Juan Channel, WA	Tidal	2	2	0	0	1	5
Sequim Bay Channel, WA *	Tidal	1	2	1	2	2	8
Tacoma Narrows, WA	Tidal	2	2	1	1	1	7
Clallam Bay, WA *	Wave	1	2	2	1	1	7
Makah Bay, WA	Wave	2	1	0	1	1	5
Neah Bay, WA *	Wave	2	2	1	1	1	7
PacWave Test Site, OR	Wave	2	0	1	1	2	6
Igiugig Village, AK *	In-River	2	0	2	2	2	8
Tanana River Test Site, AK *	In-River	2	1	2	2	2	9
Sequim Bay, WA *	NA	0	2	2	2	2	8

To narrow the list of sites, five parameters were evaluated: (1) energy resource at the site, whether tidal, in-river, or wave; (2) site accessibility; (3) competing uses that may affect the field operations; (4) permitting tasks and threatened species in the area; and (5) known physical and biological characteristics from previous research, management, or baseline data collection. Information sources, including the FERC docket site documentation, peer-reviewed literature, endangered, threatened, and marine mammal species listings, local expertise, and internal PNNL expertise were evaluated to assign each parameter a score of good (green (2)), neutral (yellow (1)), or challenging (red (0)). A cumulative score was determined for each site, with the highest being representative of the best sites for TFiT methodology testing. The result of this scoring exercise and finalist sites for TFiT activities are presented in Table 2. The finalist testing sites included Marrowstone Island, WA, and the Sequim Bay channel, WA, for the tidal sites; Clallam Bay, WA, and Neah Bay, WA, for the wave sites; and Igiugig Village on the Kvichak River, AK, and the Tanana River Test Site, AK.

After the short list of test sites was generated, specific information about the types of activities that could be performed, the local sensitive habitats or species of concern, potential limitations, and what permits may be needed, along with the responsible agencies, were collated.

2.3. Identification of Methods to Be Evaluated

A comprehensive review of the existing technologies and assessment methods that have been used to date with ME projects was performed to identify which technologies and methods should be considered for evaluation under the TFiT project. Project information was grouped into U.S.-based studies and international (all other countries) studies.

The environmental monitoring performed as of 16 July 2019, technologies, and methods used for existing ME projects were evaluated using the marine energy environmental database, Tethys, and internal PNNL knowledge of current projects not yet available on Tethys. Emphasis was placed on the methods that were used most often, and any differences in the record between the U.S. and global methods were noted. A data matrix was populated for each project listed on the Tethys knowledge base and/or map viewer. The matrix data were gathered from each project's Tethys web page, which was initially provided either by the project developers or the OES-Environmental country analysts. More details about specific projects were extracted from the literature, such as the environmental impact assessments, monitoring reports, or research articles, when available. Updates and documentation were requested from the responsible developers or consultants when little information was available. For the U.S.-based deployments under FERC jurisdiction, additional project documents were accessed via the FERC E-Library and examined for additional information. This search effort led to the evaluation of 118 ME projects (proposed, active, or completed) (Supplementary Table S1) for environmental impact assessment and monitoring methods.

Information from the populated data matrices was transferred to a Microsoft Access database to take advantage of organization and query options. Using the database, the most prevalent method/sensor for each stressor was determined. Technologies were grouped into broader categories, some of which are not actual technologies, e.g., “desktop studies” mainly refers to literature reviews and/or consultations with stakeholders to aggregate existing information and determine if field work is needed, and, if so, what that should entail; “human observers” mainly refers to land-based or vessel-based marine mammal or bird observations as well as aerial surveys and diving censuses. Additionally, any differences in the prevalent methods used in U.S. projects compared to the international record were noted either anecdotally or quantitatively.

As instrumentation and field-testing plans were finalized for each environmental concern, feedback was also gathered from the subject matter experts to ensure the most appropriate methodologies were evaluated during field testing.

3. Results

3.1. Identification of Environmental Concerns

The receptors of concern that were monitored during previously permitted ME and offshore wind deployments generally fell into the following categories outlined in the Block Island Wind Farm (BIWF) Construction and Operations Plan [18]:

- Physical oceanography;
- Geologic resources;
- Water quality;
- Benthic resources;
- Fish;
- Essential fish habitat;
- Marine mammals and sea turtles;
- Birds;
- Cultural resources;
- Marine uses.

The categories from the BIWF [18] are organized by receptor. To date, the efforts by Triton and the ME community have focused on measuring the stressors that affect the receptors. Thus, it is important to first establish strong definitions for each stressor and then begin forming a foundational understanding of each one. The outreach work of OES-Environmental identified six stressors of high concern for ME. A brief description of the stressors and applicable receptors is detailed in Table 1.

3.2. Identification of the Suitable Field Sites

The initial site screening produced seven potential tidal testing sites, four potential wave test sites, and two in-river test sites. This list was further refined using the criteria in Table 2 to identify the top two tidal, wave, and in-river test sites.

After considering the logistics, environmental conditions, and permitting concerns, the short list of potential field sites (Table 2) was further down-selected to include Sequim Bay, Sequim Bay channel, Clallam Bay, and Tanana River. All but Clallam Bay were previously used to test ME devices. Clallam Bay is close to PNNL’s MCRL, providing easy access to a small wave resource. Permitting for all sites was either complete or had been performed in the past for similar applications, so the requirements and expectations were already established. The comprehensive environmental permits obtained by PNNL covered specific types of activities in Sequim Bay, Sequim Bay channel, and Clallam Bay. For the test locations off the PNNL campus, specific knowledge of site-specific resource managers, regulators, and consultations needed for additional activities were all known. The Tanana River test site had approved permits to perform numerous activities, including the testing of turbines and physically sampling fish.

