THE CROWN ESTATE | Marine Data Exchange

Tidal Stream Energy Project:

Collision Risk Data and Evidence Summary (2025)

March 2025

A report prepared by The Crown Estate and ABP Marine Environmental Research Ltd ("ABPmer").

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Foreword

This report was prepared by the Data and Insights Team at The Crown Estate and ABPmer, to summarise the available data collected from tidal stream energy sites and to assess the conclusions regarding their impact on marine mammals. This report evaluates the methods used to quantify risk, such as identifying potential monitoring limitations, with the aim of supporting the consenting process by providing further clarity on benefits and limitations to environmental monitoring methods used at different project site locations.

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Report and more information

Tidal Stream Energy Project: Collision Risk Data and Evidence Summary, 2025 available at: marinedataexchange.co.uk

Permission has been granted by Nova Innovation for the monitoring reports from the Shetland Tidal Array to be used in the literature review.

Permission has been granted by Tethys for the use of Tethys and OES-Environmental data for the details of each tidal device.

Notice

The case studies in this review aim to provide succinct summaries on the findings of each research study, highlighting any caveats or limitations associated with the methodology used during environmental monitoring. This report has used publicly available information, and any missing information can either be found in the full report or was not available for us to include.

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Executive summary

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The UK has outlined an ambitious plan to cut carbon emissions by 68% by 2030, shifting its energy sources from fossil fuels to renewable energy alternatives (BEIS, 2022). Tidal stream technology, the process of harnessing the power of ocean tidal currents, is a reliable source of renewable energy and presents a promising option to support this clean energy transition.

While this technology is reaching the point of commercial-scale deployment, the growth of the sector has been hindered by economic challenges, and uncertainties surrounding potential environmental impacts on marine habitats and species during construction and operation. In the UK, there are consenting concerns on the negative impacts tidal stream devices may have on marine fauna, including the risk of collision, disturbance caused by underwater noise, avoidance and displacement. These concerns have contributed to long consenting timelines and the need for costly long-term data collection to fill evidence gaps and understand these impacts.

The aim of this data summary is to provide an overview of environmental monitoring data collected to date on operational or decommissioned tidal stream energy projects in the UK and globally, to assess the impacts these devices may have on marine species. The data and evidence summarised in this report primarily explores the issue of collision risk for marine mammals, as this risk remains a significant barrier to tidal stream consenting and a key concern for regulators. This project's purpose is to recognise what data has been collected to date, draw insight from monitoring, and how monitoring conclusions can inform future tidal stream energy developments in the UK. A primary objective of this report has been to assess monitoring methods used at tidal stream sites, with a particular focus on impact monitoring techniques, in order to better understand the evidence base relating to collision risk and possible displacement. By providing clarity on the advantages and limitations of tidal stream technology monitoring techniques, the report's ultimate aim is to support the tidal stream energy consenting process.

Utilising The Crown Estate's Marine Data Exchange and third-party peer reviewed journals, this report summarises monitoring data for four tidal energy sites in the UK; SeaGen Unit, Shetland Tidal Array, MeyGen Tidal Energy Project and the European Marine Energy Centre, summarising publicly available information on their potential impacts on marine fauna. While focusing on UK case studies, this report also considers evidence that has been gathered around the world to investigate lessons learned in other countries including: the United States of America, Canada and France. The breadth of sites covered in this review showcases the data gathered across the UK and globally, highlighting the existing evidence base for developers and regulators to utilise. Each case study provides insights into the advantages and limitations of monitoring techniques carried out at each location. Marine mammal monitoring techniques that were explored in this report include: Pinniped (seal) telemetry; Passive Acoustic Monitoring; underwater video footage; active sonar; and visual surveys, as well as sound measurements to assess underwater noise levels at the turbine site both during construction and operation phases. Along with this review of selected case studies, The Crown Estate liaised directly with developers to create fact sheets with a high-level overview of each site location, providing details on physical site characteristics and tidal stream device technical details.

In the case studies summarised, which consist of various devices located in differing habitats in Scotland and Northern Ireland, there have been no recorded marine mammal collisions with tidal turbines, and individuals appear to avoid turbines when they are operating. While different monitoring methods were used at each site, this does suggest that collision risk potential is low for single and small-scale arrays. Across the SeaGen, Shetland Tidal Array, and MeyGen Tidal Energy Project case studies, four of the reports concluded that there was localised avoidance of the turbine when in operation, similarly suggesting collision risk maybe be lower than previously perceived for single and small-scale arrays. However, larger-scale arrays still warrant further investigation, especially if avoidance and displacement also occur from potentially important areas for marine species' life cycles.

Through the synthesis of available evidence, this report has evaluated the methods used to quantify risk and has identified that current environmental monitoring methods can often lack standardisation and consistency, with variability in data quality and reliability, making it difficult to compare results across different sites. To address these limitations, the report recommends enhancing the evidence base through the continued development and implementation of advanced monitoring technologies as well as increased collaboration between researchers, policymakers and industry stakeholders, to help share knowledge and best practice, ultimately improving the overall quality of environmental monitoring. Whilst test and demonstration sites provide developers with the opportunity to refine device technology to reach the point of commercial scale up, they also provide a good opportunity to trial monitoring techniques for devices. Advanced technologies such as the use of active sonar and AI to automatically detect marine species in real time, could help to address uncertainties faced due to challenges of collecting nearfield data that previously resulted in the monitoring not providing definitive evidence on absence (or not) of risk.

Despite the growing evidence base on single devices or small-scale arrays, knowledge gaps persist on the potential impacts larger scale arrays may have on the surrounding marine environment which may not yet be observable in the current small-scale deployments. As tidal stream developments scale up, monitoring should take place throughout a phased deployment to evaluate change at a sufficient spatial and temporal scale to assess wider ranging impacts. By utilising technological advancements, leveraging learnings from previous data and evidence collection and encouraging collaboration, the industry can accelerate development, mitigate risks, and enhance the overall performance of tidal stream energy to enable its scale up to commercial sites.

Based on the insights concluded in this report, the following next steps are recommended:

- Further investment into test and development sites to improve tidal stream energy technological innovations and ensure consistent environmental monitoring techniques
- Deployment and testing of new monitoring technologies such as active sonar, in situ sensors and AI to automatically detect marine species in real time
- Further funding for coordinated strategic research and evidence programmes to address knowledge gaps, particularly regarding the impacts of large-scale arrays
- Improve data sharing between sites to encourage shared learnings to create a larger evidence base for developers and regulators
- Improve standardisation of monitoring methodologies by implementing data standards to reduce effort and time required to aggregate and analyse multiple data sets.

Following the publication of this report, The Crown Estate is set to advance the next phase of work which will encompass the development of a comprehensive data transferability matrix and framework, aiming to enhance the usability of tidal stream data from one site to another. This initiative reflects The Crown Estate's commitment to supporting the sustainable development of the tidal stream industry by helping to develop a robust data and evidence base, whilst encouraging the use and reuse of data collected from one site to another.

Report background

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This report recognises and builds on the contributions made by other stakeholders, inclusive of but not limited to the OES-Environmental 2020 State of Science Report (noting the 2024 version had not been published during the scoping phase of this project, however, the 2024 report was reviewed once available), Welsh Government's Marine renewable energy: environmental information notes 2022, and ORJIP Ocean Energy Information Note: Collision Risk. This report also utilises and builds upon the Tethys knowledge base launched by the Pacific Northwest National Laboratory (PNNL), which is an online information hub for marine and wind energy developments worldwide.

The Crown Estate were also in attendance at the Environmental Interactions of Marine Renewables Conference 2024 in the Orkney Islands, Scotland, which emphasised marine species' interactions with tidal turbines and the monitoring methodologies used to observe their behaviours. The team engaged with staff at the week-long event, gaining a comprehensive understanding of the extensive work completed so far and the future steps necessary to support the sector.

This report builds on information from various reports and stands out due to its technical emphasis on the methodologies used for impact monitoring at tidal stream energy sites, including advantages and limitations of those methodologies. It aims to enhance stakeholders' understanding of the current publicly available evidence base, particularly regarding UK waters, related to potential collision risk and possible displacement of marine mammals. By highlighting the strengths and limitations of various monitoring methods, the report seeks to support future improvements in these techniques, reducing uncertainties by improving the future evidence base for tidal stream and ultimately aiding project consenting.

Ultimately, The Crown Estate intends to develop a data transferability matrix and framework to examine how data from one tidal stream energy site could inform the evidence base at another location. However, the team realise the importance of thoroughly understanding the factors that contribute to a transferability matrix and the criteria that determine a dataset's transferability. This has led to the creation of this report. This foundational work has set the stage for our next phase, the creation of the data transferability matrix and framework, which we are excited to publish on the Marine Data Exchange in mid-late 2025. While this report is valuable in its own right by providing insights into effective methodologies, it is ultimately paving the way for an innovative secondary piece of work.

Report aims and objectives

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The aim of this evidence project is to summarise data collected to date on consented (pre-construction), operational, or decommissioned tidal stream energy projects in the UK and worldwide, to assess the conclusions regarding their impacts on marine species, particularly marine mammals as to date, they have been a key consenting concern in the UK.

Its purpose is to provide an insight into project impacts and outcomes, and how those conclusions can inform future tidal stream energy developments in the UK. Publicly available construction and post-construction data, including from The Crown Estate's Marine Data Exchange (MDE), are the focus for this project. A primary objective of this report has been to assess monitoring methods used at tidal stream sites, with a particular focus on impact monitoring techniques. Marine mammal surveys involving pinniped (seal) telemetry, passive acoustic monitoring, underwater video footage, active sonar, and visual surveys, as well as sound measurements to assess underwater noise levels at the turbine site both during construction and in operation, are the types of reports selected to feed into the data summary. This review focuses on four key tidal stream energy projects in the UK before briefly summarising the progress that has taken place in this sector elsewhere in the world.

The objectives of the report are to:

- Review different monitoring and modelling techniques used at tidal stream sites to understand key impacts and uncertainties associated with devices and scaling up of arrays
- Review monitoring data from tidal stream energy data held on the MDE
- Identify and review current monitoring data from existing tidal stream energy projects in the UK
- Summarise tidal stream energy development that has taken place outside the UK
- Assess different monitoring and modelling techniques used at tidal stream sites to better understand the evidence base relating to collision risk and possible displacement, while highlighting key limitations and caveats associated with the techniques
- Set the stage for our next phase, the creation of the data transferability matrix and framework, which will be published on the Marine Data Exchange mid-late 2025.

Project focal point


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Focusing on the UK, this report analyses the available monitoring data and reports that are publicly available. Five main tidal energy sites are considered: SeaGen Unit, Shetland Tidal Array, MeyGen Tidal Energy Project, the European Marine Energy Centre, and Morlais and the data and evidence summarised within each case study primarily explores the issue of collision risk for marine mammals, as this risk remains a significant barrier to tidal stream consenting and a key concern for regulators.

Seabirds and fish are also considered where they have been included in key marine mammal monitoring studies, and fish have also been taken into account when exploring worldwide case studies. Along with collision risk, it is acknowledged that there are other environmental issues concerning tidal stream energy including:

- Underwater noise, an impact highlighted in multiple case studies on the SeaGen device, and a background noise survey conducted at MeyGen
- Avoidance and displacement of marine species
- The effects of EMFs on sensitive marine species.

While focusing on UK case studies, this report also considers evidence that has been gathered around the world to investigate lessons learned in other countries **(Figure 1, page 11)**. Other tidal stream devices such as kites, or other emerging technology, have not been included due to a lack of available evidence. Tidal range technology such as barrages or lagoons, were not considered as they were not the focus of this review.

Pre-construction environmental characterisation monitoring is used to establish baseline environmental data for potential tidal stream sites. This monitoring aims to support understanding of potential environmental effects associated with projects and is therefore an important part of the consenting process. Although pre-construction data are valuable, operational and post-construction monitoring data were the focus of this project to better understand the data recorded in terms of collision risk and possible displacement, while highlighting key limitations and caveats associated with the techniques.

Figure 1. Map showing the case studies investigated in this report.

1. Introduction

1.1 Renewable energy requirement

The UK has set out plans to decarbonise all sectors of the UK economy to reach net zero by 2050. A key factor in successfully achieving this goal is to reduce reliance on fossil fuels, by increasing the production of renewable energy alternatives, and contributing to the government's target to supply all the UK's electricity from renewable sources by 2035. Delivering net zero is crucial for achieving the global Paris Agreement goal of limiting global temperature rise to within 1.5 degrees Celsius above pre-industrial levels (United Nations, 2015). The transition to renewable energy will help towards this goal by reducing production of greenhouse gases (GHGs), as well as decreasing reliance on non-renewable energy and finite resources. Achieving the UK's transition to net zero and limiting global warming will require an energy mix that is cleaner, sustainable and more diverse.

Tidal stream energy, also known as tidal current energy, could play an important role in reaching the UK's net zero targets. While tidal stream may not match offshore wind in terms of potential gigawatt capacity, it brings additional benefits to the energy mix due to its consistency and predictability. The technology involves harnessing kinetic energy from natural tidal currents, providing a reliable, inexhaustible, and renewable supply of power. It could therefore play a key role in the future of decarbonisation and a move towards 'greener' sources of energy. Test and demonstration arrays have been the main component of tidal stream energy projects to date, however, the industry is ready to scale up and develop towards commercialisation. Whilst technological readiness has previously been a blocker for the expansion of this sector, uncertainties around the environmental effects of larger scale arrays on marine fauna (Hasselman *et al*., 2023), continues to cause consenting challenges. Comprehensive monitoring and data collection are required to understand the impacts of large-scale arrays, which may place a disproportionate ask on a single developer. To support sector growth and inform stakeholders, a strategic approach to addressing knowledge gaps may be beneficial where significant uncertainties persist. This approach could ensure a more balanced expectation for developers.

The UK has a very distinctive tidal stream energy resource in its coastal waters **(Figure 2, page 14)** and is a front runner in tidal stream energy with the most MW deployed globally. The waters around the UK are considered to have the potential to generate up to 11GW of tidal resource, which equates to 11% of the UK current electricity consumption (Frost, 2022a). With a global deployed capacity for tidal stream projected to be 77GW by 2050 (Cochrane, Pinnock, and Jeffrey, 2021), should the UK tidal stream market commercialise, not only can it exploit the national resource, but it stands to benefit from up to 25% of the global market (Frost, 2022b) through exports.

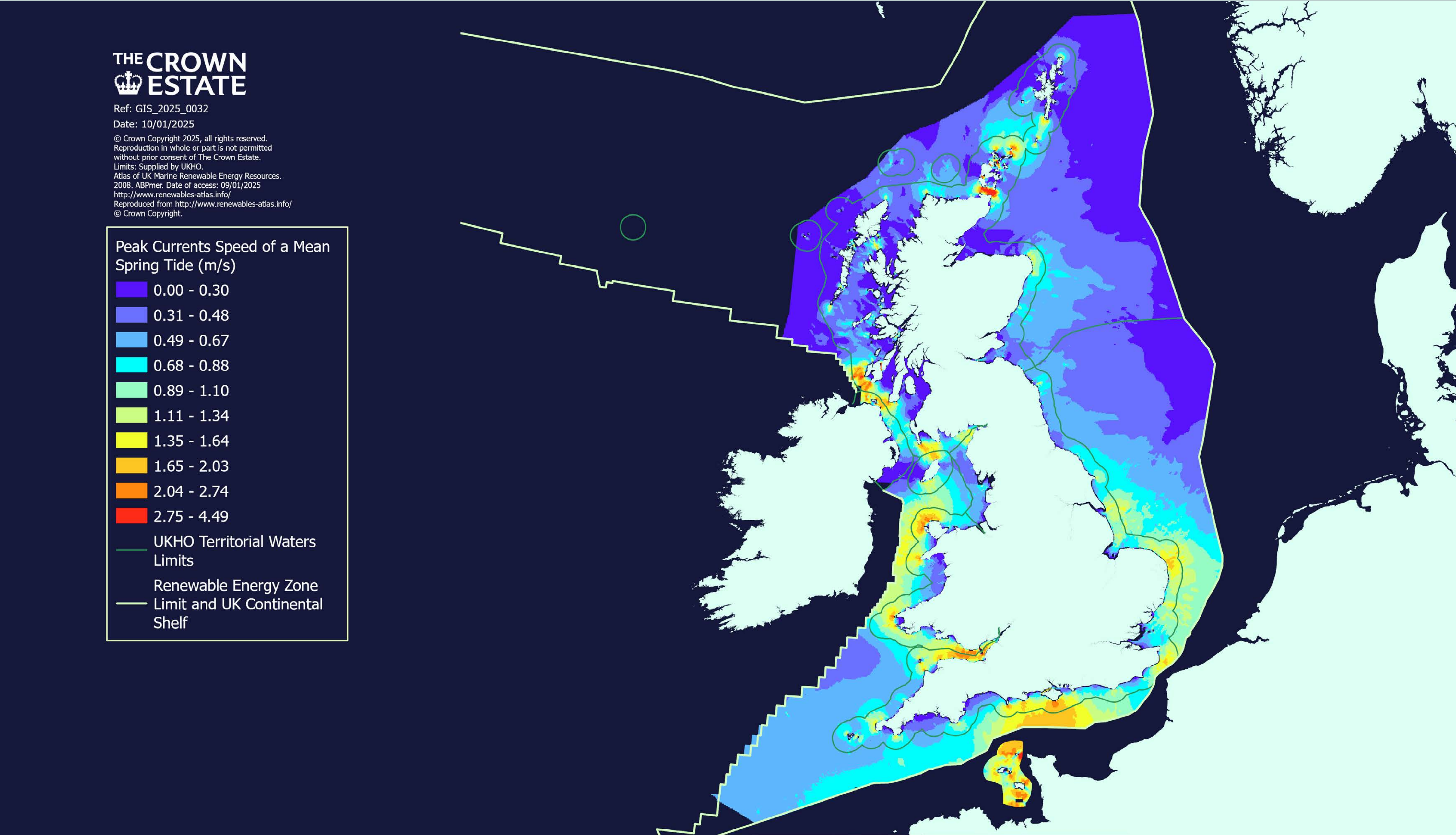


Figure 2. Map showing peak currents speed of a mean spring tide (m/s) around the UK (data source: Atlas of UK Marine Renewable Energy Resources (2008)).

1.2 Tidal stream energy technology

The UK's goal to expand renewable energy production has boosted awareness in the tidal energy sector, specifically tidal stream energy. There are several key advantages of this technology. It is a predictable resource resulting from its dependence on natural tides, and devices can continue to operate in extreme flows; it has a high energy density (per km^2 of seabed) derived from fluid properties (with density about 1000 times that of air), involves negligible terrestrial land coverage, and depending on the technology type, can have minimal visual impact (Ramos *et al*., 2013; Dai *et al*., 2023). Despite these benefits, the development of tidal stream energy faces key challenges including limited suitable locations for deployment where tidal resource is sufficient, and high initial production costs, which has the potential to be reduced, e.g. through technology convergence and commercialisation. There is also a requirement for machinery to withstand marine aggressions such as biofouling, erosion, and corrosion (Elsouk, Santa Cruz, and Guillou, 2018).

Tidal stream energy technology involves fast-flowing currents (tidal streams), which typically cause turbines to rotate, and turn a generator that converts the kinetic energy into electricity (Khare *et al*., 2019). The tidal regime of an area depends on the shape of the coastline and local bathymetry (Ramos *et al*., 2014). For example, the Bay of Fundy has the largest tidal regime in the world due to the specific geometry and bathymetry of the bay which creates a funnel of energy concurrently with the Gulf of Maine. This area has therefore been identified as highly suitable for tidal stream energy (Cornett, Cousineau, and Nistor, 2013). Similarly, the Pentland Firth located at the northern tip of Scotland is recognised for high tidal current speeds and has gained significant attention as an appropriate location for tidal stream turbines (Martin-Short *et al*., 2015). Scotland is currently home to two established operational tidal arrays: MeyGen Tidal Energy Project in the Inner Sound at Pentland Firth, and Shetland Tidal Array in the Bluemull Sound.

Tidal stream energy devices involve a diverse range of technologies and associated installation methods. For example, some devices are mounted to the seabed, some float on the surface and others can be suspended mid flow. Furthermore, securing turbines to the seabed may use techniques such as pin pilling, whereas some are secured using gravity foundations. There are also different types of tidal stream generators, including axial turbines (horizontal or vertical), crossflow turbines, flow augmented turbines, oscillating devices, and tidal kites (O'Doherty, O'Doherty and Mason-Jones, 2018); there are other more novel technologies in development not discussed here.

The primary case studies considered within this report (SeaGen Unit, Shetland Tidal Array, and MeyGen Tidal Energy Project) are comprised of a subsea bottom-mounted axial turbines, the primary turbine type that data and evidence has been collected against. On the other hand tidal kites, which are not considered in this report, involve a relatively small turbine attached to a hydrofoil wing, tethered to the seabed. Tidal current movements create a lift force that thrusts the kite forward in the water (Roberts *et al*., 2016) and as it 'flies', the current speed increases around the turbine, increasing energy extraction during slower currents (Tethys Engineering, 2024).

1.3 Impact on marine species

In the UK, regulatory authorities have concerns regarding the impact of tidal stream energy technology on marine mammals primarily, but also on fish and seabirds. Key impacts on marine species include the potential collision risk with turbines, underwater noise effects, displacement and avoidance, and electromagnetic fields (EMFs) generated by underwater cables. This section provides a synopsis of the recognised primary impacts and is not intended to be a summary of all possible impacts.

1.3.1. Collision risk

Marine mammal collision risk is a key concern. Regulators rely on collision risk modelling to assess potential impact; there are several model options and there is little evidence to support choosing one avoidance rate over another, all of which can generate large differences in the number of animals predicted to collide with a device (see section 2.1.6). Evidence has shown that the magnitude of impact is location and species specific so it is important to gather evidence to reduce uncertainty and increase our understanding of the risk. Birds and fish are also at risk of collision with a tidal stream device. This risk across birds is more probable for deep diving seabirds which use high tidal current areas as foraging habitats (Furness *et al*., 2012). Fish behaviour around tidal turbine devices is also a key area of research. In Hammar *et al*. (2013), the behaviour of coral reef fish towards a small-scale vertical axis turbine was recorded. No collisions were observed, and fish showed avoidance behaviour particularly in large predatory species, therefore it was summarised that injury from collision was unlikely, however the wider impacts to fish migration and possible restriction to movements between habitats could be a concern (Rossington and Benson, 2020).

1.3.2. Underwater noise

Underwater noise from both construction activity and turbines in operation presents a risk to marine mammals, as exposure to high levels of underwater noise can cause lethal and physical injury, auditory injury and/or a behavioural response (Garavelli *et al*., 2024). During construction, noise from increased vessel traffic and construction activity could cause site-specific behavioural responses. Construction and operational activities may result in temporary or longer-term displacement of animal groups such as pinnipeds (Savidge *et al*. 2014; Sparling *et al*. 2018). Avoidance behaviour in the area close to the turbine motors while they are in motion have also been demonstrated in seals. This near-field behaviour could result in wider scale displacement or a reduction in the abundance of these animals in the project area. However, animals may become habituated and return to the sites when construction is complete (Russell *et al*. 2016). Post-construction, noise is generated when devices are in operation, and maintenance activities may increase vessel traffic in the area.

1.3.3. Electromagnetic fields

Finally, elasmobranchs have electroreceptive organs and use electric fields for prey recognition, positioning, and navigation, and therefore have the potential to be affected by the EMFs generated by underwater cables (Gill *et al*., 2014). EMF impact studies have also focused on other animal groups including species of bony fish, crustaceans, molluscs, cetaceans, and sea turtles. Overall, EMF emissions from turbine export cables are generally deemed below the level that will create a significant risk to marine animals (Garavelli *et al*., 2024).