3.3. Identification of the Methods to Be Evaluated

An assessment of the most used methodologies and technologies for each stressor was performed to determine the potential candidates for evaluation under the TFiT project.

3.3.1. Collision Risk

A total of 77 studies (13 U.S. studies, 64 international studies) were examined for the technologies and methodologies used to address collision risk. There is some variation in the technologies used to conduct the monitoring for the collision of animals with ME devices. The record shows numerous desktop studies and several instances using models (Table 3). Some studies used passive acoustics for marine mammal vocalizations, but this type of data only provides information about mammal presence in the area, not a direct observation of a possible collision event. Likewise, human observers provide visual observations of abundance or density, which can inform collision risk, but do not directly measure collision occurrences. The main technologies used for the direct observation of collision were optical camera (mostly video but some still image), acoustic camera, multibeam echosounder, and echosounder. Sensors attached directly to ME devices, such as accelerometers and strain gauges, were also included, but they did not allow for the direct observation of an event unless they were combined with an optical or active acoustic sensor.

Table 3. Number of studies using methodologies and technologies to assess the collision risk grouped by U.S. and international (all other countries) projects.

Technology	U.S.	International
Acoustic Camera	2	2
C-PODS	0	2
Desktop Study	2	18
Device Sensor	0	5
Echosounder	2	3
Human Observer	4	14
Hydrophone	0	2
Image Camera	1	3
Model	1	7
Multibeam Echosounder	0	1
T-PODS	0	1
Video Camera	1	6
Total	13	64

Projects in the U.S. tended to use modeling and desktop studies of collision risk less often than the international projects. In addition, the number of human observer efforts were higher than the other methods used in the U.S., but as previously mentioned, this method is not likely to directly observe a collision event. Among the technologies capable of collision detection, acoustic and optical cameras and echosounders were cited most for U.S. and international applications.

Outreach work through OES-Environmental provided evidence from stakeholder groups that video and acoustic cameras are the most useful for collision or near-miss event detection at turbine installations [3,19].

Based on the census of the methodologies and technologies used to assess collision risk, TFiT determined it would use a high-resolution Sound Metrics, ARIS 3000 acoustic camera for the collision risk field trials. Staines et al. [20] fully evaluated the effectiveness of this methodology and provides recommendations for implementation in a companion paper included in this Special Issue.

3.3.2. Underwater Noise

A total of 73 studies (9 U.S. studies, 64 international studies) were examined for technologies and methodologies to address underwater noise. To measure underwater sounds, hydrophones and associated equipment for amplifying, processing, and storing data were the most cited in the record, both in the U.S. and internationally (Table 4). There are commercial varieties as well, such as C-PODS or T-PODS (underwater acoustic animal detection data loggers), and various passive acoustic monitors. A few projects used models, one project incorporated a particle-velocity sensor, and another a sonobuoy.

Table 4. Number of studies using methodologies and technologies to assess underwater noise grouped by U.S. and international projects.

Technology	U.S.	International
C-PODS	0	1
Desktop Study	2	14
Human Observer	0	1
Hydrophone	8	38
Model	0	5
Particle-Velocity Sensor	0	1
Passive Acoustic Monitor	0	2
Sonobuoy	0	1
T-PODS	0	1
Total	9	64

TFiT determined the use of the Ocean Sonics icListen and Ocean Instruments SoundTrap to be suitable hydrophone technologies aligned with the IEC TS 62600-40 technical specification for characterizing underwater noise from the ME devices and field trials. Haxel et al. [21] fully evaluated the effectiveness of this methodology and provides recommendations for implementation in a companion paper included in this Special Issue.

3.3.3. Electromagnetic Fields

A total of 32 studies (10 U.S., 22 international) were examined for technologies and methodologies to measure electromagnetic fields (EMFs). Desktop studies and modeling were often cited as the methods to assess EMFs, especially during the baseline or pre-installation stages of the projects (Table 5). The most used technologies for measuring EMFs were an EMF sensor and a magnetometer. There are several commercially available magnetometers. EMF sensors are less established commercially and even the most recent projects (e.g., Oregon State University PacWave testing site) do not have a specific unit described for this aspect of environmental monitoring.

Table 5. Number of studies using methodologies and technologies to assess electromagnetic fields grouped by U.S. and international projects.

Technology	U.S.	International
Desktop Study	1	9
EMF Sensor	5	6
Magnetometer	1	4
Model	3	3
Total	10	22

Based on this census, TFiT elected to test a commercially available sensor and an experimental low-cost sensor modified from an inertial measurement unit (IMU). Both of these options are less expensive than a custom-designed sensor and housing, such as has been developed and used in other studies [22]. The commercially available sensor chosen was a Marine Magnetics SeaSpy2. A Yost IMU was modified to record three-dimensional magnetic field data and it was placed into a custom foam housing. Grear et al. [23] fully evaluated the effectiveness of this methodology and provides recommendations for implementation in a companion paper included in this Special Issue.