1.4 Role of the Marine Data Exchange

1.4.1 What is the Marine Data Exchange (MDE)?

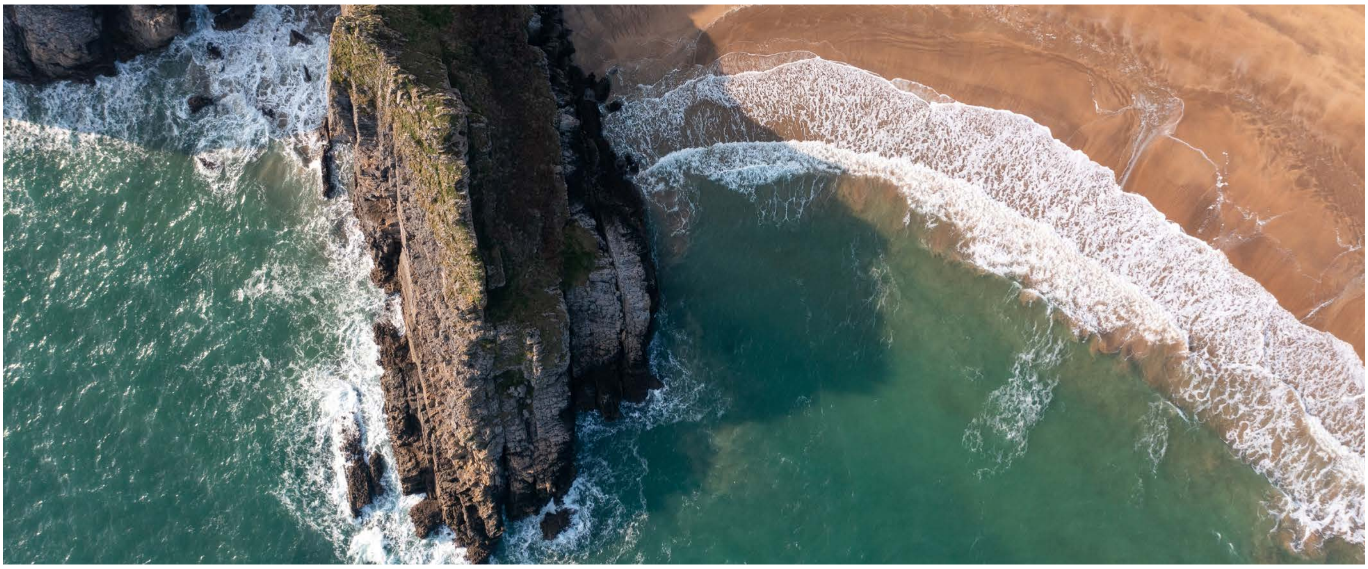
The Crown Estate have been investing in marine data and evidence for over 20 years to support sustainable marine development in British waters. This includes investment to the MDE, which holds the world's largest collection of marine industry survey data, research and evidence, aiming to make data and evidence open and freely accessible.

1.4.2 Marine data collection by offshore industry: feasibility, consenting, and post-construction monitoring

Whilst not a regulator, The Crown Estate leases the seabed around England, Wales, and Northern Ireland to offshore wind, Offshore Wind Transmission Owners (OFTO), wave and tidal, electricity interconnectors, marine mineral extraction and subsea telecommunication projects and within these leases there is a 'data clause'. This clause requires these projects to submit their survey data and reports to the MDE, meaning all the surveys collected throughout the lifetime of a project are required to be uploaded to the MDE.

1.4.3 Application to the tidal sector

Data and evidence on marine mammals and underwater noise from offshore renewable energy sectors in the UK is stored on the MDE. This includes survey data and the associated reports collected and prepared for tidal stream energy projects, with an example being the vantage point monitoring carried out at the now cancelled Ynys Enlli site in North Wales (MDE, 2023). Due to the limited number of tidal stream installations in The Crown Estate waters, we have had to rely on third-party data and have incorporated additional sources of information via publicly available reports. These data and reports primarily pertain to the research and development stages of projects, and to a lesser extent, the pre-construction, construction, and post-construction phases.



1.5 Role of stakeholders in this report

Collaboration and stakeholder input have been fundamental to the research process underpinning this report. Throughout its development, The Crown Estate has maintained an ongoing dialogue with a diverse range of stakeholders, including but not limited to academics, energy councils, regulatory bodies, statutory nature conservation body's (advisory) and developers operating within the marine industry. By actively seeking and incorporating the perspectives of these key stakeholders, this report has benefited from a wealth of expertise and insights, ensuring that the report comprehensively explores, through reviewing evidence, the complex challenges and opportunities presented by the marine environment. Stakeholder input helped with selection of case studies and identified additional site characteristics variables, as well as suggesting contacts from other relevant organisations that could add value to the report. From the engagement undertaken, it is clear that there is widespread interest in drawing the evidence base together but that there are differing views on where best to focus. Whilst this project has been informed by consultation with relevant stakeholders, this report and its findings reflect the position of The Crown Estate alone.

2. Data summary

2.1 Assessment of monitoring and modelling techniques

Monitoring marine mammals, birds, and fish for collision risk requires a multifaceted approach and is largely driven by the need to address but not limited to species specific needs, environmental variability, data accuracy, cost and resource management, as well as regulatory compliance. These factors may shift from site to site, including from country to country and are critical to observing the spatial-temporal overlap between marine species and tidal stream devices, aiming to estimate the probability of encounters and, on a larger scale, avoidance and displacement from the area through monitoring species abundance and distribution. Techniques to monitor this include visual observations through Vantage Point (VP) surveys, boat-based surveys, aerial surveys, hydroacoustic techniques (e.g. sonar), seal telemetry which involves the tagging and tracking using transmitters, and acoustic surveys to monitor vocalising cetaceans. We will highlight survey guidance and techniques further in our next phase of work, (expected completion mid-late 2025), however we would recommend viewing a report prepared by Swansea University and Ocean Ecology for additional information (Clarke *et al.*, 2021).

2.1.1 Vantage Point surveys

Vantage Point surveys are one of the most common survey techniques used to monitor marine mammals and birds in coastal areas and involve looking out to sea from a set high point on land scanning the survey area at regular intervals. They are cost-effective, can provide useful information on marine mammal and seabird presence in the project area, and when continued throughout the life of a project can enable comparison across the project phases. However, these types of surveys are restricted to daylight hours, and there is a known difficulty with accurately locating and identifying sightings across large distances (JNCC, 2005). Observer error can be influenced by meteorological condition, experience and fatigue, and the height of the vantage point. The location of the observation station influences the area of sea that can be surveyed, and features on the seabed such as rocks or peninsulas can impact the survey area (Nuuttila and Mendzil, 2014). Furthermore, features of fast current environments, such as eddies, upwellings, and surface-flow turbulence, affect seabird use and the ability of observers to spot foraging seabirds on or near the surface (Costagliola-Ray *et al.*, 2022). New technologies are being advanced to integrate laser-rangefinding devices, such as Ornithodolite (Cole *et al.*, 2018), into hand-held binoculars to increase the accuracy of seabird sighting locations. The use of binoculars which contain measuring reticles/graticules such as the rangefinder binoculars have been tested by Heal *et al.* (2021), which demonstrated they can be used to provide useful measurements of the movement of European shags *(Phalacrocorax aristotelis)* in a small coastal zone.

2.1.2 External Telemetry Devices

External Telemetry Devices (ETDs) have been used since the 1960s to monitor marine mammal and bird movement and activity that cannot be visually observed and are less invasive than internal implants (Horning *et al*., 2019). The parameters measured can be analysed to produce fine-scale 3D movements and behaviour data, however, tagging animals is difficult and obtaining data on their fine-scale underwater movements can be challenging and expensive to implement. ETDs have restricted retention times with pinnipeds due to the annual moult, and there are size constraints associated with increased battery power (Horning *et al*., 2019). An increased size, although increasing battery power, would hinder the movement of the animal and increase the risk of entanglement. Additional limitations to this monitoring method are that they monitor a small sample of a population, so only provide data on those individuals, and they can also impact the risk of entanglement, visibility and predation (Horning *et al*., 2017).

2.1.3 Passive Acoustic Monitoring

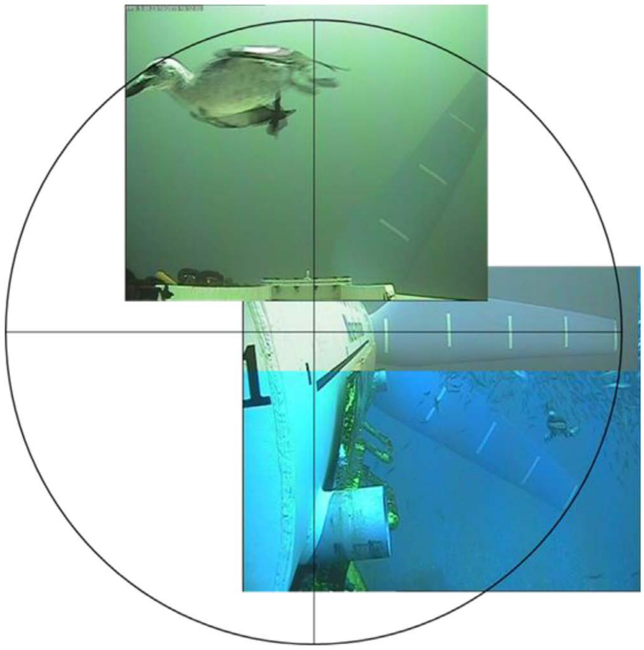
Passive Acoustic Monitoring (PAM) are acoustic monitoring devices, such as Cetacean Porpoise Detectors (C-PODs) and Timing Porpoise Detectors (T-PODs), which can be attached to a turbine to detect cetacean echolocation clicks. Harbour porpoises use echolocation, a biological active sonar used by several animal groups, for movement and detection of prey. PAM can effectively monitor the presence of echolocating cetaceans and can provide data 24 hours a day in high tidal environments. PAM data can distinguish between cetacean communication sounds and sounds produced during foraging, and is a technique being used to detect cetaceans and possibly help classify new species (Palagyi *et al*., 2024). There are some limitations with this method; some individuals may not be detected as they do not continuously vocalise, and vocalisations are directional, so individuals swimming away from the device may not be detected (ABPmer, 2020). It can only be used to monitor cetaceans, and does not detect seals which do not echolocate, or other marine animals such as fish or seabirds.

2.1.4 Hydroacoustic monitoring

Direct collision monitoring uses underwater methods which include hydroacoustic techniques, such as sonar and echosounders, and video cameras. Hydroacoustic monitoring can detect targets in the water by emitting acoustic waves which are reflected off the target (marine animal). It can distinguish individual targets from the surrounding area (Samedy *et al*., 2015). Devices can also collect data continuously across 24 hours and are not limited to daylight. Marine mammals can be differentiated by their large size and strong reflection (Williamson *et al*., 2017). However, during the collection of multibeam-echosounder (MBES) data, in Williamson *et al*. (2017), it was established that seals and birds may have been under classified, "as the default classification of single targets is fish if the U-shaped dive or target size/backscatter does not classify a target as a bird or mammal, respectively." This highlights the difficulty with recording species-specific data using this method. Hydroacoustic devices can be integrated into the tidal turbine or attached to the structure. Computer algorithms are being used and further developed to automatically detect species in the water column, which is key to reducing analysis speed, as data processing is resource intensive.

2.1.5 Underwater video monitoring

Underwater video monitoring enables a greater understanding of near-field encounters and collision risk and can provide data on the frequency of marine mammals, birds, and fish around the turbine device. It can also provide species identification, and therefore allow for species-specific analysis, and the recording of specific behaviours such as fish shoaling, avoidance and collision with turbines. However, this technique is limited to daylight hours, is restricted to depths where there is sufficient light. In addition, high levels of turbidity and biofouling can reduce image quality, therefore increasing manual processing and analysis time. Although video footage accumulated over a survey can present clear and direct evidence of collision or injury, the manual data analysis of a large amount of footage can be very resource intensive (Zhang *et al.*, 2022).



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2.1.6 Collision risk modelling

Given a lack of empirical data, modelling is a key method to inform project impact assessments with respect to understanding potential collision risk of marine mammals with tidal turbines but is considered to have limitations. The main model types applicable to risk modelling with respect to interactions between marine animals and tidal turbines are Encounter Rate Models (ERMs) and Collision Risk Models (CRMs). CRMs estimate the probability of individuals coming into contact with a device (a "collision") or being in close vicinity to the device (an "encounter"), which depends on multiple variables including animal behaviour, species size, and the size/location of the device (Buenau *et al.*, 2022). The Band model, a frequently used CRM developed originally for wind farm ornithology assessments, uses a formula approach to "estimate a collision rate from the risk of collision from a single animal transit scaled by the predicted number of transits over a given period" (Band, 2016), and assumes that the animal is moving in a horizontal trajectory (Horne *et al.*, 2023). The model is limited to horizontal axis tidal turbines (HATT), in contrast, ERM modelling can be applied to HATT and vertical axis tidal turbines (VATT). The ERM model estimates collision risk by calculating the volume per unit time swept by each blade by the tidal energy device and the density of animals in the area and works under the assumption that there is an equal probability of collision from all approaches (SNH, 2016; Horne *et al.*, 2023). Both models need to account for the avoidance behaviour of animals by applying an appropriate avoidance rate (SNH, 2016). There is also a precautionary assumption applied to these models that all collisions are fatal. However, there is a need for more information surrounding the consequences of collision as not all collisions will result in injury/death. Inaccuracy can also exist within these models, particularly when zero avoidance is considered. For example, Population Viability Analysis (PVA), a modelling technique widely used in conservation biology and in the management of threatened or endangered species, and CRM/ERM tools were applied to the Morlais Tidal Demonstration Site. Due to unconfirmed phasing and number of devices the outputs had large ranges, with several of the predictions (which did not consider avoidance) showing that the number of animals killed yearly would be greater than the population size (ABPmer, 2020).

2.2 Case studies

This section addresses the key aim of this report: to summarise key collision risk findings held on the MDE for the SeaGen Unit, and two collision risk studies conducted at Shetland Tidal Array. It also summaries some of the key studies conducted at MeyGen, which involve seal telemetry, PAM, multibeam sonar, and underwater noise measurements. In order to capture data and evidence surrounding testing tidal stream energy in the UK, environmental surveys to monitor potential species displacement at the European Marine Energy Centre (EMEC) Fall of Warness grid-connected tidal test site have been summarised. In addition, a collection of the environmental baseline research and a total of six work packages at the Morlais Demonstration Zone have also been reviewed. Finally, tidal testing worldwide has been outlined and any key results highlighted, to present the wider context of the sector at a global scale. In the worldwide case studies, research to monitor fish species collision risk has been included, due to differing consenting pressures and data and evidence priorities.

This data summary outlines what we consider to be key findings, providing varying levels of detail depending on the information available. Furthermore, the report aims to summarise papers that provide in depth analysis and discussion of the results. Therefore, readers are advised to review the original reports to gain a full understanding of the monitoring, data analysis, and/or modelling that took place, and to find all information available on the results and conclusions.

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2.2.1 SeaGen Unit, Strangford Lough

Figure 3. The SeaGen device: four-footed pin-pile foundation supporting the monopile (Royal Haskoning, 2011).

Located in Strangford Lough, Northern Ireland, a Food and Environment Protection Act (FEPA) marine construction licence for the installation of the SeaGen system was issued to Marine Current Turbines Ltd. (MCT) on 15 December 2005. Strangford Lough is a designated Marine Conservation Zone (MCZ), Special Protection Area (SPA), and Special Area of Conservation (SAC) (Strangford and Lecale AONB, 2024). The SeaGen turbine consisted of a twin blade system with a radius of eight metres which began to generate electricity in currents faster than one metre per second (Tethys, 2019). An image of this device is shown in Figure 3.

The device was commissioned in July 2008, and in December 2008 generated 1.2MW of power for the grid (Tethys, 2019). Decommissioning of the device began in May 2016, after the completion of the project's life cycle, and the turbine structure was successfully removed in July 2019. The first of its kind, the SeaGen device has provided an important resource of tidal stream energy operational survey data from the UK.

The turbine operated a precautionary approach comprising a shutdown procedure when a target travelled towards the turbine, identified through active sonar monitoring. As a design mechanism to reduce risk of collision with a moving blade, this meant that the turbine was turned off when a potential collision risk was detected. The following data summary provides a high level review of the key findings from a series of monitoring studies and surveys that have been undertaken at this site and are held on the MDE.

2.2.1.1 SeaGen on the MDE

A wide range of post-construction surveys undertaken at the SeaGen site are held on the MDE, giving valuable insight on the potential impacts of a tidal turbine device on marine wildlife. As shown in the image below (Figure 4), a primary focus of the SeaGen series held on the MDE is on marine mammals.

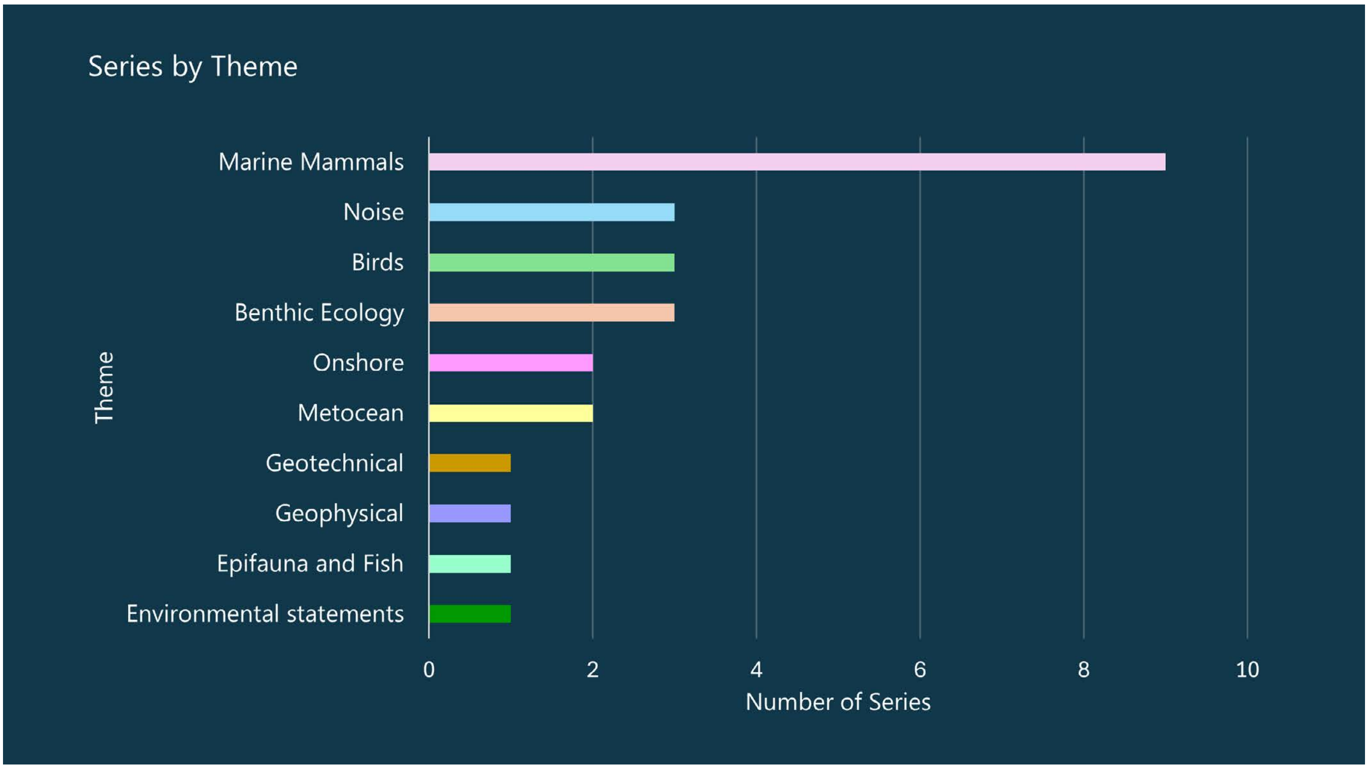

Figure 4. Themes of the SeaGen series on the MDE.

2.2.1.2 SeaGen Environmental Monitoring Programme: Final Report (Keenan *et al.*, 2011)

Royal Haskoning DHV (then Royal Haskoning) established an Environmental Monitoring Programme (EMP) to identify and reduce or prevent environmental impacts caused by turbine installation and operation. The primary concern was the potential impacts on the breeding harbour seal *(Phoca vitulina)* population, as well as grey seals *(Halichoerus grypus)* and harbour porpoises *(Phocoena phocoena)* in the area. This report is held on the MDE in the series '2005-2010, Royal Haskoning, SeaGen Strangford Lough, Environmental Monitoring Programme' (Keenan *et al.*, 2011), and the main conclusions of this report regarding marine mammals are summarised below.

A variety of data collection methods were used to monitor marine mammals in the area, namely active sonar, shore-based surveys, PAM using T-PODs, carcass postmortems, aerial surveys, harbour seal telemetry and underwater noise monitoring. Additionally, data were acquired during active mitigation measures, which aim to prevent, reduce or control negative environmental effects. The EMP has provided a comprehensive array of data, and a holistic view of the potential impacts the SeaGen turbine may have had on marine mammals.

The main findings of the EMP were:

- There was a reduction in harbour porpoise activity during installation, however, no long-term changes in abundance of harbour porpoises or both species of seal could be associated with the SeaGen device
- Sightings from the shore-based surveys were highly variable and "therefore lacked suitable statistical power to confidently rule out undetected changes"
- Metrics monitored were highly variable and therefore comparisons between phases lacked suitable statistical power to confidently rule out undetected changes. However, it was concluded that harbour porpoises and seals are wide-ranging animals, and therefore any changes directly around the turbine were unlikely to have a significant impact at a population level
- The device did not cause a barrier effect, as seals and harbour porpoises continued to travel past whilst the device was in operation
- There were fluctuations in seals and harbour porpoise movement detected at a small-scale, suggesting localised avoidance of the device
- Seals travelled past the turbine at a higher rate during slack tides, the period when the weakest currents occur between the flood and ebb currents and therefore the turbine was stationary or moving slowly
- Postmortems were conducted at key areas which were predicted to be hotspots for stranding including Ballyhenry Bay, Mill Quarter Bay and Ballyhornan Bay which involved the search for and examination of marine mammal carcasses and studying for any indication of impact. The study showed no evidence that their deaths were directly connected with the SeaGen turbine. This method of study may provide data on collision impact if an injured carcass were to be found, however a limitation of this monitoring technique is the difficulty in determining how and when such an injury occurred
- Levels of noise from the turbine while in operation were below levels expected to cause auditory injury, and surveys suggest that neither seals nor harbour porpoises were remaining close enough to SeaGen for a sufficient length of time to cause any hearing damage.

Based on the data collected in Keenan *et al*. (2011), no major adverse impacts on marine mammals were detected. However, the shutdown clause of the turbine, and the patterns of operation and methodological constraints of each monitoring technique limited the ability to detect collision and behavioural change.

2.2.1.3 Measurement and assessment of background underwater noise and its comparison with noise from pin pile drilling operations during installation of the SeaGen tidal turbine device (Nedwell and Brooker, 2008)

Measurements of background and construction underwater noise were measured by Collaborative Offshore Wind Research into the Environment (COWRIE) at the SeaGen device, and are reported within the series '2008, COWRIE, Measurement and assessment of background underwater noise and its comparison with noise from pin pile drilling operations during installation of the SeaGen tidal turbine device, Strangford lough' (Nedwell and Brooker, 2008). This research focussed specifically on harbour porpoise and harbour seal.

The main findings were:

- Background underwater sound levels in the Strangford Narrows are high. This was considered likely to be due to high tidal flow speeds in the area, producing large amounts of noise when the turbulent water mixes at the seabed and at the surface
- Pin pile drilling involves drilling a small type of pile, which generates considerably lower underwater noise levels compared to other pile driving techniques such as percussive (impact hammer) methods

- The noise measurements recorded during pin pile drilling indicate that harbour porpoise and harbour seal are "unlikely to be able to hear the pin pile drilling over background noise"
- The probability of marine species avoiding the area in the vicinity of pin pile drilling was assessed using the dB_{ht} criteria (Nedwell *et al*., 2007). The dB_{ht} species values represents the decibels above the hearing threshold. The data indicated that the noise produced by pin pile drilling did not exceed the level where strong and consistent avoidance by marine mammal species is expected.

It should be noted that the use of dB_{ht} criteria is no longer considered an advisable method to apply in underwater noise assessments (Hawkins and Popper, 2017) and is not accepted by UK regulatory authorities. The Nedwell and Brooker (2008) research study concluded that this area is already a noisy environment for marine mammals that are highly sensitive to noise and that pin pile drilling is unlikely to be audible above background noise. In summary, the data demonstrated that harbour porpoise and harbour seal were unlikely to be disturbed by the pin pile drilling noise unless they were in the immediate vicinity of the construction.

2.2.1.4 Monitoring of harbour porpoise *(Phocoena phocoena)* in Strangford Lough with focus on the Narrows (Mackey *et al*., 2010)

Several reports by Sea Mammal Research Unit regarding the SeaGen tidal turbine are held on the MDE. This section provides a data summary of '<u>Monitoring of Harbour Porpoise (Phocoena phocoena) in Strangford Lough with focus on the Narrows (April 2006 – Oct 2009)</u>'. This report forms part of the '2006-2010, SMRU Ltd., SeaGen Strangford Lough, Monitoring of Harbour Porpoise in Strangford Lough with focus on the Narrows' series. The monitoring period ranged from baseline (pre-installation) to operational (post-installation), to allow for comparison between harbour porpoise clicks before and after the device was installed.

T-PODs were the tool used by this study to investigate the usage of the Narrows by harbour porpoises both pre- and post-installation; T-PODs are advantageous for monitoring, as they log for 24 hours and are therefore able to provide continuous data. They are a reliable method for recording the presence of porpoise activity within a couple of hundred metres from the device; however, their main limitation is that they are only able to identify harbour porpoises that are actively echolocating.

PODs were deployed at the beginning of the monitoring period (April and May 2006). Locations were selected to provide the best acoustic sampling of the study area (Figure 5, page 28). Four PODs were deployed within the Narrows, three in the outer Lough, and three inside the Lough. Over the 36 months of monitoring (between April 2006 and October 2009), 7 PODs were lost, resulting in an uneven coverage of the study area. However, the four PODs in the Narrows were consistently maintained as this was the area of most interest in relation to the turbine.

Figure 5. Map showing the locations of the deployed PODs within the Strangford Lough.

Detection rates of harbour porpoise clicks were low in the Narrows compared to the Inner Lough both before and after the installation of the turbine device, implying that although clicks were low their sustained detection post-installation indicated that harbour porpoises continued using the Narrows as a passageway to the Inner Lough despite the presence of the device. Within the Narrows, there was a significant decrease in the clicks post-installation at the eastern pod locations. This result shows potential evidence of displacement as a direct result of the presence of the device; however, this was not entirely clear from this study and was possibly due to shifts in habitat use by harbour porpoises. At western pod sites, there was no significant decline in clicks.

The study highlighted that there were some limitations with the monitoring methods used. The main limitation of the analysis from this study were that it did not address patchy sampling caused by T-PODs failing to record during deployment, or coverage bias regarding the month of the year, due to the distinct seasonal pattern in detection rates. T-PODs can also rapidly saturate their storage due to tidal noise, impacting sampling periods. Overall, the data suggest that there was still use of the Narrows by harbour porpoises, however, they may have been using the Lough less frequently. Some fluctuations in click detections were noted, however no significant changes were observed between baseline and post-installation data, and harbour porpoises still travelled in the area following the installation of the device. Although the results showed variations in harbour porpoise detections, the findings that they still travelled in the area while the turbine was in operation demonstrates that the tidal turbine did not act as a barrier, and that they were not prevented from travelling into the Inner Lough.

2.2.1.5 Operational underwater noise, SeaGen Unit, technical report – Measurement (Kongsberg, 2010)

This report was prepared by Kongsberg Maritime Ltd. for Marine Current Turbines Ltd. to measure underwater sound levels generated by the SeaGen turbine, and the car and foot passenger ferry "Strangford Ferry" for comparison. It is the summary report of the series '2010, KongsbergMaritime Ltd., SeaGen, StrangfordLough, Operational Underwater Noise-SeaGen Unit' held on the MDE (Kongsberg, 2010).

The method used to record underwater noise involved a hydrophone, amplifier, and an analogue-to-digital converter. The hydrophone was deployed from a survey vessel, enabling it to be carried by the current, and the boat engine and sonar were turned off during measurements. Sound measurements were taken during the day on 3 and 4 November 2009 from a five-metre water depth and involved "drifting runs" where the hydrophone drifts from selected start points upstream of the turbine device. When the device was not operating (on slack tides), acoustic recordings were also made to allow comparison with measurements taken during operation. The species of interest were harbour seal, grey seal, and harbour porpoise.

Table 1. Species for which dB_{ht} values have been generated (source: Kongsberg, 2010).

Species		
Common name	**Latin name**	**Hearing threshold reference**
Common seal	Phoca vitulina	Møhl, B. (1968)
Grey seal	Halichoerus grypus	Ridgway, S.H. and Joyce, P.I. (1975)
Harbour porpoise	Phocoena phocoena	Kastelein, R.A. *et al.* (2002)

Each frequency spectrum was annotated with the unweighted Sound Pressure Level (SPL) for the entire spectrum. SPL can be calculated as twenty times the logarithm to base 10 of the ratio of the root mean square sound pressure over a stated time interval to the reference value for sound pressure, and is defined as:

$$SPL_{RMS} = 20 \cdot \log_{10}\left(\frac{P_{RMS}}{P_{ref}}\right)$$

Table 2. M weighting systems for which values have been generated (source: Kongsberg, 2010).

M weighing system name	Applicable species	Weighing reference
Mhf	high frequencies hearers (i.e. porpoise, river dolphins and the genera Kogia and Cephalorhynchus)	Southall, B.L. *et al.* (2007)
Mpw	pinnipeds (i.e., seals, sea lions, and walruses) listening in water	Southall, B.L. *et al.* (2007)

The dB_{ht} for the species of interest **(Table 1, page 29)** and the selected M weighting systems **(Table 2)** were also determined. These metrics represent the perceived (or sensation) level.

Overall, Power Spectral Density sound levels across all sites monitored from the north of the device were generally higher than levels across all sites monitored from the south. The greatest unweighted SPL was found 311m to the north of the operational turbine at 140.8dB re 1µPa and the lowest unweighted SPL was found 2,937m south of the operational turbine at 126.4dB re 1µPa **(Table 3)**. While the SeaGen turbine was not in operation, background noise measured 100m from the device during slack tide was measured to be 108.7dB re 1µPa. For all three species of interest, dB_{ht} values were greater at 2,937m south than 311m north suggesting that noise levels at the higher frequencies at which these species are most sensitive was greater at the site to the south compared to the site located to the north. As noted previously, the use of dB_{ht} criteria is no longer considered an acceptable method to apply in underwater noise assessments and should be interpreted with caution.

Table 3. Summary of results (source: Kongsberg, 2010).

Range to SeaGen (m)	Unweighted SPL (dB (re.1µPa))	Common Seal (dB_{ht})	Grey Seal (dB_{ht})	Harbour porpoise (dB_{ht})	Mhf weighting (dB_{ht})	Mpw weighting (dB_{ht})
150 (South)	133.7	57.2	52..3	73.8	135.6	136.4
299 (South)	133.6	53.3	48.2	67.2	135.8	136.4
618 (South)	130.6	52.8	47.4	70.8	131.4	132.0
1197 (South)	127.6	59.3	54.8	79.6	128.4	128.7
2937 (South)	126.4	62.7	58.8	85.6	128.9	128.5
311 (North)	140.8	62.2	57.9	78.7	143.0	143.6
695 (North)	138.0	56.2	52.6	76.0	140.4	140.9
899 (North)	135.1	52.8	49.0	78.6	136.9	137.8
FERRY NOISE (50m from ferry)	131.2	55.3	49.4	76.0	131.5	133.1
BACKGROUND NOISE (100m from SeaGen)	108.7	0.3	<0	56.4	104.1	104.3

Unweighted SPL measurements conducted 50m from the "Strangford Ferry" were found to be similar to those recorded 618m south and 899m north of the turbine. At 50m from the ferry, dB_{ht} values for all species of interest were less than they were at 2,937m south of the SeaGen turbine indicating that the level of noise perceived by these species is greater in the Strangford Lough straits than 50m from the ferry.

This study gives us an understanding of how underwater noise generated by the turbine can vary with distance and as a result of the local bathymetry of the area. The study does not comment on whether the levels of noise recorded were considered to be a concern or not.

2.2.1.6 Summary report on the variation in sonar target detections between night and day (Hastie, Mackey and Du Fresne, 2010)

This summary report is contained within the series '2008-2009, SMRU Ltd., Sea GenStrangford Lough, Sonar Monitoring of Marine Mammals around SeaGen' held on the MDE (Hastie, Mackey and Du Fresne, 2010). Two types of data were analysed: sonar and seal telemetry.

The Tritech Superseaking sonar system on the turbine detected targets within a radius of approximately 50m from the turbine. Daytime data were collected between July 2008 and June 2009, and night-time data between September and December 2009. A total of 480.6 hours of data were collected during these periods. Data collected in the day included periods of both operation and non-operation of the turbine. There was no night-time operation of the turbine during this survey period. During the day, target detections could be supported by visual sightings from marine mammal observer (MMO) surveys, however, target detections during night-time data collection could not be supported by visual sightings. In other words, MMOs were not able to differentiate between marine mammals and other targets, such as diving birds, at night given the lack of visibility and any interpretation from the results should take this into account. Additional analysis was carried out using seal telemetry techniques, which involve the tagging and tracking of seals using transmitters.

The telemetry data indicated that tagged seals hauled out during the day and spent more time in the vicinity of the turbine during the night. Contrastingly, the sonar analysis indicated there were fewer marine mammals in the water at night compared to during the day. This survey highlights possible issues with relying exclusively on one form of monitoring for marine mammal detection. The occurrence of different targets detected by sonar (e.g. birds, seaweed) may 'mask' the movement patterns that were able to be detected by telemetry. In addition, telemetry data is only transmitted when the seal is on the sea surface, so seal movements underwater can only be inferred from previous and subsequent surfacing of the animal.

This study highlights some gaps in knowledge surrounding the differences in seal behaviour between day and night, and the limitations of using sonar methods when monitoring marine mammals. The collection of further data comparing day and night abundances may support the future shutdown of tidal turbines at night. A limitation of this study was that there was no operation of the turbine at night when data was collected.

2.2.1.7 Using telemetry to investigate the effect of SeaGen on harbour seal behaviour and movement at Strangford Lough, Northern Ireland (Sparling *et al.*, 2010)

A study using seal telemetry was conducted by SMRU Ltd. spanning from pre-construction in 2006 to post-construction in 2010. The report is held within the series '2006-2010, SMRU Ltd., SeaGen Strangford Lough, Using Telemetry to Investigate the Effect of SeaGen on Harbour Seal Behaviour and Movement'.

A total of 36 individual seals were tagged across three deployment years. They were fitted with electronic tags to obtain data on animal location, diving behaviour and haul-out behaviour. Tagging took place in 2006 (April-July, pre-installation), 2008 (March-July, during installation and commissioning) and 2010 (April-July, operation), with 12 seals tagged in each study year. The Global Positioning System (GPS)/Global System for Mobile Communications

(GSM) tags were programmed to obtain a GPS location every 20 minutes (10 minutes in 2010) and logged when animals were hauled out. Detailed dive data were collected but were only assessed briefly in the study. Further information on the methodology is provided in detail within the report. This includes details on the telemetry tracking system, environmental data, dive depth, animal tracks, transit definition, uncertainty in transit locations and times, testing for differences between years, and Potential Biological Removal (PBR) calculations.

The main findings were:

- There was no overall difference in the rate at which seals travelled up and down the narrows past the location of the turbine between the three years of deployment
- In 2010, there was evidence that the frequency rate at which seals passed through the Narrows reduced when the turbine was operating compared to when it was idle
- Throughout the three years of monitoring, the number of transits was higher at slack tide (when the turbine was idle) compared to when the current was at higher speeds and the turbine was in motion
- Despite visual observations suggesting local avoidance of seals in 2010, high year-to-year variability limits the ability to distinguish any significant difference in behaviour
- The average rate of seals transiting the vicinity of the turbine (<25m) were three transits per year per seal. This suggested that approximately 300 transits may have happened between April and August 2010. There were 210 emergency shutdowns of the turbine during this period to reduce collision risk.

Towards the end of the study, some of the tags transmitted very intermittently. This is thought to have resulted from drained batteries or damaged aerials reducing the quality of the transmissions, and this reduced the data available to estimate movements. In summary, this study concluded that the operation of the turbine influenced the movement of seals in the area, and consequently the collision risk with the SeaGen turbine may be lower than previously estimated. This was due to the assumption that no avoidance by seals of the area in the vicinity of the turbine would take place.

2.2.1.8 SeaGen Data Summary

The reports summarised here indicate that there were likely to be no significant collision risk impacts of the SeaGen device on marine mammals in Strangford Lough, however this is highly caveated by the shutdown clause as any collision was physically prevented from occurring by this mitigation strategy. There is some evidence that they avoided the area during the operation of the turbine. Noise measurements suggest that the device is audible above background noise and emphasises the importance of also measuring background noise during noise surveys for context. Levels of noise from the turbine while in operation were below levels expected to cause auditory injury, and surveys suggest that neither seals nor harbour porpoises remained close enough to SeaGen for a sufficient length of time to cause hearing damage. However, this research highlights the potential for operational noise to cause disturbance over a wider area.

2.2.1 SeaGen Unit, Strangford Lough

FACT SHEET

Factor	SeaGen
Country	Northern Ireland, United Kingdom
Developer	Marine Current Turbines (MCT)
Project start date	December, 2008
Project status	Decommissioned
Project scale	Single device
Support structure/anchor type	Monopile supported by four pin piles
Technology	Surface piercing, bottom-mounted
Installed capacity	1.2MW
Physical site	Constricted channel, shallow channel (<40m), narrow channel (<2km), noisy environment (>80dB)
Water depth	24m
Marine mammals	**Monitoring focus:** harbour seal **Other species observed in the area:** harbour porpoise, grey seal, otter
Collision monitoring	Shore-based surveys, passive acoustic monitoring (T-PODs), carcass postmortems, aerial surveys, harbour seal telemetry, two 375 kHz manually-scanning sonar systems (Tritech Super SeaKing) sonar target detections
Other monitoring	Underwater noise monitoring, ADCP survey data
Seasonality of monitoring	**Shore-based marine mammal surveys:** May 2005 to December 2010 **Aerial surveys:** 2006 to 2010 **Harbour Seal Telemetry:** Pre-installation: April 2006 to July 2006 During installation and commissioning: March 2008 to July 2008 Operation: April 2010 to July 2010 **Passive Acoustic Monitoring (T-PODs):** 2006-2011 **Marine Mammal Carcass Monitoring:** Until September 2009

	Active Sonar: Started July 2008 **Underwater noise:** 23th April 2008 between 09:00 and 21:00 during drilling operations on the North-West foot of the SeaGen base **Benthic ecology:** Pre-installation: March 2008 Post installation surveys: July 2008, March 2009, July 2009 and April 2010 **Ornithology:** April 2005 to March 2011
Number of collisions recorded	No collisions observed
Advantages and limitations of monitoring techniques (inclusive of but not limited to)	N/A
Main consenting concern	Marine mammals, benthic ecology, and tidal flow and energy
Licensing conditions	A detailed Environmental Monitoring Programme (EMP) and associated suite of mitigation measures were established as a condition of the FEPA Licence

*The details included in each fact sheet depend on the availability and reliability of data from third-party sources as well as contributions and opinions from some industry stakeholders. Licensing conditions mentioned are the original conditions that were placed in the EMP at the time of consent

2.2.2 Shetland Tidal Array, Bluemull Sound

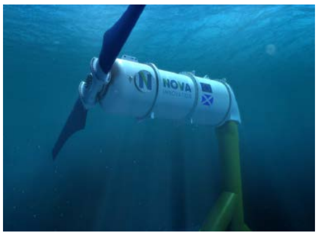

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Figure 6. Nova Innovation M100 turbine models: original M100 (left) and updates M100D (right).

The Shetland Tidal Array is one of Nova Innovation's tidal projects in Scotland which is located in the Bluemull Sound, Shetland, between the Yell and Unst islands. From 2015 to 2017, the first three Nova M100 2-bladed horizontal axis devices were installed (100KW capacity each). These three tidal devices were the world's first offshore tidal array to provide electricity to the national grid with over 17,000 hours of generation reached in 2019 (Tethys, 2023a). Licences were granted in 2018 to extend the tidal array to six turbines. A fourth turbine, with an updated design with no gearbox (M100D), was installed in August 2020. Two more 100kW turbines were added to the tidal array in 2023 (Tethys, 2023a).

The Nova turbines function at a maximum speed of 2.6m/s and are made up of a cylindrical nacelle unit, rotor, and tripod base which attaches them to the seabed (Wills, 2020) (**Figure 6**). The installation method involves no piling or drilling, as they use gravity base foundations (Smith, 2021). The total height of each turbine from the bottom of the feet to the tip of the blades is less than 14m. To ensure there is sufficient draught clearance for vessels, the devices are installed at depths that guarantee that all parts of the turbines are at least 15m below lowest astronomical tide (LAT) (Wills, 2020).

Important monitoring and research priorities identified by the Offshore Renewable Energy Joint Industry Programme for Ocean Energy (ORJIP OE) include developing appropriate methods for monitoring the presence and distribution of birds, marine mammals, fish and basking sharks around tidal arrays, monitoring marine wildlife behaviour, gathering sound (acoustic) data, and hydrographic modelling to forecast changes in water flow (Smith and Simpson, 2018). The wide-ranging EMP by Nova Innovation continues to gather data and has been ongoing since the first turbine was deployed in 2015. It provides a significant source of evidence on these key research areas identified by ORJIP OE, focusing on the relationship between the operational array and marine species, including seabirds and marine mammals (Tethys, 2023a).

The following data summary aims to review key monitoring data of marine mammals and other marine wildlife provided by the EMP and focuses on two main Shetland Tidal Array monitoring reports: Subsea video monitoring EnFAIT-0364 Version 4.0 and EnFAIT-0347 Vantage Point (VP) surveys.

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2.2.2.1 Subsea video monitoring - EnFAIT-0364 Version 4.0 (Smith, 2021)

Between October 2015 and March 2020, underwater cameras were used to monitor the activity of mobile marine species in the close vicinity of the array, such as fish, birds, and marine mammals. Three turbine mounted cameras were attached to each of the three deployed turbines: one attached to the side of the nacelle pointing towards the blades, one attached to the top of the nacelle pointing towards the blades, and one attached to the bottom of the nacelle pointing downwards (towards the seabed). The monitoring generated nearly 20,000 hours of footage, providing a valuable source of data and evidence. Video recording was continuous; however, footage was only preserved when motion was detected. The total dataset of accumulated footage comprised almost 1 million videos, amounting to a storage footprint over 3TB.

It was not possible to manually analyse the entire 20,000 hours of video footage due to limited resources and was therefore reduced into the following four subsets, which comprised a total of 4,049 hours representing approximately 20% of all footage retained between October 2015 and March 2020:

- Subset 1: 28 hours of video footage captured during the day and after the cameras had been cleaned to remove biofouling, providing higher quality images
- Subset 2: 18 hours of video footage that aligned with high counts of black guillemot *(Cepphus grille)* and European shag recorded by the VP survey data (Smith, Date, and Waggitt, 2021)
- Subset 3: Three hours of video footage which aligned with the timings of marine mammal sightings from the VP survey data
- Subset 4: 4,000 hours of video footage, comprising footage commencing in March 2016 and ending January 2017.

No diving birds or marine mammals were observed in any of the footage when the turbines were operating. There were no occurrences of physical contact between marine species and the tidal turbine blades in any of the four subsets of video footage and stills examined.

Marine species behaviour was analysed, and trends were observed. The marine fish, saithe *(Pollachius virens)*, was the most commonly observed species around the turbine, and often grouped together around the device at slack tide. Other mobile species noted were European shag, black guillemot and harbour seal, which were only seen while the turbines were not in operation. Lion's mane jellyfish *(Cyanea capillata)* were infrequently detected drifting by in the video footage (Figure 7, page 37).

Patterns observed in the footage during video analysis suggests that there is a very low risk of encounters between operational tidal turbines and mobile marine species. Encounter rate is defined in Martin *et al*. (2015) as "the rate at which an animal and a boat will be close enough in space and time to potentially collide." Seabirds and marine mammals were only seen in the footage when the turbine blades were stationary and not in operation. When the tidal currents were stronger and the turbines began operating, fish were commonly seen to moving down the water column to the seabed. Further information and the interpretation of the results is provided in the report.

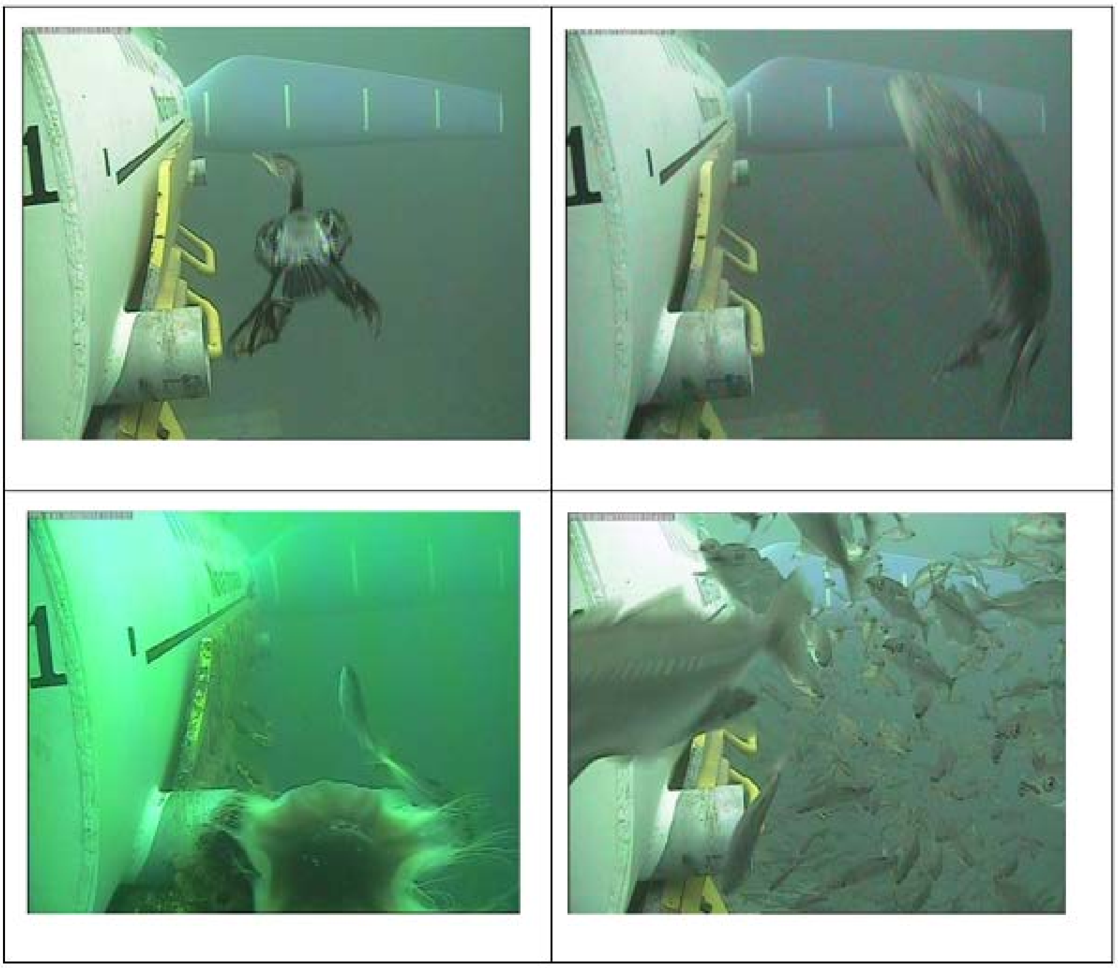

Figure 7. Screenshots from video footage: European Shag (top left), harbour seal (top right), Lion's mane jellyfish (bottom left) and saithe (bottom right) all taken when turbines were not rotating.

The main disadvantage of using underwater camera monitoring in this survey was that it is limited to daylight hours, particularly in the winter months when daylight hours were restricted to 6 to 7 hours. Three cameras per turbine in this monitoring method provided suitable spatial coverage, and the two cameras facing the turbine blades enabled a 60-65% video coverage of the rotor swept area. The report does not detail which parts of the turbine blades may pose the most risk to animals in terms of injury. Biofouling can negatively impact image quality and make it harder to determine what is shown on the images and therefore increase manual processing and analysis time. Using multiple cameras on multiple turbines meant that it generally took months before footage was unusable due to biofouling. During this survey, camera lenses were regularly cleaned during turbine maintenance procedures. For future studies, Nova Innovation is investigating a variety of biofouling management options, such as UV lights.

2.2.2.2 EnFAIT-0347 Shetland Tidal Array monitoring report: Vantage point surveys (Smith, Date, and Waggitt, 2021)

As part of Nova Innovation's EMP, land-based VP wildlife surveys were carried out in Bluemull Sound between November 2010 to October 2019, covering pre-operational, construction and operational phases of the project. The monitoring provides a huge resource for data and evidence, as data from 5,208 10-minute snapshot scans for seabirds and 3,120 20-minute scans for marine mammals have been analysed. The analysis focused on exploring the likelihood of encounters between seabirds, marine mammals and basking shark *(Cetorhinus maximus)* with the Shetland Tidal Array.

The methodology for these surveys was based on a technique described by NatureScot (formerly Scottish Natural Heritage (SNH)) which involves scanning the survey area, usually divided into sections, to provide instantaneous 'snapshot' assessments (Jackson and Whitfield, 2011). Over the nine-year programme, 33 bird species, eight marine mammal species and one basking shark were recorded. Of these, 15 bird and seven mammal species, as well as the basking shark are physically capable of diving to the minimum depths where the turbines are located (15m below sea level), subsequently making them 'at risk' of close encounters with turbine blades (the marine mammal uncapable of diving to minimum depths was the Eurasian otter, *Lutra lutra*). Therefore, these species were the focus of the analysis presented in the monitoring report.

The majority of the diving birds recorded were black guillemot and European Shag, accounting for more than 90% of birds observed. Diving species were present throughout the seasons; however, the Atlantic puffin *(Fratercula arctica)* was only observed in the summer. Three species were seen on less than five occasions: northern gannet *(Morus bassanus)*, red-throated diver *(Gavia stellata)*, and common guillemot *(Uria aalge)*. The most frequently observed species, black guillemot, was only recorded in 11% of all scans and diving in the array area in less than 3% of scans. The European shag was recorded in less than 3% of all scans and diving in the array area in 1% of scans. This reveals a low level of location-based overlap between diving bird species and the tidal array. However, monitoring behaviour and tagging individuals to determine the mechanisms of diving behaviour and dive depth utilisation is important to collect to inform risk of collision with turbine blades.

Marine mammals (and the basking shark) were only observed occasionally and in small abundances. The following species were only recorded once or twice over the whole nine-year survey period:

- Humpback whale *(Megaptera novaeangliae)*
- Minke whale *(Balaenoptera acutorostrata)*
- Risso's dolphin *(Grampus griseus)*
- Killer whale *(Orca orcinus)*
- Basking shark.