3.3.4. Changes in Habitat

Various technologies and methodologies examining the changes in habitat were employed 223 times across 70 project sites (25 times in the U.S. and 198 times internationally). The changes in habitat were not addressed at each project site, but when they were, the methodology and gear used varied greatly (Table 6). Typically, the objectives were to characterize either the sediment type, the benthic communities (infauna and/or epifauna), or both, and the methodology used differed accordingly. The physical sample collection was the most common methodology, both domestically and globally, followed by video footage and still images, which can all serve the dual purpose of characterizing the sediments and organisms, to a certain extent. Echosounders (multibeam or not), sub-bottom profilers, desktop studies, human observers, and models were also used at several sites.

Table 6. Number of studies using methodologies and gear to assess the changes in habitat grouped by U.S. and international projects.

Technology	U.S.	International
Desktop Study	3	18
Echosounder	2	6
Human Observer	3	14
Image Camera	2	27
Model	0	2
Multibeam Echosounder	0	19
Physical Sample Collection	7	46
Side-Scan Sonar	3	16
Sub-Bottom Profile	2	9
Video Camera	3	41
Total	25	198

The specific type of gear differed greatly depending on what type of sample was collected (see Hemery et al. [9] for an in-depth review). Sediment dredges and van Veen grabs were most commonly used for sampling the sediments, but cylindrical cores and vibrocoring was also used. The most common gear used for collecting benthic organisms were bottom trawls for epifauna and Day grabs or Gray–O'Hare box cores for infauna.

The methodologies for collecting video footage and still images were also diverse. Drop-down video and/or photography systems and remotely operated vehicles (ROVs) were used equally, mostly at deeper sites. Scuba divers recorded underwater videos or images at most of the shallower sites (along transects or within quadrats). A towed camera was also used on a few occasions. Domestically, the most used methods were physical sample collection (using a diversity of gear), but often in conjunction with the collection of video or still images.

TFiT determined the need to conduct a more thorough literature review of the different technologies used for surveying habitats and monitoring changes [9]. In addition, discussions with subject matter experts led TFiT to select a 360-degree underwater video camera for the changes in the habitat field trials, in order to test the promising capabilities of this technology as a drop-down camera system for monitoring the artificial reef effect of

ME devices and associated structures. Hemery et al. [24] provides a full description and evaluation of these methods in a companion paper included in this Special Issue.

3.3.5. Animal Displacement

A total of 145 studies (27 U.S., 118 international) were examined for the technologies and methodologies used to measure animal displacement. Internationally, animal displacement was assessed mainly through human observations, either land-based or vessel-based, and by using binoculars or scopes, but also on a few occasions by Scuba divers (Table 7). Desktop studies and sample collections ranked second and third, respectively. Other advanced technologies (e.g., hydrophones, telemetry, or video) were only used occasionally. Projects in the U.S. used human observations and physical sample collections equally as the most common methodologies to monitor this stressor.

Table 7. Number of studies using methodologies and technologies to assess animal displacement grouped by U.S. and international projects.

Technology	U.S.	International
C-PODS	1	4
Desktop Study	4	27
Echosounder	2	3
Human Observer	7	43
Hydrophone	1	5
Image Camera	1	4
Model	0	2
Multibeam Echosounder	0	1
Passive Acoustic Monitor	2	4
Physical Sample Collection	7	11
Side-Scan Sonar	0	1
Sonobuoy	0	1
Telemetry	1	4
T-PODS	0	1
Video Camera	1	7
Total	27	118

The displacement of animals by a single ME device is unlikely [25]. Therefore, no TFiT activities focused on this stressor.

3.3.6. Changes in the Physical Systems

A total of 99 studies (15 U.S., 84 international) were examined for the technologies and methodologies used to measure the changes in physical systems. The characterization of physical systems prior to device deployments, as well as the monitoring for changes during and after deployments, were predominantly addressed by the use of acoustic Doppler current profilers (ADCPs), either vessel- or bottom-mounted (Table 8). There was no consistency among the ADCP manufacturer or the settings selected. These technologies were used to measure the water current velocities, but were also often deployed to measure wave height and direction. Wave buoys and desktop studies were also commonly used for assessing this stressor.

It is unlikely that any changes in the physical systems could be detected around a single device or a small array [26]. Consequently, no TFiT activities focused on this stressor.

To focus the field-testing efforts, the state of knowledge of the various stressors, the variety of existing technologies that have been used to evaluate the stressors, and the likelihood that a stressor could be adequately characterized for a single ME device or small array were considered. TFiT activities were focused on the collision risk, underwater noise, electromagnetic fields, and changes in habitat. The testing and analyses of the methodologies for each of these stressors are reported in the other papers included in this Special Issue.

Table 8. Number of studies using methodologies and technologies to assess the changes in physical system grouped by U.S. and international projects.