The most frequently recorded species were:

- Grey seal
- Harbour seal
- Harbour porpoise.

These most frequently recorded species however, were rarely spotted in the tidal array area. The harbour porpoise made up 45% of all mammal sightings, but was only recorded in 5% of survey scans, and in 0.71% of scans within the array. Harbour seals were recorded in 12% of scans and 0.32% of scans within the array. Grey seals were recorded in 5% of scans and 0.06% within the array. This again highlights a low level of location-based overlap with the Shetland Tidal Array. Detailed results on occupancy by zone and month, occupancy by time, and occupancy by tidal period for each species can be found within the report.

This data indicates that the use of Bluemull Sound by diving birds, marine mammals, and the basking shark is low. During the survey, diving birds in the tidal array area were uncommon and marine mammal sightings were low. The capability to monitor near-field encounters was effective, giving increased confidence in the findings that the probability of near-field encounters between marine species recorded in the site during the nine-year programme of surveys and the tidal turbines is very low.

2.2.2.3 Shetland Tidal Array data summary

The environmental monitoring reports that were prepared by Nova Innovation of the Shetland Tidal Array are a significant source of post-construction data covering the behaviour of a variety of marine wildlife and their relationship with a tidal array. They provide a comprehensive insight into the risk of key marine species encountering turbines. Video footage has provided an important source of data, exploring the relationship between the tidal array, when the turbines were on and off, and marine species. The monitoring results have increased the knowledge base on the interaction between tidal turbines and key species.

The results of the VP survey indicate that marine mammal and bird presence in the array area is generally very low. The most frequently recorded marine mammal species in the VP survey, harbour porpoise, made up 45% of all mammal sightings, but was only recorded in 5% of survey scans, and in 0.71% of scans within the array. The most frequently recorded bird species in the VP survey, black guillemot, was only recorded in 11% of all scans and diving in the array area in less than 3% of scans. In the footage analysed from the underwater video monitoring survey, no diving birds or mammals were observed in any of the recordings when turbines were operating, and no occurrences of physical contact between marine mobile species and the tidal turbine blades were observed. Overall, both monitoring reports concluded that the likelihood of encounters between species and the turbines is low.

The monitoring programme at the Shetland Tidal Array is ongoing, and turbine-mounted subsea cameras are still being used, along with further development of machine learning for more efficient data analysis. The most recent report (Smith, 2024) continues to show that encounter rate is very low and no collisions or near misses were detected.

2.2.2 Shetland Tidal Array, Bluemull Sound

FACT SHEET

Factor	Shetland Tidal Array
Country	Scotland, United Kingdom
Developer	Nova Innovation
Project start date	March, 2016
Project status	In operation
Project scale	Array
Support structure/anchor type	Gravity foundation
Technology	Bottom-mounted
Installed capacity	0.3MW
Physical site	Constricted channel, shallow channel (<40m), narrow channel (<2km), noisy environment (>80dB), hard-bottom habitat
Water depth	30-40m
Marine mammals	**Monitoring focus:** harbour seal **Other species observed in the area:** grey seal, harbour porpoise, humpback whale, minke whale, Risso's dolphin, killer whale
Collision monitoring	Monthly land-based surveys and high-definition cameras on all turbines in the array
Other monitoring	Sound levels of turbines
Seasonality of monitoring	**Vantage Point Surveys:** Conducted over a nine-year period spanning November 2010 to October 2019. Surveys were split quarterly as follows: • February to April • May to July • August to October • November to January. **Subsea video monitoring:** Commenced in October 2015 it was stored and recorded over the period of all turbine installations until August 2017
Number of collisions recorded	No collisions observed

Advantages and limitations of monitoring techniques (inclusive of but not limited to)	**Advantages:** Monthly land-based bird and mammal survey: • Cost-effective and simple technique • Provide information on presence, occupancy patterns and behaviour of animals in and around the project site to gain general insights into the potential for collision risk • Enable better understanding for other potential impacts to species such as disturbance or displacement • Allow for comparison between different project phases. Subsea video monitoring: • Cost-effective and simple subsea monitoring technique • Provide information on presence, occupancy patterns and behaviour of animals around the turbines • Enable better understanding for near-field encounters and collision risk. **Limitations:** Monthly land-based bird and mammal survey: • Do not provide information on animals at turbine depth so data are not accurate for assessing collision risk • Caution required in data analysis and interpretation (e.g. availability bias, influence of meteorological conditions and other wider factors affecting populations and individuals). Subsea video monitoring: • Only gathers useful data in daylight and good water clarity • Generates huge quantities of data for analysis and storage • Requires time-consuming manual analysis or development of AI tools • As with any subsea sensor, biofouling can affect performance.
Main consenting concern	Harbour seal is the primary consenting constraint due to the declining status of the Northern Isles population. Collision Risk Model outputs in combination with other tidal developments affecting the same population (MeyGen, EMEC) exceed Potential Biological Removal (PBR) values for this population. Impacts on other marine mammals are also a concern. The key species of concern are all European Protected Species (EPS) (harbour porpoise, killer whale, Risso's dolphin, humpback whale, minke whale). Several bird species were also raised as concerns in consenting, due to proximity of various Special Protection Areas. The Appropriate Assessment (available on the Marine Scotland Interactive website) concluded no Likely Significant Effect (LSE)

Licensing conditions	The main condition is 3.2.1.1 relating to the need for a Project Environmental Monitoring Plan (PEMP) and regular monitoring reporting. The wording of the condition itself isn't prescriptive about the nature of the monitoring. To ensure it was focused and had clearly defined objectives, Nova developed and agreed a PEMP scoping document with Marine Scotland Licensing and its advisors. Once the objectives were agreed it gave the monitoring clear purpose (detecting any collisions or near misses between marine mammals and diving birds and the turbines, and understanding their behaviour in the nearfield area around the turbines)

*The details included in each fact sheet depend on the availability and reliability of data from third-party sources as well as contributions and opinions from some industry stakeholders. Licensing conditions mentioned are the original conditions that were placed in the EMP at the time of consent

2.2.3 MeyGen Tidal Energy Project, Inner Sound

The Crown Estate (now in Crown Estate Scotland waters) granted SAE Renewables, formerly named SIMEC Atlantis Energy Ltd., an Agreement for Lease (AfL) for the development of an Inner Sound tidal site on the 21 October 2010 in Pentland Firth between Scotland's coast and Stroma (Tethys, 2024a). The lease is for 398MW of Tidal Stream Energy, making it the largest planned tidal stream project globally (SAE, 2023).

Four 1.5MW turbines are currently in operation as part of Phase 1 of the project, while Phases 2 and 3 have a marine licence in place. The turbines that are currently installed and in operation comprise one Atlantis Resources Limited AR1500 turbine (Figure 8) and three Andritz Hydro Hammerfest HS1500 turbines. Both designs are bottom-mounted, have a rotor diameter of 18m, and a gravity foundation (Tethys, 2024a), and therefore do not require piling.

Figure 8. AR1500 model.

Environmental monitoring at the MeyGen project site has taken place since the AfL was secured in 2010. This data summary summarises the publicly available monitoring and research outputs.

2.2.3.1 Quantifying the effects of tidal turbine array operations on the distribution of marine mammals: Implications for collision risk (Onoufriou, 2021)

To track the movement of seals around the MeyGen turbines, Fastloc® GPS/GSM tags (SMRU Instrumentation) were attached to 14 harbour seals in 2011 and 2012, and Fastloc® GPS/Ultra High Frequency (UHF) tags (Pathtrack Ltd.) were attached to 40 harbour seals from 2016 to 2018. As telemetry data records presence only data, data were modelled using a use-availability design to analyse seal distribution with respect to turbine presence/absence and operation/non-operation. Models produced were fitted within the R package MRSea, and final models fitted using Generalised Estimating Equations (GEE). Due to the potential for seals to display behavioural responses to turbine presence, tracking data were analysed and compared between periods when the turbines were present or absent (pre- and post-installation). After installation, data collected during periods when the turbines were turning, and subsequently generating electricity, and idle or off were compared. "A total of 2,493 and 1,442 trips to sea were collected for the presence and operation analyses, respectively. Of the trips used during the operational phase, 1,153 were during non-operational periods and 289 were during operational periods which represented a total of 23,070h and 4,649h of seal data, respectively."

The data collected show that seals demonstrated clear avoidance responses when the turbine was generating electricity, with a significant decrease in abundance within approximately 2km of the array during turbine operations. The mean negative change in usage within 2km of the turbine was -27.6% (mean 95% confidence intervals (CIs): -11% and -49%). This change suggests operating turbines may be undesirable for seals.

Between pre- and post-installation of turbines, no significant change at sea distribution was shown. Sustained barrier effects were not identified. When observing these results, it is important to emphasise that the study did not consider data from harbour seal breeding or moulting seasons, in which may elicit a different response. Future research monitoring behavioural responses during breeding and moulting seasons would be valuable. Nonetheless, these findings provide an important insight into the relationship between the turbine devices and the behaviour of harbour seals.

The reduction in collision risk due to increased avoidance must be considered alongside potential barriers to foraging sites or transit routes. In this study, foraging site boundaries did not appear to be reduced. Nevertheless, potential changes in foraging behaviour between pre- and post-installation is a key research goal to be progressed in the future. Understanding this is important in determining if the scale of tidal turbine arrays can be increased. Continuous monitoring of local population patterns and fine-scale behaviour around turbines, as well as monitoring species in the lower trophic levels, is also key to researching potential long-term impacts.

2.2.3.2 Passive acoustic methods for tracking the 3D movements of small cetaceans around marine structures (Gillespie *et al.*, 2020)

Gillespie *et al.*, (2020) developed a methodology to monitor the movement of small cetaceans around a tidal turbine though their vocalisations. Their PAM technique comprised 12 hydrophones attached to a turbine to detect echolocating marine mammals (Figure 9, page 45). The hydrophones monitored harbour porpoise echolocation clicks and gave an estimate of small cetacean movement in the vicinity of the turbine. The turbine chosen to trial this technique was the Atlantis Resources Ltd. AR1500. PAM can effectively monitor the presence of harbour porpoise due to their distinct echolocation sounds. As stated in the assessment of monitoring and modelling techniques section, there are caveats associated with PAM monitoring. Generally, PAM data cannot be used to differentiate between the absence of cetaceans, cetaceans that are in the area but not vocalising, or cetaceans that are not recorded due to their orientation. Nevertheless, porpoises use their echolocation to navigate through the water column so it is highly improbable that they would stop vocalising close to an audible structure in an environment with strong currents and low visibility.

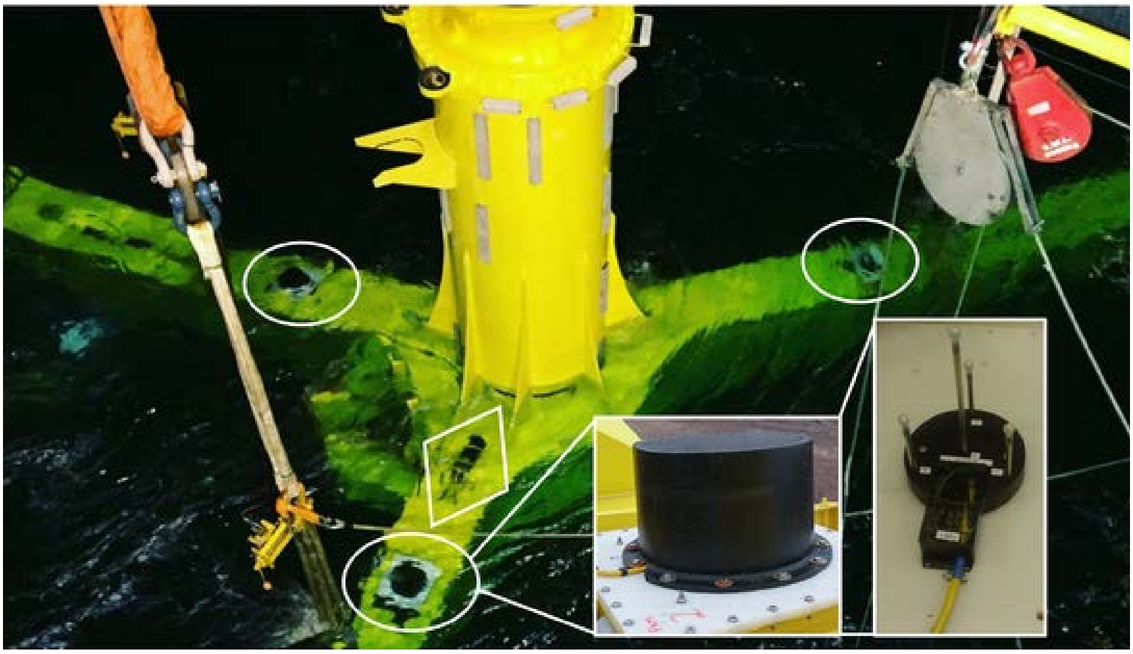

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Figure 9. Photograph of three hydrophone clusters installed on a turbine support structure during installation showing the locations of the three hydrophone clusters (circled) and acquisition junction box (in diamond).

PAM data was collected on 365 days between 19 October 2017 and 31 January 2019. PAM was not operational between 23 September 2018 and 19 December 2018 due to turbine maintenance.

The passive acoustic data that were collected enabled movements to be tracked and provided information on the behaviour of harbour porpoises in relation to the tidal turbine. Calibration of the devices determined "the system can accurately localise sounds to 2m accuracy within 20m of the turbine but that localisations become highly inaccurate at distances greater than 35m." This method was used between 2017 and 2019 at MeyGen, and produced subsequent studies, two of which are summarised (right).

2.2.3.3 Harbour porpoises exhibit localized evasion of a tidal turbine (Gillespie *et al*., 2021)

Between October 2017 and April 2019, clicks from 344 porpoise events were located near to the selected turbine. Across the study period, data was collected across all tidal flow states, therefore turbines were not continuously operational. During this period, 111 clicks occurred when the turbine was rotating and 233 when the device was stationary (Figure 10, page 46). Of these events, only one animal distinctly travelled through the rotor swept area when the turbine was not in operation. No harbour porpoises were detected passing through the rotor swept area when the turbine blades were rotating. Sound measurements revealed relatively high levels of noise when the turbine was operating; therefore, it is probable that the harbour porpoise, which uses sound to detect structures/prey, would have been aware of the turbine in the water column. "Low frequency (less than 1kHz) sound was 5dB above measured background levels over 2km from the turbine and an additional 20kHz noise was detectable above background levels to at least 200m."

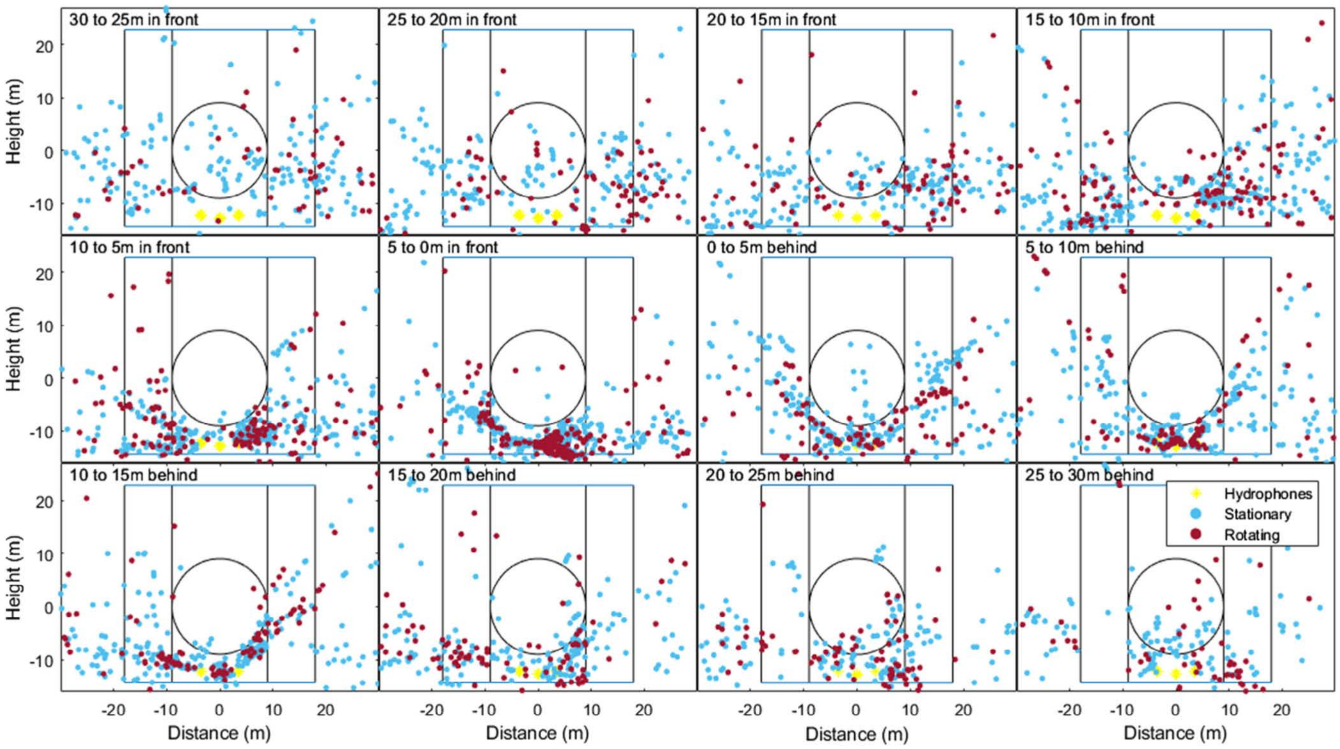

Figure 10. Spatial distribution of localized clicks around the turbine during periods of rotation and non-rotation for different distances in front of and behind the turbine. Each panel shows the distribution of clicks around the turbine in a 5-m spatial slice either in front of or behind the rotors. The central circle is the area swept by the turbine rotor, also shown are the regions described above and used in the statistical modelling (Source: Gillespie *et al*., 2021).

The results of this analysis are particularly significant in the context of concerns about collision risk, as the potential risk of a collision taking place would be reduced if harbour porpoises actively avoided moving turbines. This research concluded that although harbour porpoises were detected near the turbine, they avoided the turbine rotors during operation, therefore suggesting the collision risk is likely to be very low compared to if they exhibited no avoidance techniques. The study undertaken by Gillespie *et al*., (2021) focuses on localised harbour porpoises around a single operational turbine, however, there is still a knowledge gap in data surrounding larger scale displacement impacts and those associated with tidal arrays (Palmer *et al*., 2021).

2.2.3.4 Harbour porpoise *(Phocoena phocoena)* presence is reduced during tidal turbine operation (Palmer *et al*., 2021)

This article addresses concerns regarding collision risk associated with cetaceans and turbine blades using the same 12 hydrophone acoustic survey as Gillespie *et al*. (2020; 2021) to detect porpoise vocalisations in the vicinity of the turbine. Porpoise presence was modelled using Generalised Additive Modelling (GAM), and the mean percentage change in porpoise presence between turbine rotating and not rotating was estimated as a function of flow speed. Parametric bootstrapping was used to produce 95% CIs.

Harbour porpoise numbers varied seasonally, daily, and with the tide. Higher numbers of harbour porpoise were present during the winter, at night, and at high current speeds on the flood tide (Figure 11). When the turbine was in operation, harbour porpoises showed significant avoidance behaviour within tens to 150m froam the turbine; in high flow speeds, porpoise numbers were "reduced by up to 78% (95% CI, 51%, 91%) on the flood tide and up to 64% (95% CI, 3%, 91%) on the ebb tide." This study demonstrates that avoidance rates are important values to feed into CRM and ERM models. However, it is important to note that a single value will only represent a particular level of avoidance during a particular period of the tide (i.e. 78% avoidance only represents the highest level of avoidance in high flow speeds).

The results of the model also show that "avoidance behaviour increases with increasing numbers of operational turbines; porpoise presence was significantly reduced when three of the other turbines in the array were operating (P<0.001)." The report highlighted that this is beneficial in terms of reducing the level of collision risk, however the avoidance of large arrays as the sector scales up could have other adverse impacts on harbour porpoises. It is therefore important to establish how porpoises use the areas where arrays will be constructed, as the avoidance of arrays in areas where porpoises travel between foraging sites may lead to a barrier effect or displacement from key habitats. There is a possibility that porpoises may habituate to the noise created by tidal turbines in the long-term, however this was not possible to determine from this study as the identity of individual porpoises could not be ascertained and no pre-construction data were collected.

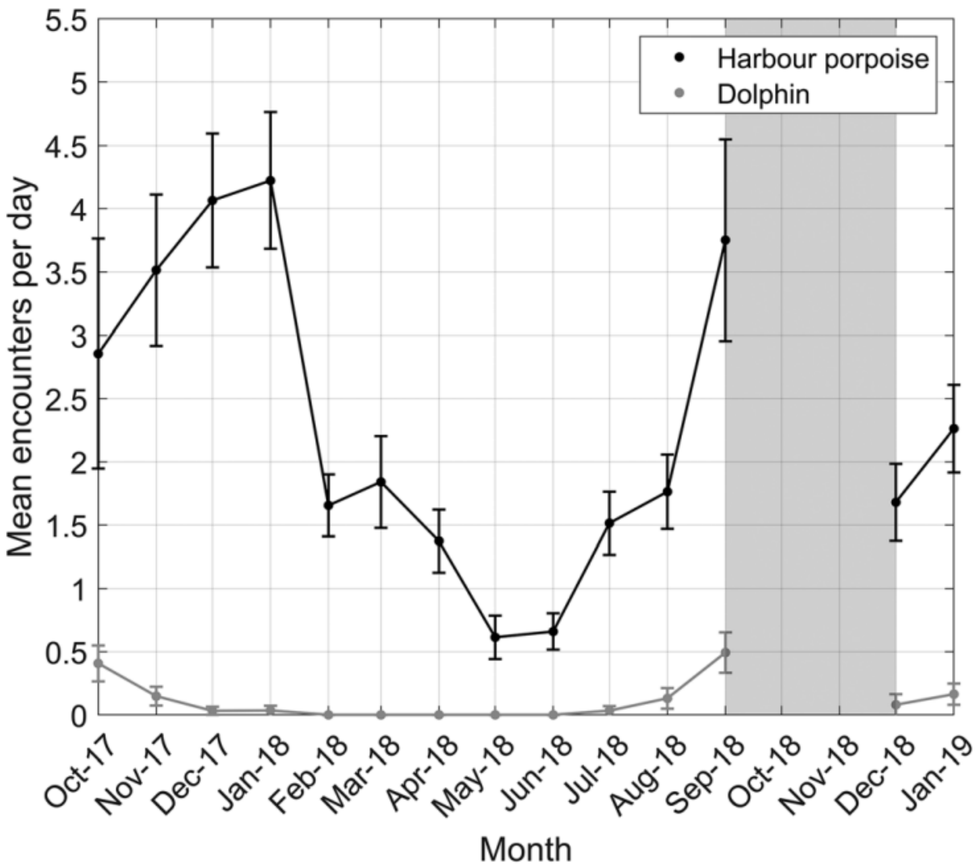

Figure 11. Mean number of harbour porpoise and dolphin detections per monitored day each month. Error bars represent ± one standard error of the mean.

Due to the temporal variation in porpoise numbers both interannually and diurnally, future research should perform long-term monitoring throughout the year to consider daily/seasonal changes in more detail. Future projects should ensure baseline (pre-installation) surveys collect data for longer temporal scales to be able to better understand baseline diurnal/seasonal patterns and if there has been a change following the installation of the device. Although future projects will be able to take account of the available evidence that demonstrates that an avoidance behaviour near to the turbine will reduce the risk of a collision taking place, they will still need to consider the potential adverse impacts associated with any larger-scale avoidance and displacement, for example, in terms of resulting in a barrier to and/or from important habitats or the animal no longer using or moving through the area.

2.2.3.5 Automated detection and tracking of marine mammals in the vicinity of tidal turbines using multibeam sonar (Gillespie *et al*., 2023)

Although PAM is useful for the detection of small cetaceans, a key limitation of this acoustic monitoring technique for seals is that they rarely vocalise underwater, making them harder to detect using these methods. Seal telemetry data has been previously used to map broad-scale surface distributions and diving behaviour, however, tagging animals is challenging and producing data on their fine-scale underwater movements can be challenging and expensive to implement. Therefore, to progress the development of new techniques, Gillespie *et al*., (2023) recently conducted a study in which multibeam sonar collection methods were used at MeyGen. A MBES survey is a method which uses sonar to detect objects in the water by emitting acoustic waves. Continuously over one year, two high-frequency multibeam sonars were stationed at MeyGen collecting marine mammal data. By 2023, manual auditing of 266 days of data was completed. Past research has shown that this equipment can consistently detect marine mammals up to 45m distances without resulting in observable behavioural responses.

In this study, 359 marine mammal tracks were identified, alongside several thousand fish and diving bird tracks. Some false detections were caused by moving turbine parts, however, as the locations of the turbines are known and the devices themselves are static it would be straightforward to remove these false records from data analysis. The results from this study are currently being defined in terms of parameters to investigate how these species react to the moving turbine devices. The data are also being used to investigate the development of improved automated detection and classification algorithms to increase the speed of data analysis.