Technology	U.S.	International
Acoustic Doppler Current Profiler	4	25
Acoustic Wave and Current Device	1	7
Current Meter	0	3
Desktop Study	3	13
Image Camera	0	1
Model	2	10
Video Camera	1	1
Water Collection	3	10
Wave Buoy	1	14
Total	15	84

4. Discussion

4.1. Identification of Environmental Concerns and Appropriate Methodologies and Technologies

The analysis of the various sampling plans for the technologies and methodologies indicated that the most consistent monitoring methodologies were used in the physical or abiotic categories. Physical oceanography, geologic resources, benthic resources (abiotic), essential fish habitat (benthos), cultural resources, and marine uses were typically well studied and have somewhat standardized monitoring and data collection protocols, or they fall under desktop studies and modeling. In contrast, the baseline information about animal resources (fish, marine mammals, sea turtles, invertebrates, and birds) is typically lacking in the high-energy areas where the ME devices would be sited. Additionally, the breadth of information needed to adequately characterize the risk to animal resources (e.g., life history, seasonal abundance and distribution, and behavior) is often lacking. This leads to a precautionary approach by regulators and resource managers, who may require extensive baseline and post-installation monitoring studies. Yet, there is little consistency in the methodology used to collect and analyze the data needed to approve a permit.

A wide variety of methodologies and technologies have been employed to date, to address the most common environmental stressors associated with ME installations [4,9]. Given the many technologies to choose from, it can be difficult for ME technology or project developers to identify the appropriate monitoring technologies and methodologies to address the regulatory concerns about their projects. The benefits and challenges associated with existing monitoring technologies informed which technologies would be tested during TFiT activities. These benefits and challenges are briefly discussed below, and in more detail in each paper included in this Special Issue.

4.1.1. Collision Risk

The risk of animals colliding with or being struck by a current turbine is viewed as a major risk by regulators [19], and there is a high level of uncertainty associated with the documentation of such collisions. There have been few observations of a strike or near-miss events for fish to date [27,28], and the methods for consistently observing these possible interactions remain elusive. While each method has its limitations, the most promising technologies for detecting close-range events, such as collisions or near misses, are optical cameras or acoustic cameras.

Optical cameras are the preferred sensor used to observe close-range events, but many parameters—such as frame rate, pixel resolution, and external lighting—need to be optimized to provide the highest quality data. Many commercial off-the-shelf (COTS) cameras designed for underwater applications have a high-resolution, high variable frame rates (e.g., >30 frames per second), auto focus, and cover the color wavelength spectrum. These characteristics are often limitations when applied to the task of observing animal being struck by current energy converters. These limitations are twofold. First, high-resolution, high frame rates, and color increase the total data storage per frame captured.

For monitoring that can last for months, it is important to reduce the data accumulation as much as possible. Second, features, such as variable frame rate and auto focus, remove the consistent data collection characteristics that automation algorithms require. So, having camera models (e.g., Machine Vision) that allow users to control all aspects of data collection such as frame rate, focus, and resolution will allow for better use of automation technique research in the future. These camera sensor characteristics will allow for a reduction in data accumulation by removing the unneeded camera options, such as high resolution or color, and will reduce data-processing time by collecting consistent data, allowing the automation algorithms to be more effective [28,29].

However, high-turbidity environments, such as glacial rivers, preclude the use of optical cameras. An acoustic camera is a compromise that may be required in these situations. A collision event may be difficult to detect due to pixel-resolution limitations and "blind" spots directly next to the device created by the sensor-transmitted sound backscatter from parts of the device [30]. A number of targets that may possibly collide with a turbine blade may be the best outcome using current technology and processing techniques.

Acoustic cameras may also benefit from optimization techniques. The "blind" areas near a moving turbine blade could be minimized by optimizing the acoustic beams' range and angle of incidence. Parameter optimization combined with improved or novel data-processing techniques may improve the ability of acoustic cameras to detect collision or near-miss events.

The goal of TFiT was to apply, in situ, a state-of-the-art, commercially available sensor in a turbid environment where an operational turbine and fish could potentially interact. Capturing these data provides information about the advantages and challenges of using an acoustic camera and provides a datapoint relative to the overall record of collision risk to date [20].

4.1.2. Underwater Noise

The primary environmental concern related to underwater noise is its possible effect on animal communication space, and its potential for masking important critical acoustic life functions, such as foraging, finding a mate, navigation, and predator/prey avoidance [31,32]. The existing acoustic measurements from ME devices show that underwater-noise-generated frequencies fall within marine animals' hearing ranges, indicating that marine animals could detect and be affected by ME-produced sound [33]. ME-generated underwater noise may cause a behavioral change in acoustically sensitive animals and thus an effect. Conversely, the noise may be ignored, creating a situation with no effect on the animal.

In 2019, the International Electrotechnical Commission (IEC) published a technical specification for the acoustic characterization of ME converters [8]. The IEC document provides uniform methodologies for the consistent and accurate measurement of the acoustic emissions from ME converters, but the specification still needs to be put into practice for differing hydrophone sensor technologies and in different environmental and project settings. Additionally, the effectiveness of using the IEC 62600-40 technical specification for underwater noise measurement and reporting needs to be evaluated in the context of satisfying the regulatory requirements for the permitting and licensing of ME projects.

The goal of TFiT for underwater noise monitoring was to apply suitable, cost-effective COTS hydrophone technologies exercising the IEC 62600-40 technical specification at an ME project site. Activities were focused on underwater noise measurements at a tidal turbine using drifting hydrophone technology [21].

4.1.3. Electromagnetic Fields

The potential to change animal behavior or create barriers to movement is the main environmental concern related to EMFs produced by device components, cables, and junction boxes [34]. Scalar EMF values can easily be detected with commercially available towed units, but obtaining vector EMF values is much more difficult. CResearch and development efforts are ongoing for vector devices and few commercial options are available, making acquisition challenging or impossible for the broader ME community. While collecting both scalar and vector EMF data is necessary for model validation [34], the goal of TFiT was to investigate repeatable, cost-effective methods for environmental monitoring. Consequently, the project activities focused on conducting vessel-based magnetic field detection towing a SeaSpy magnetometer for scalar measurements [23].