2.2.3.6 Characterisation of underwater operational sound of a tidal stream turbine (Risch *et al*., 2020)

Alongside collision risk, the impact of anthropogenic underwater sound on cetaceans is another key concern associated with tidal devices. Therefore, it is important to gain meaningful data on the sound generated by active turbines. For this study, turbine and background noise were measured using Lagrangian drifters (Figure 12, page 49), which are oceanographic instruments comprised of a float secured to a drogue which ensures high levels of drifter accuracy. The Atlantis AR1500 turbine T4 was acoustically monitored on 6 August 2018. The Lagrangian drifters had an acoustic recorder and hydrophone attached to them, to measure underwater sound. It should be noted that the rotational speed of the Atlantis AR1500 turbine was relatively low at the time of the measurements and therefore the levels of noise recorded are likely to be lower than when the turbine operates at higher rotational speeds.

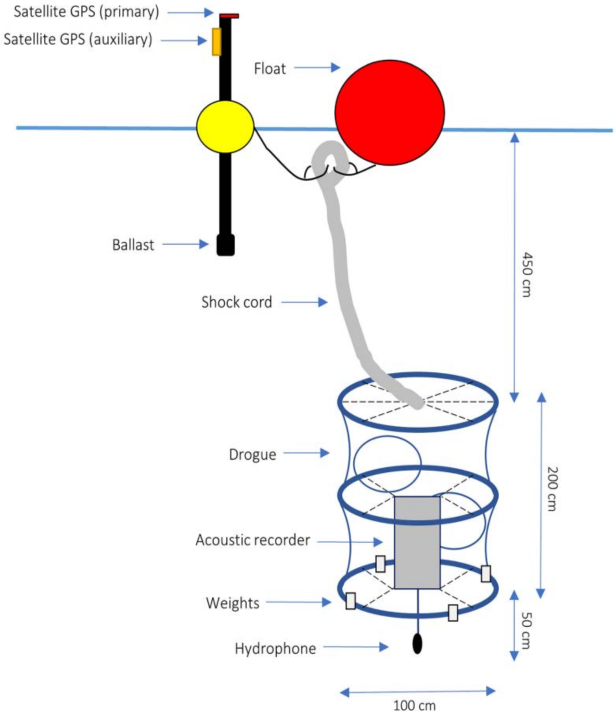

Figure 12. Schema of Lagrangian drifter equipment, with satellite GPS system, carrying the hydrophone and acoustic recording system used in this study (Risch *et al.*, 2020).

Noise levels from the turbine recorded by this study were approximately 30-40dB re 1μPa above background noise levels (ambient) in calmer sea states and was detectable over 2,000m away (Figure 13). A 20kHz tone was detected when the turbine was generating power, likely produced by electromagnetic interactions. A clear relationship between tidal current speed and rotations per minute (RPM), and an increase of 10-20dB at higher current speeds and turbine RPM, were found by the study. This increase may be beneficial in terms of making the turbine more detectable to marine mammals. However, it again highlights the possibility of an increased area of avoidance, such as decreased foraging in the area or barrier effects. Although turbine rotations per minute were known, the operational state of the Atlantis AR1500 turbine throughout this study was unknown. Risch *et al.*, 2020 concluded that in future research, assessing different operational states of the active turbine would be useful, and may also provide valuable information on turbine health diagnostics.

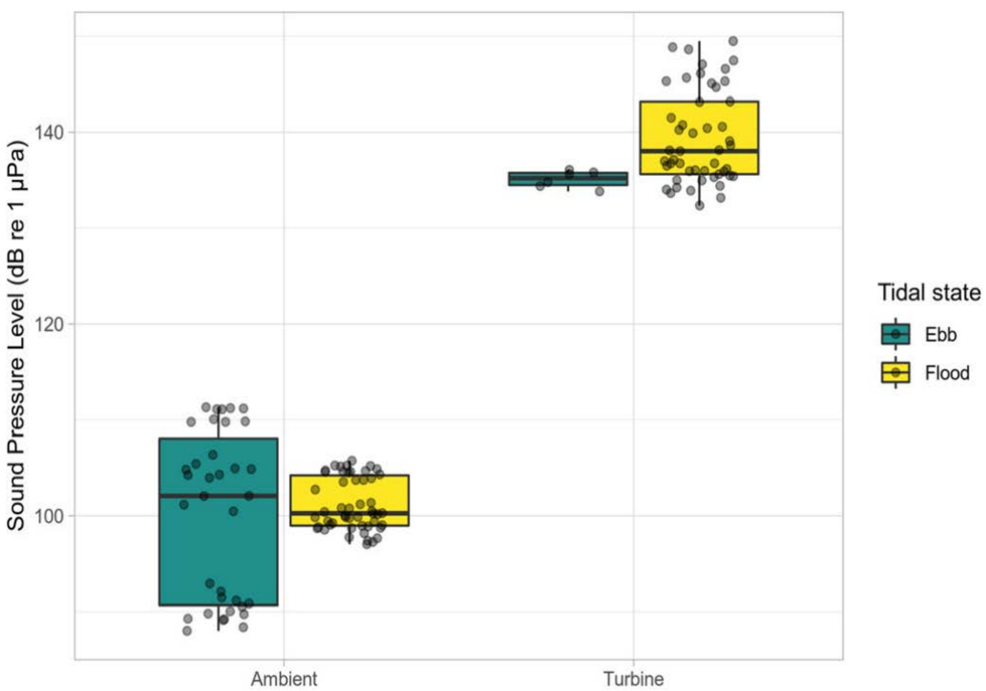

Figure 13. Boxplot of sound pressure levels (SPLs) within 60m of the Atlantis AR1500 turbine.

This in-situ research emphasises the importance of observational sound measurements.

Additional research, however, is required to study the sound generated by turbine arrays and to estimate the noise levels of gradually increasing turbine arrays as the industry expands. The report highlights that evaluating the validity of sound propagation models is crucial to support realistic ecological impact assessments of tidal-stream arrays.

2.2.3.7 Underwater Noise of Two Operational Tidal Stream Turbines: A Comparison (Risch *et al.*, 2023)

To build upon the previous study of the Atlantis AR1500 turbine (Risch *et al.*, 2020), Risch *et al* (2023) measured operational noise of the Andritz Hammerfest AHH 1500 turbine at the same location on 12 and 13 April 2021 using Lagrangian drifters. This aimed to enable comparisons between turbine types and array structure, highlighting the importance of taking into account the turbine type, array configuration, and number of turbines when estimating underwater noise generated by tidal stream energy devices. The three Lagrangian drifters were deployed upstream of the turbine from a small vessel, which cut its engines to minimise boat noise.

When interpreting the results, it is again important to consider the caveat of the previous study; the rotational speed of the Atlantis AR1500 turbine was relatively low at the time of the measurements, and at higher rotational speeds noise levels produced would likely be higher. The comparison between the results of both turbine operational noise showed that "within 100m from the operating turbine, median noise levels in the peak one-third octave band (centred at 100Hz) measured from the Andritz turbine (120dB re 1μPa) were about 10dB lower than those for the Atlantis turbine (133dB re 1μPa)" (Figure 14). The 20kHz tone detected in the earlier study on the Atlantis turbine was not detected at the Andritz turbine.

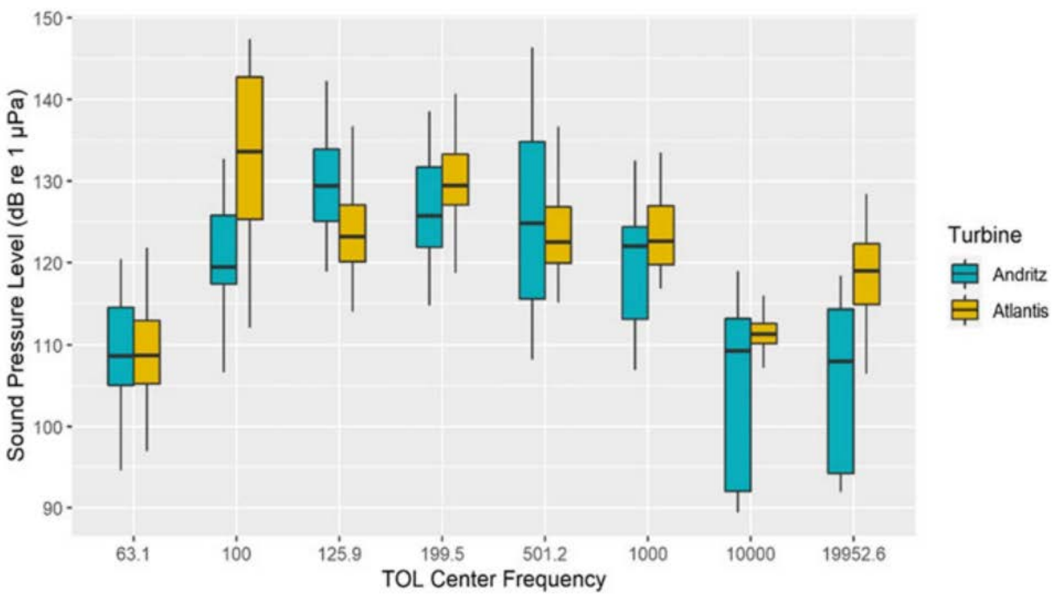

Figure 14. Boxplot of one-third octave sound pressure levels (SPLs) measured within 0-100m from the Andritz Hammerfest AHH 1500 (blue) and Atlantis AR 1500 (yellow), respectively. Measurements were taken during flood tide, sea state less than or equal to 2, and maximum RPM.

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The results of these measurements were used to model noise levels for all four MeyGen Phase 1 array turbines. Modelled broadband (25Hz–25kHz) noise levels of the turbines at peak power generated an acoustic spatial footprint of 1.5km^2 (maximum radius: 845m) above average ambient sound. This area was 0.2km^2 (maximum radius: 334m) when noise levels were weighted using recommended auditory weighting functions for the best hearing of seals. This suggests the array is detectable to harbour seals at a range of at least 300m. However, detection distances can be influenced by tonal signals, ambient sound levels, and turbulence.

These data demonstrate that harbour seals will detect operating turbines at ranges that are likely large enough to avoid collision. Data also suggest that the acoustic spatial footprint of an array will be larger if there is greater spacing between individual turbines. This may have the potential to increase the likelihood of habitat loss. When reviewing this research and considering the mitigation of collision risk alongside potential barrier effects or large-scale habitat loss, it is important to take into account that different tidal stream turbines produce different noise levels which vary with rotation speed and tidal current speed.

2.2.3.8 MeyGen data summary

In summary, the surveys at MeyGen found that marine mammals showed signs of avoidance behaviour near to the turbine, which indicates that collision risk may be lower than previously assumed. However, it is still important to consider the potential implications of larger scale displacement and total avoidance from the area causing a barrier effect, particularly when increasing the number of turbines in an array and scaling up the industry.

The PAM data collected at MeyGen over two years (2017-2019) have provided the following key observations:

- Clear seasonal variation in rates of marine mammal encounters
- A drop in harbour porpoise encounters when the turbine is operating
- Harbour porpoises avoid the turbine rotors.

Seal telemetry data showed seals actively avoided the turbines when in operation but continue to use the site during non-operational periods. The presence of turbines did not cause significant change of at sea distribution, and sustained barrier effects were not identified. In general, movement behaviour did not appear to be obstructed by the presence of turbines, suggesting that pre-installation foraging sites have not been significantly blocked.

2.2.3 MeyGen Tidal Energy Project, Inner Sound

FACT SHEET

Factor	MeyGen Tidal Energy Project
Country	Scotland, United Kingdom
Developer	SAE Renewables
Project start date, 1st power	November, 2016
Project status	In operation
Project scale	Array
Support structure/anchor type	Gravity foundation
Technology	Bottom-mounted
Installed capacity	6MW
Physical site	Constricted channel, shallow channel (<50m), wide channel (>2km), hard-bottom habitat
Water depth	30-50m
Marine mammals	**Monitoring focus:** harbour seal, grey seal, harbour porpoise **Other species observed in area:** humpback whale, minke whale, Risso's dolphin, killer whale
Collision monitoring	GPS tags, Passive Acoustic Monitoring (PAM) using hydrophones, drifters, active sonar data, video recording
Other monitoring	Pre-consent bird survey
Seasonality of monitoring	**Seal GPS Traking:** GPS tags deployed on 40 harbour seals • March to September 2011 • September to October 2016 • April 2017 • April 2018. **PAM:** PAM using hydrophones on Turbine Support Structure and drifters to detect cetacean and track movement. October 19, 2017 to September 22, 2018 (PAM system operational 322 days) then December 18, 2018 to October 15, 2019

	Multibeam Sonar: Over 12 months of active sonar data collected June 2022 to July 2023. Located 32m at right angles to the main flow, the sonar painted the entire structure from seabed upwards **Underwater operational sound:** Acoustic baseline surveys before turbine installation were carried out on October 1, 2015, May 24, 2016, June 23, 2016, June 24 2016. The acoustic survey of the Atlantis AR1500 turbine was carried out on August 6, 2018
Number of collisions recorded	No collisions observed
Advantages and limitations of monitoring techniques (inclusive of but not limited to)	**Advantages:** Fine scale interactions have been obtained using: • passive acoustic techniques for echolocating cetaceans • active sonar to provide a side view of rotor encounters • video cameras with limited field of vision due to technology available at the time and the size of the rotor. All of these methods provided an insight into fine scale iteration of marine species with the turbine rotor and foundation. Each method addresses a different form of assessment and unfortunately, they were not all active at the same time **Limitations:** A data set providing a continual record of fine scale interaction is needed, and while each of the above data sets provide valuable input to collision risk modelling, a concurrent data set would have provided a greater level of certainty as to the level of species avoidance and risk or collision
Main consenting concern	Collisions between marine mammals and installation vessels, collisions between marine mammals and the devices, and disturbance to fish due to EMFs from subsea cables
Licensing conditions	N/A

*The details included in each fact sheet depend on the availability and reliability of data from third-party sources as well as contributions and opinions from some industry stakeholders. Licensing conditions mentioned are the original conditions that were placed in the EMP at the time of consent

2.2.4 European Marine Energy Centre (EMEC) Fall of Warness grid-connected tidal test site

The EMEC tidal test facility is based in Orkney just west of the island of Eday, in a body of water called the Fall of Warness which is approximately 3.5km long and 2km wide (Norris and Droniou, 2007). This is a high tidal energy site with a current velocity of almost 4m/s (Zhu *et al*., 2017). The site offers the opportunity for developers to test their devices **(Table 4)**, and provides environmental and meteorological data on the site, as well as technical support and advice regarding consenting issues (Norris, 2009). The full-scale tidal test site has been active since 2005, and OpenHydro was the first tidal device to initiate testing in 2006.

Table 4. Tidal turbine devices at EMEC and device status (Tethys, 2023b).

Device	Developer	Installed	Status
OpenHydro Turbine	OpenHydro	December 2006	Removed 2022
AK-1000	Torcado	August 2010	Decommissioned November 2011
Deepgen	Alstrom	September 2010	Decommissioned 2016
SR250	Orbital Marine Power	March 2011	Decommissioned 2013
AR1000	Atlantis Resources Corporation	August 2011	Decommissioned October 2012
HS1000	ANDRITZ HYDRO Hammerfest	December 2011	Decommissioned April 2015
HyTide 1000	Voith Hydro	September 2013	Decommissioned April 2015
PLAT-O	Sustainable Marine Energy	Planned 2016	Cancelled
SR2000	Orbital Marine Power	October 2016	Decommissioned September 2018
CoRMaT	Nautricity	April 2017	Decommissioned 2019
T2 Array	Torcado	May 2017	Operation ended December 2017
ATIR Tidal Platform	Magallanes Renovables	February 2019	Ongoing
O2	Orbital Marine Power	May 2021	Ongoing

2.2.4.1 Wildlife monitoring

Throughout the testing of these various devices, EMEC has carried out a wildlife monitoring programme to research the presence of marine species and the possible impacts of device operation in the area. The study, funded by the Scottish Government, SNH, and Highlands and Islands Enterprise, covers almost ten years of observational data and amassed to approximately 18,000 hours of monitoring records (Long, 2018).

The report 'Analysis of Bird and Marine Mammal Data for Fall of Warness Tidal Test Site, Orkney' by Robbins (2012) aims to summarise bird and marine mammal land-based VP observation data for the EMEC tidal test site from 2005 to 2011 (**Tables 5 & 6**), to better understand where and when certain species may more frequently encounter tidal turbine devices.

Table 5. Total number of survey hours that birds were observed between 11 July 2005 and 19 December 2010 (Robbins, 2012).

a)	2005	2006	2007	2008	2009	2010
January		12	22	16	24	38
February		16	26	26	31	48
March		23	35	26	28	52
April		37	29	26	46	52
May		20	35	37	36	28
June		32	35	39	28	42
July	24	47	36	34	33	30
August	18	36	27	29	31	47
September	18	38	27	23	32	49
October	17	32	32	31	55	45
November	22	25	17	25	47	38
December	11	16	21	23	38	20
Total	**110**	**334**	**342**	**335**	**429**	**489**

Table 6. Total number of survey hours that marine mammals were observed between 11 July 2005 and 29 March 2011 (Robbins, 2012).

b)	2005	2006	2007	2008	2009	2010	2011
January		11	10	13	16	23	25
February		16	15	12	27	39	29
March		20	18	14	12	39	18
April		25	22	14	25	30	
May		18	27	24	24	17	
June		31	30	28	23	36	
July	24	45	33	32	27	21	
August	18	34	26	26	30	41	
September	18	37	27	22	31	40	
October	17	32	32	25	53	42	
November	21	19	17	19	39	34	
December	8	14	14	14	23	25	
Total	**106**	**302**	**271**	**243**	**330**	**387**	**72**

The main findings were:

- Interannual variation in the abundance of most species at the site was clearly shown, reflecting breeding and wintering seasonal cycles
- Daily variations at the site were seen in harbour porpoise, grey seal, eider species *(Somateria sp.)*, diver species *(Gavia sp.)*, cormorant species *(Phalacrocoracidae sp.)*, black guillemot *(Cepphus grille)*, and puffin *(Fratercula sp.)*
- Auk species *(Alcidae sp.)* and harbour porpoise were seen more regularly in the open ocean whereas harbour seals, grey seals, black guillemots, eider species, gannets, cormorant species were found closer to the coast
- Species favoured different tidal states: common guillemots were more common in flood tides (low to high tide), whereas cormorant species and harbour seals were more common in ebb (high to low tides)
- Bird species (eider species, diver species, cormorant species and black guillemot) encounter rates decreased when wind speed increased.

The main limitation of visual observational monitoring is that weather conditions can hinder the reliability of sightings. High sea states (a 'choppy' sea) and glare from the sun can impact the observer's ability to observe and identify species. The results over the wildlife monitoring show little indication that seabirds and marine mammals were displaced from either of EMEC's two grid-connected sites (Billia Croo grid-connected wave energy test site and Fall of Warness grid-connected tidal energy test site) (OES, 2022).

2.2.4.2 Displacement analysis: Analysis of the possible displacement of bird and marine mammal species related to the installation and operation of marine energy conversion systems (Long, 2017) and No evidence of long-term displacement of key wildlife species from wave and tidal energy testing (Long, 2018)

To maintain confidentiality and developer anonymity, no results from the operational data collected were attributed to a specific device. Data were collected through VP surveys, 20 hours per week, split into five four-hour watch periods. Models were produced using the observational data to estimate species distribution and abundance using 'MRSea', a statistical modelling R package developed by the Centre for Research into Ecological and Environmental Modelling (CREEM) at the University of St Andrews. Outputs produced from the fitted models suggested that the highest change in species density occurred when the construction of the device took place. In Long, 2017, for the majority of species in the EMEC test site, this level of change was lessened during operation, suggesting the cause of this change was due to the increased ship traffic and movements in the area for construction rather than the operation and presence of the device itself. Similarly, in Long, 2018, for birds in the area, specifically the great northern diver *(Gavia immer)*, black guillemot, common guillemot, cormorants and shags, numbers in the area changed during construction but abundance reverted to original numbers when the installation was complete. This pattern was also observed for marine mammals. However, there are caveats with accepting this conclusion. Ship movement data collected during the observational survey was anecdotal, rather than quantitative. Future research should obtain more accurate vessel traffic information using Automatic Identification System (AIS) data. Furthermore, due to the Fall of Warness site's operational status continually varying, the conclusion that the decrease in the scale of change with increasing site impact level as evidence of habituation is debatable. Additional research is necessary to understand the impact of long-term operation at a population level, and wider barrier-effects.

2.2.4.3 Fall of Warness Tidal Test Site: Additional acoustic characterisation (Harland, 2013)

In 2011 and 2012, Chickerell BioAcoustics was contracted by the EMEC to undertake work to further characterise the background sound at their tidal energy test site. The site is an area frequented by local fishing boats and ferries, therefore shipping noise is expected in the environment. Furthermore, several fish farms are found in the area, and seal scarer devices may be present. As Tidal Energy Converter (TEC) devices are installed at the test site, construction and operation will further contribute to anthropogenic noise produced. In terms of background sound, waves on the Eday and Muckle Green Holm shorelines have an impact, and the fast current speeds (7 knots) during spring tides will cause sediment movement and fast current to further contribute to background sound produced. Weather conditions, such as wind and precipitation, and breaking waves, also contribute to the background sound at the site. Finally, biological noise such as communication between marine mammals and vocalisations also contribute to the ambient noise.

The study was carried out on the 20 September 2011, using Drifting Ears equipment, and 23 and 26 of March 2012, using Drifting Acoustic Recorded and Tracker (DART) equipment. A hydrophone was deployed at a 5m depth from a flotation buoy. Since the study was carried out across three days, it only provides a snapshot of the acoustic environment at the site and does not represent the complete breadth of noise sources and measurements. Future research should measure noise over a breadth of tide and meteorological conditions.

Due to sound generated by fast currents, noise above 1kHz varied by up to 26dB re 1µPa, and rain increased background noise levels by 30dB re 1µPa. From the results of this study, it was summarised that the impact of additional noise from a single device would likely cause "little or no impact on the echolocation systems used by marine mammals unless the animal is very close to the generator." However, the EMEC site aims to support multiple operating turbine devices. Harland (2013) concluded that additional surveys into noise levels generated by multiple TECs would be required to increase knowledge and understanding of this. The impact on echolocation systems was not expressed in terms of disturbance or injury.

2.2.4.4 FLOw, Water column and Benthic ECology 4D (FLOWBEC-4D)

FLOWBEC-4D is a collaboration between Natural Environment Research Council (NERC) and Department for Environment, Food and Rural Affairs (Defra) to research the impact of wave and tidal devices. FLOWBEC is a sonar platform made up of multiple instruments to capture two weeks of data on tidal conditions during entire spring-neap tidal cycles. A multifrequency echosounder (Simrad EK60) is synchronised with a multibeam sonar (Imagenex Delta T), an Acoustic Doppler Velocimeter (ADV) records flow data, and a fluorometer is fitted to record chlorophyll levels, to provide an indirect means of measuring phytoplankton levels, and turbidity (Williamson *et al*., 2016).

The FLOWBEC frame has been deployed six times at tidal and wave sites in Scotland, and a study by Williamson *et al*. (2017) focused on two deployments: one 22m away from the Atlantis turbine structure and the other a control deployment not in the vicinity of a turbine structure, both deployed in summer 2013 to align with bird breeding season. Measurements can be analysed to reveal how species prefer different tidal conditions and how they might interact with tidal turbine devices. This research effectively showed monitoring of seabirds, fish, and fish schools in the water column around a turbine structure, using novel algorithms to distinguish these individuals from the strong levels of backscatter in an acoustically noisy environment caused by fast-flowing current speed (4m/s). New processing techniques were developed which effectively filtered out turbulence and reflections and identified biological individuals for tracking.

Acoustic monitoring using multifrequency echosounder and multibeam sonar enables surveys to be conducted 24 hours a day, regardless of daylight hours, visibility, or whether an individual is vocalising. In the future, additional equipment could be added to provide more data, such as cameras, and Acoustic Doppler Current Profilers (ADCPs) to measure current speed. The FLOWBEC frame is portable so could be used at additional sites, as individual turbines are up scaled to arrays and new sites undergo marine spatial planning.