4.1.4. Changes in Habitat

Multiple concerns fall within the changes in habitat stressor category, the main ones being the initial characterization of endemic, rare, and/or fragile habitats that may be damaged or lost with the installation of ME devices, and the biofouling and artificial reef effects potentially increasing the local biomass and providing settlement opportunities for non-native invasive species [35]. Methods and technologies for assessing these issues are disparate due to the long record of field studies in benthic ecology, and some might be better suited than others for evaluating the ME environment.

The goal of TFiT for changes in habitat was to identify and test the COTS technology to efficiently and accurately monitor the potential artificial reef effects of the ME devices. The field activities focused on testing a 360-degree camera as a novel but promising technology to monitor any changes in habitat [24].

4.1.5. Animal Displacement

The displacement of animals is a negligible risk at the scale of a single ME device, but it may become significant as larger arrays are deployed and multiple ME devices are simultaneously tested at facilities, such as PacWave. Uncertainties remain about the cumulative effects that multiple devices, mooring lines, cables, and their emitted sounds and EMFs will have on marine organisms that are present year-round or seasonally in the area, and how these effects will contribute to organism displacement. Animals may be displaced from foraging, mating, resting, socializing, or other critical life behaviors when sharing habitats with ME devices. This stressor requires additional technology development and research to monitor and track marine wildlife behavior in areas where ME devices will be tested and installed.

Although aerial technologies were not included in our analysis, newly developed approaches with aerial platforms for wildlife monitoring, such as airplanes, unoccupied aerial systems [36], and tethered balloon systems [37], provide novel perspectives and information for understanding the changes in biodiversity, detection of species presence, individual identification, and species behavior over time, all of which are necessary for measuring the displacement of animals in a marine environment. The suitability of these technologies for monitoring animal displacement in marine systems is yet to be evaluated. The ability to perform long-term monitoring is essential for informing our understanding of the potential animal displacement as ME projects increase in scale to larger arrays, so that we can determine if mitigation is necessary [25].

4.1.6. Changes in the Physical Systems

Single ME devices are not expected to alter the physical system more than localized turbulence [26]. However, commercial-scale arrays are anticipated to modify local and potentially regional hydrodynamics and sediment transport. This issue will require additional monitoring and study as ME projects increase in scale to determine if mitigation measures are needed. Additionally, several models have been developed to predict such changes, but they need to be validated with reliable empirical data acquired by environmental monitoring campaigns and specific marine-grade, at-sea technologies.

4.2. Identification of the Suitable Field Sites

While a number of suitable test sites for TFiT activities were identified (Table 2), the project team prioritized data collection at the sites where ME devices were deployed to address logistical and budgetary limitations. After the initial site selection, opportunities arose to test methodologies and collect data at two additional sites around the deployed ME devices. This included a tidal turbine attached to Portsmouth Memorial Bridge near Portsmouth, New Hampshire (NH), and a wave energy converter (WEC) deployed near the Scripps Institution of Oceanography in La Jolla, California (CA). The University of New Hampshire's Living Bridge project had a tidal turbine at Portsmouth, NH, and had approved permits to perform TFiT-related research. The TFiT research team obtained permits to perform tests near the WEC near the Scripps Institution of Oceanography. Final testing locations and TFiT activities performed at each site are shown in Figure 1.

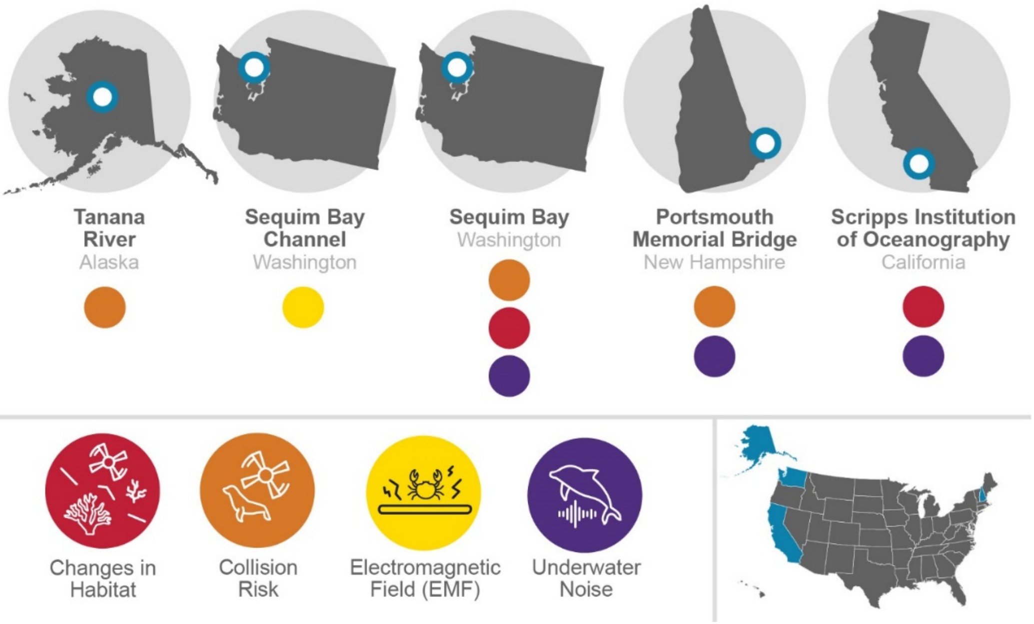

Figure 1. Final test locations of TFiT activities.