2.2.4 European Marine Energy Centre (EMEC) Fall of Warness grid-connected tidal test site

FACT SHEET

Factor	Orbital Marine Power O2 at EMEC	Magallanes Renovables ATIR at EMEC
Country	Scotland, United Kingdom	Scotland, United Kingdom
Developer	Orbital Marine Power	Magallanes Renovables
Project start date	April, 2021	February, 2019
Project status	In operation	In operation
Project scale	Single device	Single device
Support structure/anchor type	Mooring lines, gravity anchors	Mooring lines, gravity anchor
Technology	Floating	Floating
Installed capacity	2MW	1.5MW
Physical site	Open coast, constricted channel, isolated/quiet environment (<80dB), hard-bottom habitat	Open coast, isolated/quiet environment (<80dB), hard-bottom habitat
Water depth	12-50m	
Marine mammals	**Monitoring focus:** harbour seal, grey seal and harbour porpoise **Other species observed in area:** minke whale, Risso's dolphin, humpback whale, sperm whale, killer whale, common dolphin, bottlenose dolphin, Atlantic white-sided dolphin, white-beaked dolphin	
Collision monitoring	Surface cameras, underwater cameras and preparing for active acoustics	
Other monitoring	Bird and marine mammal observations (2023-2025)	

Seasonality of monitoring	**Vantage Point surveys:** Conducted daily from July 2005 to 2011. 4hrs a day 5 days a week across winter, spring, summer and Autumn **Video monitoring:** Between June and July 2009 and June 2010 **Hydrophone:** The study was carried out on the September 20, 2011, using Drifting Ears equipment, and 23 and 26 of March, 2012, using Drifting Acoustic Recorded and Tracker (DART) equipment **Sonar:** FLOWBEC frame deployed twice in summer 2013	
Number of collisions recorded	No collisions observed	
Advantages and limitations of monitoring techniques (inclusive of but not limited to)	**Disadvantages:** Battery life on video monitoring and acoustic data unless power source available Very high energy environment to deploy/recover equipment and maintain	
Main consenting concern	Acoustic disturbance due to increase vessel presence onsite, installation and maintenance work and the direct acoustic output from the turbine during operation Risk of entanglement of marine megafauna with the mooring system and dynamic cable Displacement and disturbance to species in the immediate vicinity Seabed clearance including impact to benthos Biofouling and introduction of non-native species during towing operations Collision risk of marine megafauna with the moving parts of the device	Disturbance and/or displacement due to the presence and operation of the ATIR and associated vessels Disturbance from the acoustic output from the operational ATIR and vessels associated with installation, maintenance and decommissioning Risk of interaction/collision with the turbines installed on the ATIR Risk of entanglement or entrapment with the mooring system for the ATIR Disturbance from breeding/ migratory routes through electromagnetic interference Biofouling and introduction of non-native species Pollution from accidental discharges
Licensing conditions	Collision risk modelling Device acoustic characterisation	Collision risk modelling Device acoustic characterisation

*The details included in each fact sheet depend on the availability and reliability of data from third-party sources as well as contributions and opinions from some industry stakeholders. Licensing conditions mentioned are the original conditions that were placed in the EMP at the time of consent

2.2.5 Morlais Demonstration Zone

The Morlais Demonstration Zone, managed by Menter Môn, is a Welsh tidal stream energy test centre currently in development, following consent that was granted by Welsh Government in 2021 and a marine licence by Natural Resources Wales. The intention of the Morlais Demonstration Zone (MDZ) is to support the tidal stream energy sector in the early development and consenting phases, by providing multiple developers with an opportunity to deploy their devices without needing to seek additional grid connection or consents, therefore reducing their costs and enabling a faster deployment. The consent obtained for Morlais covers a range of tidal device types and technologies including seabed mounted, mid water column and floating devices **(Figure 15)**.

The 35km^2 area has the potential to generate up to 240MW of energy (Morlais Energy, 2024b). Currently, infrastructure is being put in place to enable turbine device installation at the site; the project substation was completed in October 2023 and turbine devices are expected to be in the water by 2026 (Offshore Energy, 2024). A phased approach to deployment is required as part of the Adaptive Management for this project. Monitoring is being undertaken to observe marine wildlife in the area as part of the Morlais Marine Characterisation Research Programme (MCRP) where an innovative adaptive management system is being demonstrated on the Marinus buoy. The project has collected vital baseline data during phase 1 which will be used to help inform decision making around the safeguarding of marine species, as the Morlais project progresses into operation. During phase 2, which is ongoing at the time of this report, new monitoring and mitigation technology will be demonstrated during the phased development of the site. Funded by the European Regional Development Fund, The Crown Estate and Nuclear Decommissioning Authority, the MCRP aims to test innovative monitoring technologies and collect environmental data to enable the safe phased deployment of turbines in the MDZ. In doing so, the MCRP intends to address key evidence gaps surrounding the impacts of tidal stream deployment on the marine environment, reduce consenting risks and therefore support the growth of the tidal stream sector in the UK more widely.

The data collected as part of the MCRP, which includes a collection of pre-construction monitoring reports and data collection surveys with a focus on marine mammals and seabirds,

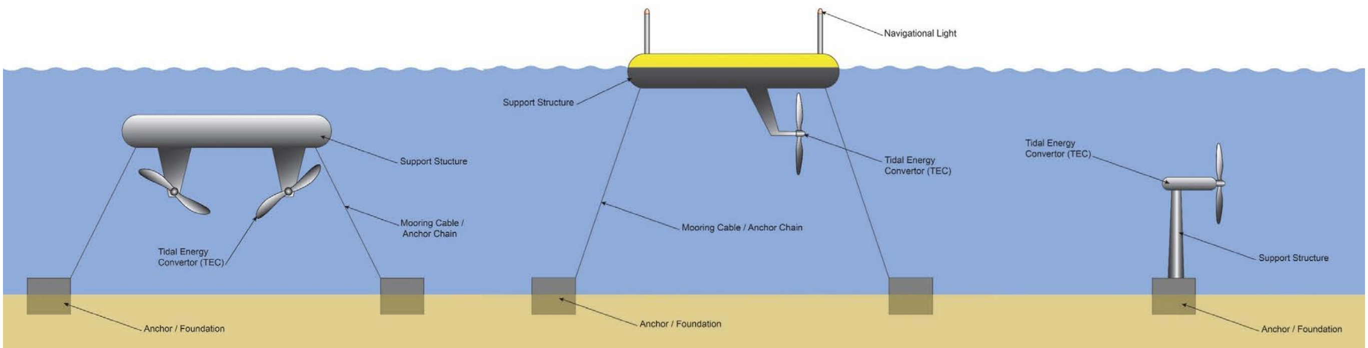

Figure 15. Graphic illustrating the range of different device types consented.

will be hosted on the MDE and therefore made public for academics, stakeholders, regulators, and other developers. The recent upload from the MCRP (January 2025), published over 40 terabytes of work packages. They comprise of different surveys and research using a variety of monitoring techniques, for example:

- Hydrophones
- Sonar
- PAM
- Underwater cameras
- Land-based VP surveys
- Boat-based surveys
- Photography
- Drones
- GPS/GSM tagging.

A considerable amount of information is held within the work packages, however only some of the techniques and the resulting results from the list above are explored in this review (Appendix 1). This is because the work packages contain pre-construction data or technology trials, whereas the primary aim of this review is to highlight existing construction and post-construction collision risk data. As there are no turbine devices in the water, this cannot at present be monitored at the MDZ. A collection of the research for the MCRP are summarised below:

2.2.5.1 2022-2023, Swansea University, Marine Characterisation Research Project, Auk tagging (WP7) (Cole *et al.*, 2024)

Collecting pre-construction baseline data is important to assess the potential impact of devices going in the water, and to allow for comparison with post-construction data so that any changes in species abundance or distribution can be identified in the future. Data can also be used to feed into collision risk models, for example in this series, razorbills and guillemots were GPS tagged to map their foraging locations and track the number of dives in the MDZ to support future collision modelling.

2.2.5.2 2022-2023, University of St Andrews, Marine Characterisation Research Project, Harbour Porpoise Dive Profiles (WP1b) (MacAulay *et al.*, 2023)

PAM was used to determine porpoise diving and foraging behaviours, and differences in site use by different life stages. Porpoises were detected throughout the survey and across all tidal states. The monitoring enabled porpoise diving tracks to be constructed in 3D, and showed porpoises regularly dived to the seabed and swam across the whole water column. These data aim to support future quantitative collision risk assessments by providing swimming depths of porpoises.

2.2.5.3 2022-2023, University of St Andrews, Marine Characterisation Research Project, Targeted Acoustic Startle Technology (TAST) effects on Dolphins (WP8) (Janik, Zein, and Götz, 2023)

This work focussed on potential mitigation measures to deter marine mammals from the turbine. This series tested the acoustic startle method using a Genuswave Ltd. TAST device, to deter common bottlenose dolphins *(Tursiops truncatus).* Deterring marine mammals aims to reduce potential collision risk, therefore it is vital to test potential methods that could reduce the chance of a turbine encounter taking place. Initial trials were also undertaken into the use of the TAST to deter diving seabirds, with initial results being positive.

2.2.5.4 2023-2024, Ocean Science Consulting, Marine Characterisation Research Project, Surface (WP3) and Underwater (WP4) Imaging (Ocean Science Consulting Ltd, 2024)

This series consists of data collected from a camera system, consisting of a subsea RGB (red, green, blue) camera and associated computers and power supply, developed and deployed on a buoy at the MDZ. This subsea camera collected data and ran a custom Machine Learning (ML) detection algorithm in real-time. Data were successfully recorded over a four month and 16-day period during four deployments. These data have been collected to investigate the feasibility of surface and underwater cameras to detect marine fauna, with the aim of providing an automatic detection and classification system for marine animals to enable the automatic triggering of deterrents at the Morlais Demonstration Zone.

2.2.5.5 2022-2023, University of St Andrews and Sea Mammal Research Unit and Scottish Oceans Institute, Scottish Oceans Institute, Marine Characterisation Research Project, Seal Tagging (WP13) (Longden and Hastie, 2024)

This series assesses the use of the area within and surrounding the MDZ by grey seals. Twenty SMRU Instrumentation GPS Phone Tags were deployed on grey seals in July/August 2023 which collect GPS locations and dive data over a period of months. The tags were successfully deployed over a two-week period on both sexes and across age-classes of seals. Data collected will be analysed to provide an understanding of seal distribution and behaviour within the MDZ, and a quantitative assessment of dive data will be conducted to quantify the relative time spent in the at-risk depths of turbine rotor blades.

2.2.5.6 2023, Sea Mammal Research Unit, Morlais, Marine Characterisation Research Project - Active Sonar (WP2) (Hastie *et al*., 2023)

This work package was designed to develop an active sonar monitoring system to detect marine mammals in close proximity to operational tidal turbines and help mitigate the risks of collision. The monitoring system will monitor near field avoidance behaviour by marine mammals to turbines, determine whether tidal state may influence avoidance behaviours, trigger mitigation actions and potentially provide data to monitor the efficacy of mitigation actions. This report describes the software development progress, data collected and analysed to support the developments, and result of pilot tests on a turbine at MeyGen.

2.2.5 Morlais Demonstration Zone

FACT SHEET

Factor	Morlais Demonstration Zone
Country	Wales, United Kingdom
Developer	Menter Môn
Project start date	December, 2021
Project status	Pre-construction
Project scale	Test site
Support structure/anchor type	Multiple (Monopile, gravity foundation, mooring lines, gravity anchor, drag embedment anchor, rock anchor)
Technology	Multiple (Bottom-Mounted, Suspended in Water Column, Floating)
Installed capacity	Up to 240MW
Physical site	Isolated/quiet environment (<80dB), soft-bottom habitat, hard-bottom habitat
Water depth	40m
Marine mammals	**Monitoring focus:** harbour porpoise, grey seal, bottlenose dolphin, common dolphin, Risso's dolphin, minke whale **Other species observed in area:** harbour porpoise, common dolphin, Risso's dolphin and bottlenose dolphin
Collision monitoring	As this test site is in pre-construction, no collision monitoring has been performed to date. Monitoring at Morlais include soundtrap recorders, hydrophones, PAM, towed PAM, subsea cameras, land-based vantage point surveys, GPS/GSM tagging, underwater noise monitoring, boat based surveys, drones (+technology testing)
Other monitoring	Sonar, boat based technology deployment
Seasonality of monitoring	**Soundtrap (15 static PAM units):** December 2022 to November 2023 - 12 months continuous deployment **Bottom and surface mounted Hydrophones:** November 29, 2022 to July 25, 2023 - four field trips collected 139 hours of drifting array data **Surface and subsea cameras:** June, 2023 to March, 2024

	Land based vantage point surveys: May 2022 to September 2022 **Bird tagging:** June 2022 and June 2023 **Colony counts:** April 1, 2022 to July 15, 2022 and April 1, 2023 to July 15, 2023 **Underwater noise modelling:** February 11, 2023 to February 12, 2023 **Boat based surveys:** April 2022 to March 2024 **Drones:** March 2023 to September 2023 **Towed 3D PAM:** November 29, 2022 to July 25, 2023 **Seal tagging:** July 2023 to March 2024 **Sonar:** 12 months **Boat based technology:** June 1, 2023 to September 12, 2023
Number of collisions recorded	N/A
Advantages and limitations of monitoring techniques (inclusive of but not limited to)	**Advantages:** Boat based surveys, colony counts, tagging (seal and bird) and underwater noise monitoring are tried and tested survey methodologies. This reduces the likelihood of difficulties with the techniques. The data analysis is relatively standard and therefore not complex The EMMP intergrated monitoring system is expected to allow deployment of tidal stream devices in very sensitive areas, whilst effectively managing any potential risk of collision **Limitations:** As with all data collection, the volume of data that is collected, then has to be stored. This is particularly relevant with the sound trap data - 12 months worth of data from 15 sound traps was collected. This all needs to be processed as well as stored. The processing time is human time hungry Limitations of the subsurface cameras is the visibility on site Weather on site - e.g. preventing boat based surveys Vantage point surveys - the limitation of these surveys was that it was not possible to clearly see the MDZ from the cliff, therefore removing any benefit of these surveys The number of experts in some of the fields (i.e. seal tagging) is small, therefore reducing options

	The main limitation of the mitigation system is that this is not an off the shelf system. It is being developed as part of the project as no such mitigation system is commercially available. As the system is being developed, and this development involves the training of AI systems to identify objects seen on sonar imagery, this takes time. There are also setbacks when developments do not go according to plan
Main consenting concern	The ES produced in relation to the original application identified potentially significant effects upon some marine mammal and diving seabird species, particularly through collision with operational TECs and displacement if the Project was to be deployed to maximum installed capacity without mitigation measures Underwater noise from operational turbines and any acoustic deterrent devices (ADDs) used will not result in the significant disturbance of marine mammals (harbour porpoise) in the North Anglesey Marine/Gogledd Môn Forol SAC Visual impact is also a major consideration at the site given its proximity to the Area of Outstanding Natural Beauty (AONB)
Licensing conditions	There are many conditions, however the most relevant are: Requirement for the development and implementation of an EMMP (Environmental Mitigation and Monitoring Plan) Requirement for the development and implementation of a MMMP (Marine Mammal Mitigation Plan) for any construction activities Species specific marine mammal collision limits: Harbour porpoise: 3 per year Grey seal: 5 per year Bottlenose dolphin: 2 over 3 years Common dolphin: 5 per year Risso's dolphin: 1 per year Minke whale: 1 per year All other cetaceans: 1 per year Confirmatory visual impact assessments required before array deployments to allow consent with a wide range of possible technologies under the Project Design Envelope approach Confirmatory Navigation Risk Assessments required before array deployments to allow consent with a wide range of possible technologies under the Project Design Envelope approach

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2.3 Worldwide

Tidal stream energy is in its early stages of development worldwide, primarily due to the limited evidence and uncertainty over environmental impacts; the MeyGen project and Shetland Tidal Array are both key examples of operational arrays currently gaining data and evidence. The UK is at the forefront of tidal stream technology regarding operational developments and installed capacity and plays a vital part in the current tidal stream energy landscape.

Globally, France, Canada, China, and the USA all have a high capacity of tidal energy currently in development with a number of technology developers (Serin, 2023). Around the world, there has been a push to advance the energy transition towards marine renewable technologies. South Korea have launched a strategy so that by 2030, there will be 700MW of energy generated by tidal stream energy (Choi, Kim, and Yoo, 2022).

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Following a study by Zheng *et al*. (2015), which concluded that China has the potential to supply over 8.2GW of electricity from this technology, mainly in the Zhoushan Islands, Zhejiang Province, China has become one of the leading countries in tidal stream energy. In 2021 they ranked second worldwide for installed tidal stream energy generation (Qin, 2023). A variety of test projects have been conducted to date due to the identified potential resource in China. Multiple demonstration projects were undertaken; Zhejiang University (ZJU) conducted trials with a 5kW horizontal axis turbine in 2006, and tested a subsequent 25kW device in 2009. The second device generated 30kW of power at peak rate at a current speed of 2.4m/s (Li *et al*., 2008). Northeast Normal University (NENU) also developed a 2kW horizontal axis turbine, trialled in Qingdao (Zhu *et al*., 2012). More recently, a project neighbouring Xiushan Island, Zhoushan, Zhejiang has been successfully generating tidal stream energy. A 1.03MW single-capacity turbine was installed in 2022 named 'Endeavour', and its total capacity is expected to reach 3.3MW (OES, 2023). No publicly available collision risk data was available to highlight from projects located in China.

The global drive towards marine renewable technologies strengthens the need for increased data and evidence on tidal stream energy. This section aims to provide a summary of tidal stream test projects and projects currently in development outside of the UK to provide a global view of advances in the technology, and highlight any key publicly available environmental data.

2.3.1 France

The French Government has pledged to provide at least 65 million euros for the new tidal turbine farm Flowatt, due to begin operation in 2026. The project involves seven 2.5MW vertical axis turbines at the Raz Blanchard demonstration site in Normandy (Germain, 2023). Flowatt is being developed by HydroQuest with backing from Qair. When completed, it is estimated to supply enough energy for 20,000 people for 20 years (Artelia, 2023).

This project builds on previous tidal testing at Paimpol-Bréhat in Brittany, established in 2008 by EDF. The first project was operated by OpenHydro which tested its Tidal Energy Converters resulting in two 1MW turbines in 2016, and HydroQuest began testing 1MW tidal turbines at the site in 2019 (Moreau *et al*., 2021) (Figure 16), and developed a small-scale trial for the Flowatt project. Flowatt is expected to be of huge significance in the French tidal energy sector, and will bring France into the operational tidal stream sector alongside the United Kingdom.

2.3.1.1 Sabella D10 Tidal Turbine at Ushant Island

Off Ushant Island in Brittany, France, the tidal turbine Sabella D10 was installed between 2015 and 2016 in the Fromveur Passage. The tidal device is a 1MW turbine with a horizontal axis and six blades, and it was the first French tidal turbine connected to the grid and producing electricity (Paboeuf *et al*., 2016). In 2018, the turbine was reinstalled as part of the European Intelligent Community Energy (ICE) project (Tethys, 2024b). New developments at the tidal device include a small electrolyser connected to the turbine to trial green hydrogen production in December 2022. Video camera monitoring has taken place at the tidal device to monitor collision risk of marine mammals, fishes and birds. Observation showed low abundance of fishes around the turbine rotor, and fishes only being present when the turbine was not generating electricity during slack tides (Sabella, 2020).

In 2024, Inyanga Marine Energy Group purchased the D10 turbine and became the operator for the project, following liquidation of Sabella in January 2024.

Figure 16. 1MW turbine deployed on Paimpol-Bréhat test site in Brittany (source: HydroQuest).

2.3.1 France

FACT SHEET

Factor	D10 Tidal Turbine
Country	France
Developer	Previously Sabella, now Inyanga (Oct 2024)
Project start date	June, 2015
Project status	In operation
Project scale	Single device
Support structure/anchor type	Gravity foundation, gravity anchor
Technology	Bottom-mounted
Installed capacity	1MW
Physical site	Open coast, hard-bottom habitat, noisy environment (>80dB)
Water depth	55m
Marine mammals	**Observed in the area:** harbour porpoise, Atlantic bottlenose dolphin, common dolphin, striped dolphin, long-finned pilot whale, Risso's dolphin, grey seal
Collision monitoring	Video cameras, hydrophones, C-PODS, surface measurements
Other monitoring	ACDPs, biofouling
Seasonality of monitoring	**Underwater video monitoring:** October 2018 to April 2019 and April to September 2022. Monitoring in 2022 stopped because of biofouling on the camera. Data collected not analaysed by Sabella **C-Pod data:** June 2021 to January 2022 (no turbine immersed). C-POD data summer 2022 (with turbine), data not analysed by Sabella
Number of collisions recorded	No collisions observed
Advantages and limitations of monitoring techniques (inclusive of but not limited to)	**Advantages:** Camera on the turbine allowing live acquisition of the data. C-Pods able to record independently and very reliable **Limitations:** Biofouling on camera that occasionally needs to be cleaned. Analysis of the videos very time-consuming and tedious (no automatic software). Lots of problems with the instruments not located on the turbine (ADCPs, cameras on separate structures, etc.). Standard hydrophone not relevant

Main consenting concern	Biofouling, interactions with fishes (collision), acoustic (mammals), impact on sediment transportation (adressed by numerical modelling). More recently, cable electromagnetism and impacts of coatings and anodes
Licensing conditions	Report on environmental monitoring to be transmitted every semester Following monitoring required: acoustic (acoustic environment, marine mammals; equipment must be able to identify species), current, video (interferences fauna/turbine), analysis of species close to the demonstrator and collision risk, diving birds, biomass (biofouling) This was determined following the Environmental Impact Assesment carried out as part of the permitting process

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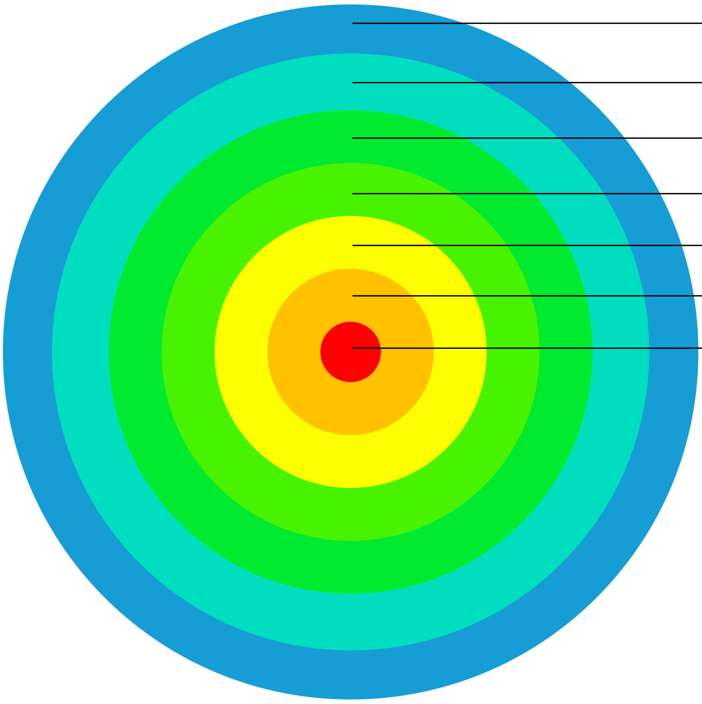


Figure 17. Recreated image of conceptual probabilistic framework for quantifying the likelihood of collision risk for marine animals and operational tidal energy turbines (Copping *et al*. 2023).

2.3.2 Canada

North America is home to the largest tides in the world, particularly in the Bay of Fundy, Canada, where Minas Basin has a tidal range of 16m (McMillan *et al*., 2008). The region, especially Minas Passage, has been recognised as an area for renewable tidal energy generation potential (Cornett, Durand and Serrer, 2010); numerical simulations show that almost 2.5GW of renewable energy can be extracted from the area (McMillan *et al*., 2008).

2.3.2.1 Fundy Ocean Research Centre for Energy (FORCE)

FORCE, established in Minas Passage in 2009, is Canada's leading test centre for the demonstration of tidal stream energy technology. FORCE provides infrastructure (e.g., subsea power export cables, a grid-integrated substation) to support testing of tidal turbine technologies at its test site, and conducts a series of environmental monitoring programs to assess the effects of tidal technologies on marine animals transiting through Minas Passage and surrounding habitat. This initiative has provided the infrastructure required for testing tidal technology performance, and the series of environmental monitoring programs and associated research programs have generated numerous reports and publications related to the physical environment of Minas Passage and its biological constituents. Some of this work focuses on the understanding the risk of key environmental concerns surrounding this industry in Canada such as collision risk, which are likely to be applicable to the UK.

FORCE collaborated with tidal stream energy proponents and OES-Environmental in 2023 to publish a peer-reviewed paper in the Journal of Marine Science and Engineering. This study outlines a stepwise probabilistic methodology for understanding collision risk of marine animals with tidal turbines (Copping *et al*., 2023). The method outlines a sequence of steps, each with an associated probability of occurrence, for a marine animal to come close to a tidal turbine and be injured or incur mortality (**Figure 17**). The method concludes that the possible risk of harm being caused by tidal turbines to marine animals is expected to be low (Copping *et al*., 2023).

An Environmental Effects Monitoring Program (EEMP) at FORCE has taken place since 2009 and the most recent report is from 2024. These reports aim to showcase key results of monitoring at the FORCE site and include results from international surveys and research undertaken by its partners. The current version of the EEMP focuses on research in anticipation of the deployment of tidal energy devices and the adoption and implementation of best-practices for monitoring approaches (FORCE, 2023).

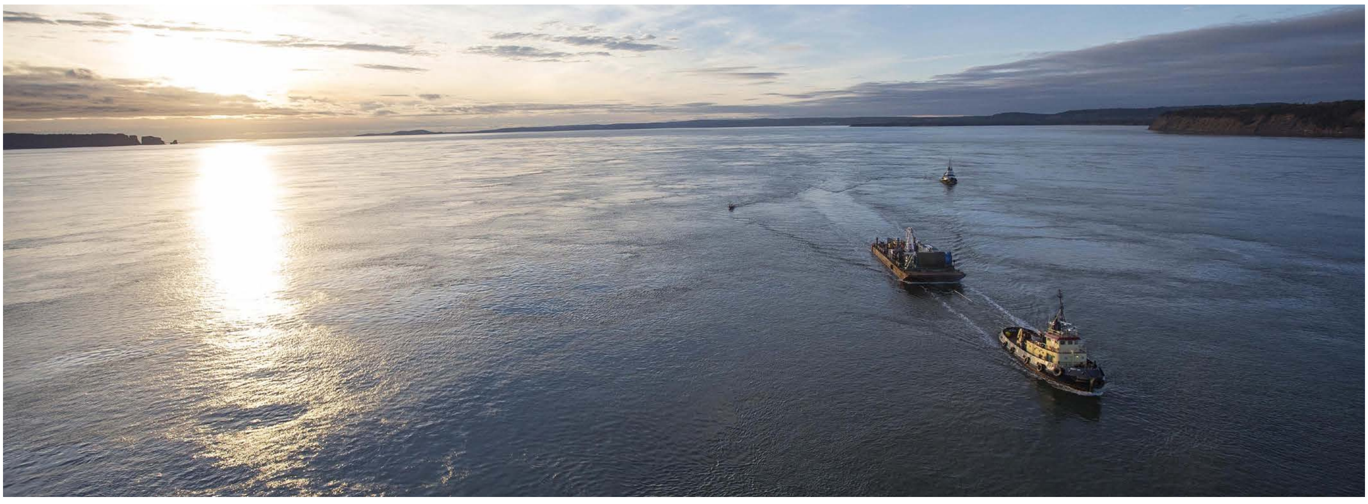
2.3.2.2 Baseline presence of and effects of tidal turbine installation and operations on harbour porpoise in Minas Passage, Bay of Fundy, Canada (Tollit *et al*., 2019)

Harbor porpoise are the primary marine mammal found at the FORCE site. Monitoring using passive acoustic devices (C-PODs) recorded 1,210 days of data to capture harbor porpoise echolocation activity within and outside of the FORCE area between May 2011 and May 2018. Five C-PODs were deployed, and recorded harbour porpoise echolocation clicks on 98.9% of days. Statistical modelling confirmed seasonal changes in harbour porpoise presence (peaks in mid-June and early November). It also suggested that harbour porpoise presence varied by current speed and time of day (more echolocation activity at night). Some limitations of the C-POD methodology were noted, including monitoring 'time lost' due to high levels of ambient noise during periods of elevated current speed that saturated the C-POD detection buffer.

The possible environmental effects of 130 days of operations of a 16m diameter 2MW OpenHydro tidal turbine on Harbor porpoise were assessed. C-POD data revealed harbor porpoises did not leave the wider study area during turbine installation, but there was a reduction in echolocation activity at sites closest to the device (200-230m) when the turbine was operational, suggesting some localized avoidance behaviour. However, at a monitoring site 1,690m from the turbine, echolocation activity increased during turbine operation. Before conclusions can be made, Tollit *et al*. (2019) recommends the collection of additional data from longer-term turbine deployments. After the turbine was removed, the echolocation activity "returned to pre-installation baseline rates."

2.3.2.3 PLAT- I, Grand Passage

In 2018, Sustainable Marine Energy installed PLAT-I 4.63 in Grand Passage (between Long Island and Brier Island, in Digby County, Nova Scotia). PLAT-I is a floating platform with four SCHOTTEL SIT250 70kW turbines (ABPmer, 2020) and 6.3m diameter rotors (Meza and Rojas, 2020). In February 2019 the turbines began to generate electricity, and in June 2019 the first phase of testing was completed (Tethys, 2020). Operational monitoring occurred through visual surveys during turbine operation, underwater video cameras that were deployed and aimed at all four turbines, and hydrophones. Additional details on the methodology for the underwater video data collection were unavailable at the time of this writing. Visual surveys were conducted for marine animals at 30-minute intervals during turbine operation. Across both types of monitoring, no contact between marine animals and the turbines was observed. In the video footage, few marine animals were detected around the turbines. In May 2022, Sustainable Marine announced the delivery of the first floating in-stream tidal power to Nova Scotia's grid, using the 420kW PLAT-I 6.40 (Force, 2022). The PLAT-I 6.40 was built on the lessons learned from previous deployments in Nova Scotia and Scotland. Sustainable Marine Energy has since filed for bankruptcy and no longer has a presence in Canada.



2.3.2 Canada

FACT SHEET

Factor	Fundy Ocean Research Centre for Energy (FORCE)
Country	Canada
Developer	Fundy Ocean Research Center for Energy
Project start date	September, 2009
Project status	In operation
Project scale	Test site
Support structure/anchor type	Rock-bolt anchors, gravity foundations and gravity anchors
Technology	Bottom-mounted and floating tidal devices
Installed capacity	Up to 30MW
Physical site	Constricted channel, deep channel (>40m), wide channel (>2km), noisy environment (>80dB), hard-bottom habitat
Water depth	45m
Marine mammals observed	**Observed in area:** harbour porpoise, harbour seal, minke whale, sei whale, fin whale, North Atlantic right whale
Collision monitoring	C-POD, acoustic telemetry
Other monitoring	Lobster - Before/After, Control/Impact (BACI) study design using modified commercial traps Fish - Hydroacoustic surveys Seabirds - Observation-based surveys Marine sound - drifting and stationary hydrophone deployments
Seasonality of monitoring	Program dependent, but largely continuous between May 2011 and May 2018; intermittent thereafter based on requirements **Lobster catchability surveys:** Two surveys conducted in the fall of 2009 (before and after turbined deployment). One survey in spring of 2010 Baseline lobster catchability survey conducted over 11 days in 2017 582 lobsters tagged and released in fall 2021. Phase 1: August 29, 2021 to September 2, 2021. Phase: September 27, 2021 to October 1, 2021 **Fish hydroacoustic surveys:** Three 24-hour surveys pre-deployment (May, August, October 2016) and four 24-hour surveys during operation (November 2016, January, March, May 2017). Additional surveys after removal of Cape Sharp turbine (July, August, November 2017)

	Marine sound: Deployment of drifting hydrophone in October 2016 and March 2017 **Marine Mammals:** 2011 to 2020: Continuous passive acoustic monitoring (PAM) using C-PODs
Number of collisions recorded	N/A - operational devices not deployed for long enough to assess collisions
Advantages and limitations of monitoring techniques (inclusive of but not limited to)	**Limitations**: High flow conditions place limitations on monitoring instrument performance generally Surveys using active acoustic devices are impacted by entrained air due to turbulence associated with tidal flows Minas Passage is a noisy environment, and the detection buffer of CPODs quickly becomes saturated with flow noise at high current speeds leading to lost monitoring time
Main consenting concern	Collision risk with fish - particularly those afforded protection under Canada's Species at Risk Act, but also those of commercial and recreational value and those of cultural relevance to Indigenous communities
Licensing conditions	Specifics around monitoring requirements are being determined under a 'revised staged approach' to tidal project permitting proposed by DFO that stems from the final report of the Tidal Task Force on Sustainable Tidal Energy Development in the Bay of Fundy

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2.3.2 Canada

FACT SHEET

Factor	PLAT-I 4.63	PLAT-I 6.40
Country	Canada	Canada
Developer	Sustainable Marine Energy	Sustainable Marine Energy
Project start date	September, 2018	May, 2022
Project status	Decommissioned	Ended April 2023
Project scale	Single device	Single device
Support structure/anchor type	Mooring line, Drag embedment anchor	Mooring line, Drag embedment anchor
Technology	Floating	Floating
Installed capacity	0.28MW	0.42MW
Physical site	Constricted channel, shallow channel (<40m), narrow channel (<2km)	Constricted channel, shallow channel (<40m), narrow channel (<2km)
Water depth	14m	14m
Marine mammals	**Observed in the area:** harbour porpoise, dolphin, grey seal, harbour seal	**Observed in the area:** harbour porpoise, dolphin, grey seal, harbour seal
Collision monitoring	Hydrophone, underwater cameras, visual marine animal observations	Hydrophone, underwater cameras, visual marine animal observations
Other monitoring	VEMCO Tag detector	VEMCO Tag detector
Seasonality of monitoring	**Video monitoring:** Recorded continuously through operating periods, which occurred intermittently between February 2019 to February 2020. Operatings were limited to daylight hours **Visual marine animal monitoring:** Every 30 minutes during turbines operation	**Video monitoring:** Recorded continuously through operating periods May to November 2022. Operatings were limited to daylight hours **Visual marine animal monitoring:** Every 30 minutes during turbines operation
Number of collisions recorded	No collisions observed	No collisions observed

Advantages and limitations of monitoring techniques (inclusive of but not limited to)	**Advantage:** Underwater video monitoring can provide species identification, and therefore allow for species-specific analysis, and the recording of specific behaviours such as fish shoaling, avoidance and collision with turbines **Limitations:** Video only effective during daylight hours and hydrophone only provides present (positive) indication of 1 or more individual porpoise or dolphin	**Advantage:** Underwater video monitoring can provide species identification, and therefore allow for species-specific analysis, and the recording of specific behaviours such as fish shoaling, avoidance and collision with turbines **Limitations:** Video only effective during daylight hours and hydrophone only provides present (positive) indication of 1 or more individual porpoise or dolphin
Main consenting concern	Fish	Fish
Licensing conditions	Hydrophone and underwater video monitoring; intermittent marine life visual observation; daylight-only operation; cease operations if Species at Risk sighted within 100m; quarterly reporting	Hydrophone and underwater video monitoring; daylight-only operation; cease operations if Species at Risk or whale sighted within 100m; quarterly reporting

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2.3.3 United States of America

In the USA, there have been several test and demonstration projects with a number of devices in various stages of development. In 2022, the U.S. Department of Energy (DOE) pledged $35 million in funding from the Bipartisan Infrastructure Law to the continued development of tidal and river stream projects (Office of Energy Efficiency & Renewable Energy, 2022).

To support the U.S. DOE and address the growing need for marine energy technologies globally, the Pacific Northwest National Laboratory (PNNL) developed Tethys. Tethys is a knowledge hub for relevant research, and aims to facilitate the exchange of information and evidence on the ecological and oceanographic effects of marine and wind energy technologies, and enhance the connectedness between developers, stakeholders and researchers (Tethys, 2024d). It continues to support the renewables energy community through various projects, including this document, investigating the complexity of environmental issues associated with marine technologies.

2.3.3.1 Roosevelt Island Tidal Energy (RITE) Project Pilot

Roosevelt Island Tidal Energy (RITE) Project Pilot was a testing site located in New York City's East River (Verdant Power, 2020). Three bottom-mounted turbines were installed in 2020 and, up until their decommissioning in 2023, delivered more than 312MWh of tidal generated electricity to the grid (Tethys, 2021). This project was river-based and did not focus on marine mammal monitoring; however, it did involve monitoring plans to tackle other site-specific environmental issues such as the presence of migratory fish species, a variety of gull species, and endangered fish species (shortnose sturgeon, *Acipenser brevirostrum*, and the Atlantic sturgeon, *Acipenser oxyrinchus oxyrinchus*).

As required by the project pilot licence, Verdant Power conducted RITE Monitoring of Environmental Effects (RMEE) data collection projects, including seasonal Dual-Frequency Identification Sonar observation monitoring, seasonal species characterisation netting, tagged species detection, and a Kinetic Hydropower Turbine System-Fish Interaction Model (KFIM) (Verdant Power, 2020). One of the outputs from these efforts was a study by Bevelhimer *et al.*, (2017), conducting hydroacoustic measurements at RITE to monitor the behaviour of fish passing through the turbine array. During the research, no evidence was seen that fish were struck by

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the turbine rotors. Regulators accepted there was little evidence of potential harm to fish species. This enabled the risk to be retired for the project and allowed Verdant to limit their fish monitoring. However, there was avoidance behaviour observed, the density of fish in the study area when the turbine was absent was approximately twice the density observed when the turbine was in place, and results suggested that some fish responded to the turbine by adjusting swimming behaviour. Therefore, further research would be required to establish if this has a significant impact on fish migration and movement (Bevelhimer *et al.*, 2017).

2.3.3.2 Cobscook Bay Tidal Energy Test Site

Another test location in the USA is the Cobscook Bay Tidal Energy Test Site, Maine. Ocean Renewable Power Company (ORPC) have tested multiple tidal devices at this site (Tethys, 2023c):

- September 2012: TidGen® Power System (Figure 18)
- June 2014: OCGen® Module Mooring System
- May 2023: Single Turbine TidGen® System
- Planned for 2024: TidGen® Power System.

To fulfil licence agreements, ORPC carried out multi-year Environmental Monitoring Plans (EMPs) from 2012 to 2016 to determine the site's potential environmental impact focussing on key concerns. For example, the 'Cobscook Bay Tidal Energy Project 2012 Environmental Monitoring Report' contains a section detailing the marine mammal monitoring that took place to study marine mammal behaviour around the deployment area. The species that were most frequently identified in Cobscook Bay were harbour seal, grey seal, harbour porpoise, and the Atlantic white-sided dolphin (*Lagenorhynchus acutus)*. The most common species was the harbour seal (ORPC Maine, 2013). Trained MMOs monitored the area during construction, operation, and maintenance phases. No changes in marine mammal behaviour were observed, and there was no indication of strikes between marine mammals and the device (ORPC Maine, 2013). However, this method of marine mammal monitoring involved observing for individuals at the surface, so there is a key limitation that underwater collisions may not have been possible to detect.

2.3.3.3 Igiugig RivGen® Power System

In Alaska there is a remote community of around 70 people called Igiugig who lives alongside the Kvichak River; a vital resource for drinking water and salmon for the Igyararmiut (people of Igiugig) (Salmon *et al.*, 2022). A requirement for electricity fostered the use of diesel fuel, however, the community had been wanting to shift away from this and back to sustainable methods (Salmon *et al.*, 2022). Ocean Renewable Power Company (ORPC) partnered with the Igiugig Village Council (IVC) and successfully deployed two grid-connected RivGen © Power Systems, the first in 2019 and the second in 2023 (Tethys, 2024e) (Figure 19, page 79).

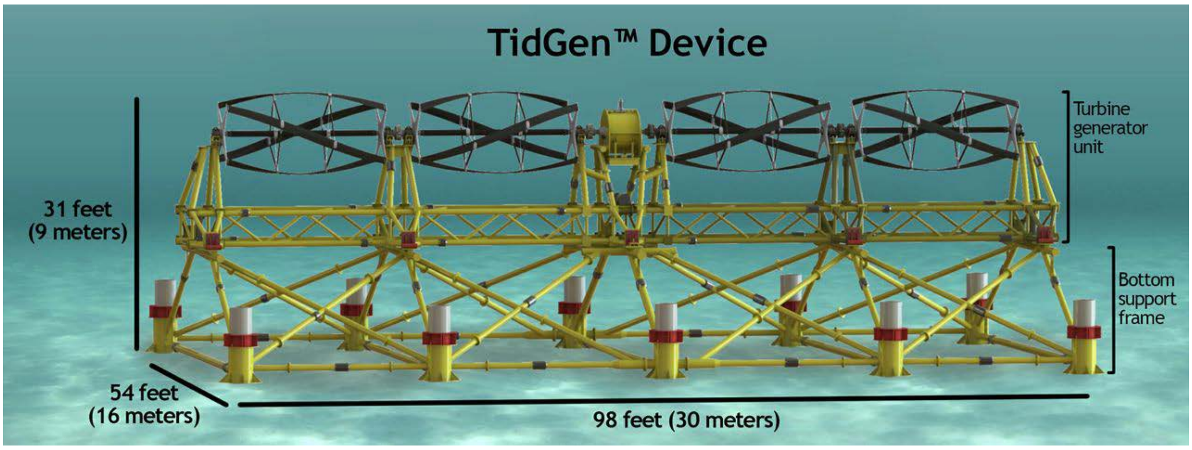

Figure 18. TidGen® device illustrating turbine generator unit (TGU) and bottom support frame.

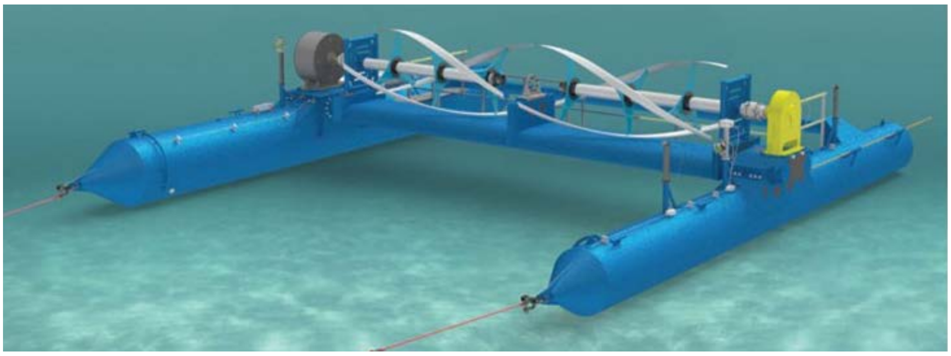

Figure 19. Schematic of RivGen © Power System

A key environmental issue concerning this project is the sockeye salmon *(Oncorhynchus nerka)* population, as the Kvichak River is one of the largest supporting natural systems for this species globally (Fair, 2003). Underwater cameras were deployed as part of research studies to monitor the relationship between sockeye salmon and the riverine energy device during the species' smolt out migration. From 21 May to 10 June 2021, a total of 2,374 sockeye salmon smolts were identified downriver of the RivGen® by reviewing 84h of real-time video imagery (Courtney *et al*., 2022). The operational mode of the turbine was recorded as stationary (<1 rpm), cogging (3-5 rpm) or production (45-60 rpm) and summarises of fish interactions were classed as the number of total fish events, the number of fish events classified as disoriented, and the number of blade strikes, as illustrated in Table 7.

Table 7. The number of fish interactions, disorientated fish and observed blade strikes in relation to the turbine deployment mode.

Turbine Mode	Interactions	Disorientated	Blade Strikes
Stationary	1646	32	0
Cogging	446	168	0
Production	282	182	36
Total	**2374**	**382**	**36**

The results indicate that fish were observed passing through the turbine in a normal and disorientated manor, where the speed of the rotating blade influenced the passage behaviour of the fish. Additionally, blade strikes were only identified when the turbine was in production, where 36 out of the 2374 (1.5%) fish interactions in all modes of turbine deployment were recorded as a blade strike. This study adds to the limited understanding on the relationship between fish and tidal stream energy devices by providing high resolution imagery of fish interactions, helping to inform strategies to mitigate the impacts on socially and culturally important fisheries. It also highlights a possible difference in responses between riverine species and species in the open ocean.

2.3.4 United States of America

FACT SHEET

Factor	Roosevelt Island Tidal Energy (RITE) Project Pilot
Country	United States of America
Developer	Verdant Power LLC
Project start date	January, 2012
Project status	Decommissioned
Project scale	Array
Support structure/anchor type	Gravity foundation
Technology	Bottom-mounted
Installed capacity	1.05MW
Physical site	Constricted river channel, noisy environment
Water depth	10m
Marine mammals	There were no resident marine mammals in the area
Collision monitoring	Dual-Frequency Identification Sonar (DIDSON), hydrophones, tagged species detection
Other monitoring	Seasonal species characterisation netting
Seasonality of monitoring	**DIDSON:** Seasonal three-week observation in close proximity to turbine system **Underwater noise:** One month and two weeks underwater sound monitoring of operating turbines
Number of collisions recorded	No collisions observed
Advantages and limitations of monitoring techniques (inclusive of but not limited to)	**Advantages:** Tag species detection was the most viable monitoring technique. Leveraging fish tagging campaigns conducted by researchers across the Eastern Seaboard, the deployment of inexpensive, robust acoustic tag detectors in and around the RITE Site enabled the collection of valuable long-duration species data at a reasonable cost

	Acoustic monitoring following IEC TS 62600-40 was a very viable monitoring technique as the standard gave clear guidance regarding methods and equipment and the regulators had confidence in the approach as it was based on an international, consensus-based standard Limitations: Netting was the least viable technique for species characterisation as netting in high current regions is very difficult and proved nearly useless The use of high-resolution acoustic cameras was partially viable if deployed for short durations in close proximity to operating turbines
Main consenting concern	Fish and diving birds were the main consenting concerns. For fish, the main concerns were the endangered/threatended sturgeon species (including the Atlantic sturgeon and short-nosed sturgeon). An additional species of interest was the striped bass. For diving birds, the main species of interest was the cormorant
Licensing conditions	For the environment, there were 6 RITE Monitoring of Environmental Effects (RMEE) protocols that were implemented as well as an additional requirement for recreational usage monitoring. Verdant Power utilised a Risk Management Framework to help quantify the risks and to provide clear evidence of risk mitigation strategies The license was granted under an Adaptive Management Framework and over time, environmental monitoring requirements were removed or reduced based on the reduction of perceived risk based on data acquired, processed and interpreted. For example, the RMEE for netting (RMEE-3) was closed due to the lack of efficacy of netting in the East River. Further, Verdant Power had a presence in the East Channel, East River for more than 15 years (and multi-year data collection in the West Channel as well) and the vast amount of data collected facilitated a meaningful understanding of the complex ecosystem and enabled the effective use of targeted monitoring equipment at specific flow-scales to answer specific questions/concerns that the regulators had The development of a probabilistic fish-turbine interaction model that was validated with in situ data collection was a very valuable tool to highlight the low risk of fish-turbine interactions at the RITE Site

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2.3.4 United States of America

FACT SHEET

Factor	Cobscook Bay Tidal Energy Test Site
Country	United States of America
Developer	Ocean Renewable Power Company (ORPC)
Project start date	September, 2012
Project status	In operation
Project scale	Test site
Support structure/anchor type	Multiple (mooring lines, drag embedment anchor)
Technology	Multiple (bottom-mounted, suspended in water column)
Installed capacity	2012 TidGen® Power System: 150 kW
Physical site	Enclosed basin, noisy environment (>80 dB), soft-bottom habitat, hard-bottom habitat
Water depth	18-45m
Marine mammals	**Monitoring focus:** harbour seal, grey seal, harbour porpoise, Atlantic white-sided dolphin **Other species observed in area:** fin whales, minke whale, North Atlantic right whale
Collision monitoring	Visual observations and hydroacoustic monitoring data (echosounder)
Other monitoring	Acoustic monitoring of the device, drop down video cameras, biofouling assessment
Seasonality of monitoring	**Fisheries Monitoring Plan:** January and March **Marine Mammal Observations:** In Cobscook Bay and Western Passage between December 2007 and December 2010 **Hydroacoustic monitoring from echosounder:** October 1, 2012 to October 5, 2012
Number of collisions recorded	No collisions observed

Advantages and limitations of monitoring techniques (inclusive of but not limited to)	Method involved observing for individuals at the surface, so there is a key limitation that underwater collisions may not have been possible to detect
Main consenting concern	There are multiple threatened or endangered species with potential to occur in the Cobscook Bay test site area, including the Shortnose Sturgeon
Licensing conditions	Feasibility studies, including environmental monitoring surveys, and pre-filing consultation were conducted, resulting in ORPC's filing of a draft pilot project license application with FERC on July 24, 2009. The final pilot project license application was filed on September 1, 2011

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2.3.4 United States of America

FACT SHEET

Factor	**RivGen®**
Country	United States of America
Developer	Ocean Renewable Power Company (ORPC)
Project start date	January, 2019
Project status	In operation
Project scale	Array
Support structure/anchor type	Mooring line and drag embedment anchor
Technology	Floating
Installed capacity	0.07MW
Physical site	River, isolated/quiet environment (<80 dB), soft bottom habitat
Water depth	5m
Marine mammals/fish	**Monitoring focus:** Sockeye Salmon **Other species observed in area:** Beluga whale, rainbow trout, Arctic char, Arctic grayling
Collision monitoring	Video monitoring
Other monitoring	Hydrodynamic monitoring
Seasonality of monitoring	**Video imagery:** Juveniles/smolts: May 21, 2021 to June 10, 2021 Adults: June 25, 2021 to July 15, 2021
Number of collisions recorded	No collisions observed
Advantages and limitations of monitoring techniques (inclusive of but not limited to)	**Advantage:** Provides information on presence, occupancy patterns and behaviour of animals in and around the project site to gain insights into the potential collision risk **Limitations:** • Requires good water clarity (low turbidity) • Potential to generate large quantities of data which requires storage • Requires time-consuming manual analysis • Biofouling can affect performance.

Main consenting concern	Main concern is the ecological effect on fish, including the risk of blade collision and behavioural impacts such as the disruption of migratory behaviour. The Kvichak River is one of the largest supporting natural systems for the sockeye salmon globally
Licensing conditions	N/A

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3. Recommendations

To facilitate the growth of the tidal stream sector, a robust, accessible and comprehensive evidence base is essential. The tidal stream energy sector not only relies on technological innovations to improve the efficiency and reliability of tidal stream devices but on developing knowledge and understanding of key environmental impacts through, for example, more accurate methodologies to account for collision risk.