5. Conclusions

Peplinski et al. [2] evaluated the cost of environmental compliance for wave, tidal, and ocean/river current projects in the U.S. Of the 19 projects evaluated, only 8 projects had detailed financial records that allowed for an estimation of the environmental compliance contribution to the total project cost. The environmental compliance costs ranged from approximately 10% for the larger projects (up to USD 50 Million) to 25% of the total project budget for the smaller projects (less than USD 5000). While these environmental compliance costs include activities such as regulatory agency coordination and stakeholder engagement, there are opportunities to reduce the costs associated with environmental monitoring technologies. These include activities ranging from the improvements and innovations to reduce the cost of the technologies themselves, and methods for data collection and analysis, to verifying that the technology and methodology collect the type of data required to address regulatory concerns. The time associated with environmental monitoring affects the overall cost and is an important component to consider. The length of time required for specific environmental monitoring will vary based on the regulatory or permitting requirements and the scale of the project, such that short-term demonstrations will need less data than multi-year commercial installations. In the absence of industry standards, the adoption of a consistent set of monitoring methodologies can be used to generate a robust data record for each stressor of concern, which, in turn, can be used to assess the actual environmental risk posed by marine energy installations and help future projects complete the permitting process in a more efficient manner.

Recent re-analysis studies of long term data sets indicated an increase in wave power over time, both globally [38] and at more localized scales [39], highlighting the potential for wave power as a renewable energy source and the need to consider potential changes in resource during the device design phase. A similar long-term record for environmental concerns does not yet exist. It may not be feasible for a single ME project to collect long-term data on environmental concerns from a project budget perspective, nor necessary to satisfy the regulatory requirements. As previously mentioned, the time frame for environmental data collection for an individual project is influenced by the size and duration of the deployment. However, the wide-scale adoption of a consistent set of methodologies and technologies for environmental concerns could enable the creation of a cumulative, long-term dataset, by compiling data from multiple projects in a region. Future re-analysis studies of these aggregate datasets could examine the trends or changes in the environmental impacts of marine energy in conjunction with climate change.

The overarching goal of the TFiT project was to evaluate the methodologies and technologies for four common environmental concerns related to ME deployments (collision risk, underwater noise, EMF, and changes in habitat) and make recommendations to promote more consistent and streamlined data collection. The studies undertaken by TFiT provide acceptable methods for addressing the key environmental concerns faced by the ME industry.

This Special Issue contains additional papers that provide detailed descriptions of how and why the specific methodologies and technologies identified above were chosen to be tested for each TFiT stressor area, the results of the field test, and the recommendations for future data collection at the ME sites. The use of models to address the environmental concerns for each stressor and how the data collected via the tested methodologies can be used to validate or enhance existing models are also discussed. The adoption of consistent methodologies will allow technology and project developers to avoid a trial-and-error approach to environmental monitoring and enable them to use their available time and budgets more effectively.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/jmse10020177/s1: Table S1. A complete list of the 118 projects evaluated to determine the type and number of methodologies and technologies used to monitor each stressor presented in Tables 3–8.

Author Contributions: Conceptualization, S.L.E., G.H.-K. and S.G.; methodology, G.H.-K. and G.S.; formal analysis, G.H.-K., M.P. and G.S.; investigation, G.H.-K., M.P. and G.S.; writing—original draft preparation, S.L.E.; writing—review and editing, G.S. and G.H.-K.; supervision, G.H.-K. and M.P.; project administration, S.L.E., G.H.-K. and M.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the U.S. Department of Energy, Energy Efficiency and Renewable Energy, the Water Power Technologies Office to the Pacific Northwest National Laboratory (PNNL) under contract DE-AC05-76RL01830. The APC was funded by contract DE-AC05-76RL01830.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data is contained within the article and Supplementary Material.

Acknowledgments: We thank Alicia Amerson and Joe Haxel for their thoughtful review of the manuscript. We thank Susan Ennor of PNNL for assistance with the manuscript.

Conflicts of Interest: The funders played a collaborative role in the conceptualization of the study and the writing of the manuscript.

References

1. Copping, A. *2020 State of the Science Report, Chapter 2: Marine Renewable Energy: Environmental Effects and Monitoring Strategies*; Copping, A.E., Hemery, L.G., Eds.; Ocean Energy Systems (OES), Pacific Northwest National Laboratory: Richland, WA, USA, 2020; pp. 19–27. [CrossRef]
2. Peplinski, W.J.; Roberts, J.; Klise, G.; Kramer, S.; Barr, Z.; West, A.; Jones, C. Marine energy environmental permitting and compliance costs. *Energies* **2021**, *14*, 4719. [CrossRef]

3. Polagye, B.; Copping, A.; Suryan, R.; Kramer, S.; Brown-Saracino, J.; Smith, C. *Instrumentation for Monitoring around Marine Renewable Energy Converters: Workshop Final Report*; Pacific Northwest National Laboratory: Richland, WA, USA, 2014.
4. Hasselman, D.; Barclay, D.; Cavagnaro, R.; Chandler, C.; Cotter, E.; Gillespie, D.; Hastie, G.; Horne, J.; Joslin, J.; Long, C.; et al. *2020 State of the Science Report, Chapter 10: Environmental Monitoring Technologies and Techniques for Detecting Interactions of Marine Animals with Turbines*; Copping, A.E., Hemery, L.G., Eds.; Ocean Energy Systems (OES), Pacific Northwest National Laboratories: Richland, WA, USA, 2020; pp. 176–212. [CrossRef]
5. Chang, G.; Harker-Klimeš, G.; Raghukumar, K.; Polagye, B.; Haxel, J.; Joslin, J.; Spada, F.; Staines, G. Clearing a Path to Commercialization of Marine Renewable Energy Technologies Through Public–Private Collaboration. *Front. Mar. Sci.* **2021**, *8*, 1180. [CrossRef]
6. Copping, A.; Gorton, A.; Freeman, M.; Rose, D.; Farr, H. *Data Transferability and Collection Consistency in Marine Renewable Energy: An Update to the 2018 Report (Report No. PNNL-27995 Rev. 1)*; US Department of Energy (DOE), Pacific Northwest National Laboratory: Richland, WA, USA, 2020.
7. Copping, A.E.; Gorton, A.M.; Freeman, M.C. *Data Transferability and Collection Consistency in Marine Renewable Energy*; PNNL-27995; US Department of Energy (DOE), Pacific Northwest National Laboratory: Richland, WA, USA, 2018.
8. IEC. *Marine Energy-Wave, Tidal, and Other Water Current Converters—Part 40: Acoustic Characterization of Marine Energy Converters*; IEC TS 62600-40; International Electrotechnical Commission: Geneva, Switzerland, 2019; p. 44.
9. Hemery, L.; Mackereth, K.; Tugade, L. What's in my toolkit? A review of technologies for assessing changes in habitats caused by marine energy development. *J. Mar. Sci. Tech.* **2022**, *10*, 92.
10. Kramer, S.; Jones, C.; Klise, G.; Roberts, J.; West, A.; Barr, Z. Environmental Permitting and Compliance Cost Reduction Strategies for the MHK Industry: Lessons Learned from Other Industries. *J. Mar. Sci. Eng.* **2020**, *8*, 554. [CrossRef]
11. Galparsoro, I.; Korta, M.; Subirana, I.; Borja, Á.; Menchaca, I.; Solaun, O.; Muxika, I.; Iglesias, G.; Bald, J. A new framework and tool for ecological risk assessment of wave energy converters projects. *Renew. Sustain. Energy Rev.* **2021**, *151*, 111539. [CrossRef]
12. Boehlert, G.W.; Gill, A.B. Environmental and ecological effects of ocean renewable energy development: A current synthesis. *Oceanography* **2010**, *23*, 68–81. [CrossRef]
13. Copping, A.E.; Hemery, L.G.; Overhus, D.M.; Garavelli, L.; Freeman, M.C.; Whiting, J.M.; Gorton, A.M.; Farr, H.K.; Rose, D.J.; Tugade, L.G. Potential environmental effects of marine renewable energy development—The state of the science. *J. Mar. Sci. Eng.* **2020**, *8*, 879. [CrossRef]
14. Martínez, M.; Vázquez, G.; Pérez-Maqueo, O.; Silva, R.; Moreno-Casasola, P.; Mendoza-González, G.; López-Portillo, J.; MacGregor-Fors, I.; Heckel, G.; Hernández-Santana, J. A systemic view of potential environmental impacts of ocean energy production. *Renew. Sustain. Energy Rev.* **2021**, *149*, 111332. [CrossRef]
15. Copping, A.; Kramer, S. A snapshot of risk for environmental effects of marine renewable energy development. In Proceedings of the 5th Annual Marine Energy Technology Symposium, Washington, DC, USA, 1–3 May 2017.
16. O'Neil, R.S.; Staines, G.J.; Freeman, M.C. *Marine Hydrokinetics Regulatory Processes Literature Review*; PNNL-28608; US Department of Energy (DOE), Pacific Northwest National Laboratory: Richland, WA, USA, 2019.
17. Yang, Z.; Wang, T. Tidal residual eddies and their effect on water exchange in Puget Sound. *Ocean Dyn.* **2013**, *63*, 995–1009. [CrossRef]
18. Block Island Wind Farm (BIWF). *Environmental Report/Construction and Operations Plan*; Deepwater Wind: Boston, MA, USA, 2012.
19. Sparling, C.E.; Seitz, A.C.; Masden, E.; Smith, K. *2020 State of the Science Report, Chapter 3: Collision Risk for Animals around Turbines*; Copping, A.E., Hemery, L.G., Eds.; Ocean Energy Systems (OES), Pacific Northwest National Laboratory: Richland, WA, USA, 2020; pp. 29–66. [CrossRef]
20. Staines, G.; Mueller, R.; Seitz, A.C.; Evans; Wosnik, M.; O'Byrne, P. Capabilities of an acoustic camera to inform fish collision risk with current energy converter turbines. *J. Mar. Sci. Eng.* 2022; *in press*.
21. Haxel, J.; Staines, G.; Martinez, J.; Zang, X.; Deng, Z. Underwater noise measurements at a tidal turbine marine energy site. *J. Mar. Sci. Eng.* 2022; *in press*.
22. Gill, A.; Huang, Y.; Gloyne-Philips, I.; Metcalfe, J.; Quayle, V.; Spencer, J.; Wearmouth, V. *COWRIE 2.0 Electromagnetic Fields (EMF) Phase 2: EMF-Sensitive Fish Response to EM Emissions from Sub-Sea Electricity Cables of the Type Used by the Offshore Renewable Energy Industry*; COWRIE-EMF-1-06; COWRIE, Ltd.: Liverpool, UK, 2009.
23. Grear, M.; McVey, J.; Cotter, E.; Williams, N.; Cavagnaro, R. Methods for quantifying background electromagnetic fields at a marine energy site. *J. Mar. Sci. Eng.* 2022; *in press*.
24. Hemery, L.; Mackereth, K.; Gunn, C. On the use of a 360-degree underwater camera to characterize artificial reef and fish aggregating effects around marine energy devices. *J. Mar. Sci. Eng.* 2022; *in press*.
25. Copping, A.; Freeman, M.; Gorton, A.; Hemery, L. *2020 State of the Science Report, Chapter 13: Risk Retirement and Data Transferability for Marine Renewable Energy*; Copping, A.E., Hemery, L.G., Eds.; Ocean Energy Systems (OES), Pacific Northwest National Laboratory: Richland, WA, USA, 2020; pp. 263–279. [CrossRef]
26. Whiting, J.; Chang, G. *2020 State of the Science Report, Chapter 7: Changes in Oceanographic Systems Associated with Marine Renewable Energy Devices*; Copping, A.E., Hemery, L.G., Eds.; Ocean Energy Systems (OES), Pacific Northwest National Laboratory: Richland, WA, USA, 2020; pp. 127–146. [CrossRef]
27. Bevelhimer, M.; Scherelis, C.; Colby, J.; Adonizio, M.A. Hydroacoustic assessment of behavioral responses by fish passing near an operating tidal turbine in the east river, New York. *Trans. Am. Fish. Soc.* **2017**, *146*, 1028–1042. [CrossRef]

28. Matzner, S.; Trostle, C.; Staines, G.; Hull, R.; Avila, A.; Harker-Klimes, G. *Triton: Igiugig Fish Video Analysis (PNNL-26576)*; Pacific Northwest National Laboratory: Richland, WA, USA, 2017.
29. Hutchison, I.; Tait, C.; Sheehy, J.; Morgan, P. *Review of Underwater Video Data Collected Around Operating Tidal Stream Turbines*; Scottish Natural Heritage, Research Report No. 1225; NatureScot: Inverness, Scotland, 2020.
30. Viehman, H.A.; Zydlewski, G.B. Fish interactions with a commercial-scale tidal energy device in the natural environment. *Estuaries Coasts* **2015**, *38*, 241–252. [CrossRef]
31. Peng, C.; Zhao, X.; Liu, G. Noise in the sea and its impacts on marine organisms. *Int. J. Environ. Res. Public Health* **2015**, *12*, 12304–12323. [CrossRef]
32. Popper, A.N.; Hawkins, A.D. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. *J. Fish Biol.* **2019**, *94*, 692–713. [CrossRef]
33. Polagye, B.; Basset, C. *2020 State of the Science Report, Chapter 4: Risk to Marine Animals from Underwater Noise Generated by Marine Renewable Energy Devices*; Copping, A.E., Hemery, L.G., Eds.; Ocean Energy Systems (OES), Pacific Northwest National Laboratory: Richland, WA, USA, 2020; pp. 67–85. [CrossRef]
34. Gill, A.; Desender, M. *2020 State of the Science Report, Chapter 5: Risk to Animals from Electro-Magnetic Fields Emitted by Electric Cables and Marine Renewable Energy Devices*; Copping, A.E., Hemery, L.G., Eds.; Ocean Energy Systems (OES), Pacific Northwest National Laboratory: Richland, WA, USA, 2020; pp. 86–103. [CrossRef]
35. Hemery, L.G. *2020 State of the Science Report, Chapter 6: Changes in Benthic and Pelagic Habitats Caused by Marine Renewable Energy Devices*; Copping, A.E., Hemery, L.G., Eds.; Ocean Energy Systems (OES), Pacific Northwest National Laboratory: Richland, WA, USA, 2020; pp. 104–125. [CrossRef]
36. Lahoz-Monfort, J.J.; Magrath, M.J. A Comprehensive Overview of Technologies for Species and Habitat Monitoring and Conservation. *BioScience* **2021**, *71*, 1038–1062. [CrossRef]
37. Belmekki, B.E.Y.; Alouini, M.-S. Unleashing the Potential of Networked Tethered Flying Platforms for B5G/6G: Prospects, Challenges, and Applications. *arXiv* **2020**, arXiv:2010.13509.
38. Reguero, B.G.; Losada, I.J.; Méndez, F.J. A recent increase in global wave power as a consequence of oceanic warming. *Nat. Commun.* **2019**, *10*, 205. [CrossRef]
39. Penalba, M.; Ulazi, A.; Ibarra-Berastegui, G.; Ringwood, J.; Sáenz, J. Wave energy resource variation off the west coast of Ireland and its impact on realistic wave energy converter's power absorption. *Appl. Energy* **2018**, *224*, 205–219. [CrossRef]