3.1 Investing in the tidal stream sector

Continuing to invest in test and demonstration sites, as mentioned in the Conclusion of this report, will not only improve technological innovations on the efficiency and reliability of tidal stream devices but also the environmental monitoring evidence base, along with the environmental monitoring technology. To date, monitoring test and demonstration devices have provided a variety of evidence and data around the impacts of tidal stream devices on marine species, particularly concerning collision risk and avoidance. The Morlais Marine Characterisation Research Project (MCRP) represents a key step in addressing primary evidence gaps around the scaling up of tidal stream projects and will improve our understanding of environmental interactions with multiple devices as the site scales, which will in turn help to reduce consenting risk and unlock further potential in the sector. Alongside collecting valuable environmental data, the MCRP and other test and demonstration sites will provide proof of concept for several monitoring techniques and aid adaptive management. Taken together, these outputs have both regional and sector-wide value, providing valuable evidence to assist stakeholder decision-making whilst also generating benefits for other offshore renewable energy technologies, particularly where there are similar environmental risks. The Crown Estate considers that investment in research initiatives such as the MCRP are invaluable in providing relevant data, evidence, and technology to aid the scaling up and commercialisation of the tidal stream sector in the UK and beyond.

Addressing significant knowledge gaps, particularly regarding the broader impacts of large-scale arrays, will require targeted research and funding support. The Crown Estate remains committed to the tidal stream sector and will continue to fund projects such as the MCRP to help unlock these barriers to deployment. Following the success of the ORJIP Offshore Wind programme, we recognise the potential of the ORJIP Ocean Energy programme and will revisit this in the later months of 2025.

3.2 Accessibility to data

The Crown Estate understands that increasing the amount of available monitoring data from operational projects is paramount for improving our understanding of potential environmental impacts of tidal stream energy, including whether they pose a collision risk for marine mammals. The Crown Estate is in a unique position to work with its customers and stakeholders to utilise the MDE to make data and evidence publicly available and to drive the sustainable development of the seabed. The MDE currently securely stores and publishes marine survey data collected by offshore industry projects around England, Wales, and Northern Ireland and previously held legacy data from Scotland.

The recent agreement between The Crown Estate and Crown Estate Scotland to allow Scottish offshore industry survey data to be stored and published on the MDE now means new data collected in Scottish waters can be made accessible. This will enable pre-consented, consented and operational tidal stream projects from across the UK to share their data and insights through the MDE. Data from operational projects in Scotland, collected over the last decade, can now be shared and play a role in improving our understanding of the possible impact of operational tidal devices on the marine environment, while the innovative MCRP programme at Morlais can shed light on novel techniques for environmental monitoring.

Looking into the future, maximising the value of data sharing from multiple projects will require the standardisation of data collection and archiving practices across the sector. Data standards reduce the effort and time required to aggregate and analyse multiple datasets, while accepted and standardised collection methodologies enable clear comparisons between projects, both of which are vital for reducing consenting timelines.

3.3 Marine monitoring

This report highlights not only the importance of a project's capability to detect collisions effectively, but the importance of secondary data and evidence on measuring avoidance behaviours and displacement. Methodology advantages and disadvantages have been outlined, and where appropriate, limitations of each technique highlighted. Furthermore, as the tidal stream industry is a relatively new and dynamic sector, it is crucial to draw attention to the fact that standardised methodologies and protocols for data collection and analysis are important for building a future evidence base.

The Crown Estate recognises that the limitations of monitoring methods as well as the varying mitigation requirements for different projects has potentially hindered the consistency and comparability across projects and regions in terms of data transferability. Another key issue in terms of data transferability from one site to another is the lack of consistency on the use of definitions across varying projects and scientific papers, which can create misinformation or uncertainty on the potential impacts that tidal turbines may have on marine life. However, it should be noted that not all challenges surrounding data transferability have been considered in this report and will be reviewed in The Crown Estate's next phase of work.

3.4 Concluding recommendations

This report reinforces the importance of marine monitoring to support the sustainable deployment of marine renewable energy for reasons inclusive of, but not limited to:

- Assessing the impacts of devices on marine species
- Understanding the risks associated with interactions with these devices to minimise impacts on marine life and habitats
- Complying with environmental regulations
- Supporting the delivery of science-based decision making, therefore facilitating consenting of projects
- Encouraging public access to environmental monitoring data
- Standardising monitoring methodologies and data
- Gaining public trust and acceptance for renewable energy developments.

However, developers across a variety of marine renewable energy projects face challenges including high monitoring costs and lengthy consenting and permitting processes. To reduce the cost spent on environmental monitoring, decrease the carbon emissions created through the repeat collection of data, and to reduce the length of time it takes for a project to gain consent and thus increase the rate of deployment of devices, data transferability from one site to another must be considered and encouraged where possible.

Data transferability involves applying existing evidence, data analyses and insights from one site or project to another. In the case of tidal stream energy data, this usually means spanning different geographical areas such as across the UK and globally (Copping *et al*., 2018). The Crown Estate recognises that data transferability is unlikely to remove the need for all project specific evidence and monitoring, however it may act to reduce evidence collection requirements, whilst increasing the robustness of project datasets.

3.5 Next steps

Following the publication of this report, The Crown Estate is set to advance to the next phase of evidence related work for tidal stream, which is currently underway. This forthcoming phase will encompass the development of a comprehensive data transferability matrix and framework, aiming to enhance the usability of tidal stream data from one site to another. This will feature detailed examples of monitoring methods, demonstrating best practices, signposting key guidance notes and papers, as well as innovative approaches within the tidal stream sector. This initiative reflects The Crown Estate's commitment to supporting the sustainable development of the tidal stream industry by helping to develop a robust data and evidence base, whilst encouraging the use and reuse of data collected from one site to another.

4. Conclusion

4. Conclusion

This report has provided data and evidence from six reports at SeaGen, two reports at Shetland Tidal Array, and seven reports at MeyGen Tidal Energy Project, summarising publicly available information on their potential impacts on marine fauna including: risk of collision, disturbance from underwater noise, avoidance and displacement. This review showcases different data gathered across the UK and globally, highlighting the existing evidence base for developers and regulators to utilise.

In the case studies summarised, which consist of various devices located in differing habitats in Scotland and Northern Ireland, there have been no recorded marine mammal collisions with tidal turbines and individuals appear to avoid turbines when they are operating. While different methods have been used to monitor at each site, this does suggest that the collision risk potential is low for single and small-scale arrays. Existing data from GPS tracking studies between pre- and post-installation of turbines at MeyGen indicated that there has been no sustained barrier effect from single tidal devices or small scale arrays. However, avoidance responses when turbines were generating electricity were identified. Across the SeaGen, Shetland Tidal Array, and MeyGen project case studies, four of the reports concluded that there was localised avoidance of the turbine when in operation. However, if avoidance and displacement occur from important areas for marine species, there may be more implications in terms of scaling up arrays, which does warrant further investigation.

This report has systematically reviewed and synthesised available evidence to evaluate the methods used to quantify risk, such as identifying potential monitoring limitations, with the ultimate aim of supporting the consenting process by providing further clarity on benefits and limitations to environmental monitoring methods used at different project site locations. The evaluation revealed that current environmental monitoring methods often can lack standardisation and consistency which can lead to variability in data quality and reliability, making it difficult to compare results across different project sites. To address these limitations, the report recommended enhancing the evidence base through the development and implementation of advanced technologies as well as increasing collaboration between researchers, policymakers and industry stakeholders, to help share knowledge and best practices, ultimately improving the overall quality of environmental monitoring.

It should also be noted that to draw robust conclusions from telemetry data, it is essential to tag a substantial number of individuals, and that the number of tagged individuals depends on the aims of the studies and the species being studied. For seals, a 2014 report from SMRU Ltd. suggested that tagging between 21-58% of the population can provide reliable data on regional transitions between foraging and breeding seasons (Russell and McConnell, 2014). However, this high tagging requirement can place significant strain on some developers. It necessitates extensive fieldwork, which can be logistically challenging and resource intensive. It is important to consider the requirements and conditions this would set on developers in terms of cost and investment, in particular relating to single device testing, or small scale arrays. Furthermore, collaboration with experts and stakeholders can help share knowledge and resources, ultimately improving the efficiency and effectiveness of telemetry studies.

The report also highlights the need for improved night observation capabilities through sonar and PAM studies. The Crown Estate recognises that developing detection algorithms such as the use of PAM code and AI has its own challenges, and that the development of these tools is underway. Whilst this represents a significant technological breakthrough still to be achieved, it should be noted that where underwater video recordings were used to assess marine mammal behaviour around tidal turbines during daylight hours, avoidance behaviours were observed. This evidence provides an increased level of confidence that marine mammals will avoid turbines where monitoring methods are not able to confirm whether a collision has occurred.

To enhance data collection and analysis, future efforts could focus on optimising observational monitoring designs. This includes ensuring that collected data has sufficient spatial resolution (site specific and dependent) and accounts for seasonal, tidal, and temporal variability. Additionally, developing advanced automated detection and AI algorithms will expedite data processing; this is being developed and tested on the MCRP at Morlais. A key recommendation for improved monitoring identified in this report is the capability to autonomously detect collision events through technological advancements, such as collisionometers or strain gauges. Such capability is a crucial tool for the advancement of the tidal stream sector, especially as the industry scales up to larger arrays.

The knowledge base is developing for tidal stream energy which is essential for optimising the design, location, and operation of future, larger-scale tidal stream projects. By leveraging learnings from previous data and evidence collection, such as through understanding environmental monitoring limitations, the industry can accelerate development, mitigate risks, and enhance the overall performance of tidal stream energy, whilst developing more wide-ranging monitoring techniques to enable its scale up to commercial sites.

Significant knowledge gaps persist regarding the broader impacts of large-scale tidal arrays on marine mammals where, thus far, research has been limited to single or small arrays of turbines.

Notably, while our understanding of single device risks is improving, it does not come without risks due to inherent environmental, technological and operational uncertainties. A key question that needs further addressing is whether the evidence we have gathered from test and demonstration sites is truly adequate. Although initial results offer valuable insights, the data may still be fragmented or limited due to the smaller scales of these sites. It is crucial to assess whether the current evidence encompasses all variables, including different species, environmental conditions, and potential long term impacts. Furthermore, evaluating how much additional data can be collected is essential before moving forward to larger arrays. In addition to data collection, the MCRP at Morlais is developing and demonstrating innovative monitoring and mitigation technology designed to safeguard marine wildlife. Such technology should increase confidence as arrays at Morlais scale up and more data is collected. Gathering more data can enhance our understanding of collision risks and help develop even better mitigation strategies, ensuring minimised adverse effects on marine mammals and species as the tidal stream energy sector expands.

To ensure the further development of renewable energy projects, including tidal stream energy, an acceptable level of risk will need to be established through risk assessments, ongoing monitoring, and adaptive management strategies. Adopting a pragmatic approach that balances the need for renewable energy developments and potential environmental impacts will also be essential. This will involve stakeholders working together to define risk thresholds based on the available collected data and evidence.

By collecting robust data on tidal currents, turbine performance, site characteristics and environmental impacts, researchers and industry can refine tidal stream technology, optimise energy production, and mitigate potential environmental impacts. Such knowledge is essential for the successful commercialisation of tidal stream energy and its integration into broader energy portfolios. As a significant landowner and leaseholder of marine areas, The Crown Estate, in collaboration with other stakeholders, can play a supportive role in fostering this vital research. By investing in test and demonstration sites, and data collection at these sites, such as Morlais and the MCRP project in Anglesey, The Crown Estate can help answer some of those outstanding questions around tidal stream deployment and accelerate the development of the tidal energy industry not only within the UK but globally. This collaborative effort will support and safeguard a low-carbon future and ensure the sustainable management of marine ecosystems.

Appendix

Appendix 1. MDE holding of Morlais data

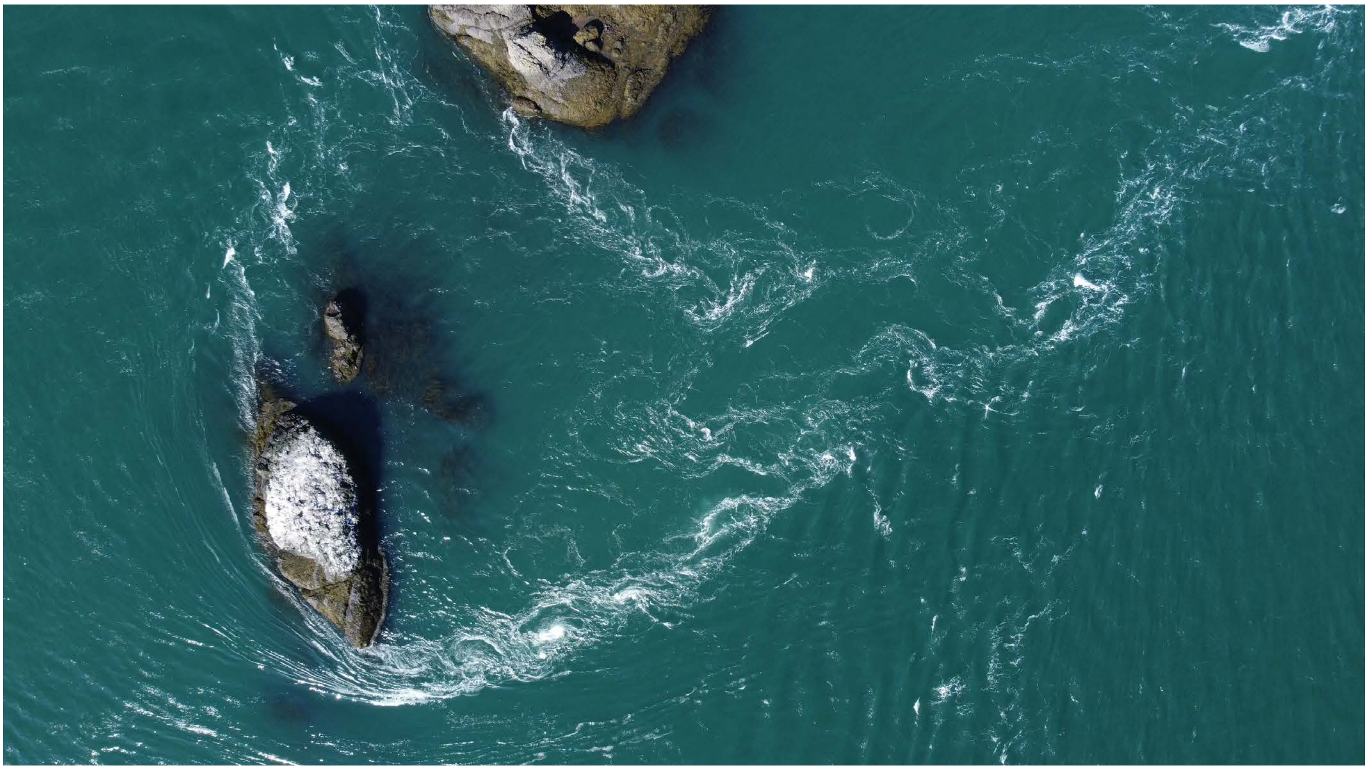
Series Name	Series Summary	Monitoring Technique	Location
2022-2023, University of St Andrews, Marine Characterisation Research Project, Seabird and marine mammal observations (WP1a)	This series is comprised of data collected from the deployment of 15 soundtrap recorders used to collect baseline data on the occurrence and relative abundance of vocalising cetacean species in and around the MDZ. Species of interest vocalise over a wide frequency range. To capture such a wide range of sounds, SoundTraps were used for data collection, which acquire data at a sample rate of 384kHz and combine automatic high frequency click detection to capture high frequency odontocete echolocation clicks, and continuous recording of the data resampled at 48kHz which can be used to detect dolphin whistles and minke whale pulsed calls.	Soundtrap recorders	MDZ
2022-2023, University of St Andrews, Marine Characterisation Research Project, Harbour Porpoise Dive Profiles (WP1b)	Data were collected on multi-channel hydrophone arrays to determine 3D locations of cetaceans off the Holyhead coast. Two PAM approaches have been developed for measuring the underwater behaviour of porpoises and dolphins using passive acoustic localisation. One approach was designed to collect behavioural data over large spatial areas and the other can be targeted at specific locations.	Hydrophones for acoustic monitoring	MDZ

2022-2023, Menter Mon, Morlais, Marine Characterisation Research Project – Active Sonar (WP2)	The series is comprised of data collected from active sonar sensors deployed near a seabed turbine in Scotland. Utilising a dual sonar and PAM system to detect, classify, and track marine mammals this can be used to form a basis for monitoring the underwater movements of marine mammals around operational tidal turbines. The data has been processed to detect primarily seals (large fish and seabirds are also detected, but are not the target species).	Sonar and PAM	Scotland Pentland Firth, MeyGen 1A site
2023-2024, Ocean Science Consulting, Marine Characterisation Research Project, Surface (WP3) and Underwater (WP4) Imaging	This series consists of data collected from a camera system, consisting of a surface Red, Green, Blue (RGB), Infra-Red (IR) camera/subsea RGB camera and associated computers and power supply, developed and deployed on a buoy at the MDZ. Data were successfully recorded over a four month and 16-day period during four deployments. These data have been collected to investigate the feasibility of surface and underwater cameras to detect marine fauna, with the aim of providing an automatic detection and classification system for marine animals to enable the automatic triggering of deterrents on a tidal turbine energy site in Wales.	Cameras	MDZ
2022, Ocean Science Consulting ltd, Marine Characterisation Research Project, Diving seabird shore based surveys (WP5)	Shore-based diving seabird surveys recording presence and behaviour within the MDZ of tidal turbine site in Wales, up to 5km from land. Nest surveys were also conducted to calculate trip duration of adults from nests during breeding season.	Land-based VP surveys	MDZ
2022-2023, RSPB, Marine Characterisation Research Project, Colony counts (WP6)	These data focus on guillemot and razorbill which hunt fish by diving. This series estimate current colony size and levels of breeding productivity, along with describing historical patterns of abundance change at South Stack and nearby colonies.	Timelapse photography, VP surveys	MDZ

2022-2023, Swansea University, Marine Characterisation Research Project, Auk Tagging (WP7)	Remote downloadable GPS and dive depth recorders (Pathtrack GEO nano-fix) were deployed on razorbills and guillemots breeding at Ynys Lawd to map their foraging locations in relation to the MDZ and model the number of dives auks perform in this area of interest. The outputs provided a broader understanding of habitat selection in auks by examining foraging locations in relation to current speed, which could further enhance parameterisation of collision risk models.	Tagging	MDZ
2022-2023, University of St Andrews, Marine Characterisation Research Project, Targeted Acoustic Startle Technology (TAST; WP8)	These data form part of a study aimed to test the acoustic startle method for deterrence on wild bottlenose dolphins in the U.K. by using a Genuswave Ltd. TAST device. During and before the experiment animal positions were tracked by land-based observers. These data were used to determine deterrence ranges, swim speed and movement trajectories. This information was used to determine the effectiveness of the tested stimulus.	Land-based observation, boat based technology deployment.	Scotland, Moray Firth
2023, Subacoustech Environmental Limited, Marine Characterisation Research Project, Monitoring and modelling of underwater noise (WP10)	Four acoustic transects were conducted within the MDZ to investigate the pre-existing background noise levels. This is part of the first step towards assessing potential underwater noise that could be generated by these devices and allows for assessment of the impacts these devices could have on marine life present in the area.	Underwater noise monitoring	MDZ
2022-2023, Bangor University, Morlais, Marine Characterisation Research Project – Echosounder surveys (WP11)	This dataset is comprised of echosounder measurements carried out within the MDZ as part of the MCRP to estimate prey availability in the study site. These data support monthly boat-based line transect surveys collected to understand spatial and temporal variation in the distribution of seabirds and marine mammals.	Boat-based surveys	MDZ

2022-2023, Bangor University, Marine Characterisation Research Project, Marine mammal Acoustic Surveys (WP11)	The series is comprised of acoustic hydrophone data used to detect the presence of marine mammals (primarily harbour porpoise). These data were recorded during monthly boat based marine mammal observation surveys.	Boat-based surveys	MDZ
2022-2023, Bangor University, Marine Characterisation Research Project, Seabird and marine mammal observations (WP11)	The series is comprised of the results from monthly observational boat-based line transect surveys carried out within the MDZ to understand spatial and temporal variation in the distribution of seabirds and marine mammals.	Boat-based surveys	MDZ
2022-2023, Bangor University, Marine Characterisation Research Project, Aerial Drone Broad scale surveys (WP12)	The series is comprised of vertical aerial UAV imagery collected during line transect surveys to capture abundance and distribution of marine mammal and seabird species around the Morlais tidal turbine Magellanes site.	Drones	MDZ
2022-2023, Bangor University, Marine Characterisation Research Project, Aerial Drone Fine scale surveys (WP12)	The series is comprised of Fine-scale boat based drone surveys consisting of multiple drone (multirotor drone type DJI Mavic 3) video hovers (stationary drone with a downward-facing camera) at minimum altitudes of 40m to monitor the site for marine fauna (seabirds and marine mammals) abundance and behaviour prior to tidal energy device installation.	Drones	MDZ
2022-2023, University of St Andrews, Sea Mammal Research Unit, Scottish Oceans Institute, Marine Characterisation Research Project, Seal Tagging (WP13)	GPS/GSM (Global Positioning System/Global System for Mobile communication) tags deployed on grey seals in the area surrounding the Morlais Marine Demonstration Zone around the coast of Anglesey to collect data on their distribution, movement, and behaviour. These tags record data on the at-sea locations and dive depths of seals.	GPS Tagging	MDZ

2022-2023, HR Wallingford, Marine Characterisation Research Project, Current Models (WP14)	This dataset consists of spatially modelled tidal currents, water levels and depths. The data files contain finite element model results on a triangular grid, saved in the SELAFIN binary file format of the TELEMAC-2D hydrodynamic model (www.opentelemac.org). The files are split into time periods of three months and data saved at regular time intervals of 15 minutes.	Modelling	N/A
2022-2023, University of St Andrews, Morlais, Marine Characterisation Research Project, Towed PAM (WP15b)	Data collected on multi-channel hydrophone arrays to determine 3D locations of cetaceans off the Holyhead coast.	Towed PAM	MDZ
2023-2024, RSPB, Marine Characterisation Research Project, LoRaWAN seabird tagging (WP15c)	The aim of this project was to research, develop and manufacture solar powered avian leg ring tags using LoRa technology which is already proven in a number of areas including agriculture and conservation.	Technology testing	MDZ



References

ABPmer (2020) 'Review of Potential Collision Between Tidal Stream Devices and Marine Animals.' NRW Evidence Report No: 444, 65 pp, NRW, Bangor.

Artelia (2023) 'Flowatt tidal turbine farm' [online] Available at: https://www.arteliagroup.com/project/flowatt-tidal-turbine-farm/. Accessed 17/04/2024.

Band, B. (2000) 'Windfarms and seabirds: calculating a theoretical collision risk assuming no avoiding action.' Scottish Natural Heritage Guidance Note.

BEIS (2022) 'United Kingdom of Great Britain and Northern Ireland's Nationally Determined Contribution' Available at: https://assets.publishing.service.gov.uk/media/633d937d8fa8f52a5803e63f/uk-nationally-determined-contribution.pdf

Bevelhimer, M., Scherelis, C., Colby, J., Adonizio, M. (2017) 'Hydroacoustic Assessment of Behavioral Responses by Fish Passing Near an Operating Tidal Turbine in the East River, New York.' *Transactions of the American Fisheries Society*, 146(5), pp. 1028-1042.

Buenau, K.E., Garavelli, L., Hemery, L.G. and García Medina, G. (2022) 'A review of modeling approaches for understanding and monitoring the environmental effects of marine renewable energy.' *Journal of Marine Science and Engineering*, 10(1), p. 94.

Choi, K-R., Kim, J-H., and Yoo, S.H. (2022) 'The public willingness to pay for the research and demonstration of tidal stream energy in South Korea.' *Marine Policy,* 138, p. 104981.

Clarke, D.R.K., Bertelli, C.M., Cole, E.L., Jones, R.E., Mendzil, A.F., Lowe, C.D., Griffin, R.A. and Robinson, M.T. (2021) 'Review of monitoring methodologies and technologies, suitable for deployment in high energy environments in Wales, to monitor animal interactions with tidal energy devices.' *A report produced by Swansea University and Ocean Ecology for Welsh Government.*

Cochrane, C., Pinnock, S., and Jeffrey, H. (2021) 'What is the value of innovative offshore renewable energy deployment to the UK economy?' Supergen Offshore Renewable Energy Hub Policy Paper. Available at: https://www.policyandinnovationedinburgh.org/uploads/3/1/4/1/31417803/supergenorehub_what_is_the_value_of_innovative_offshore_renewable_energy_deployment_to_the_uk_economy_1.pdf

Cole, E.-L., Waggitt, J.J., Hedenstrom, A., Piano, M., Holton, M.D., Börger, L. & Shepard, E.L.C. (2018) 'The Ornithodolite as a tool to quantify animal space use and habitat selection; a case study with birds diving in tidal waters.' *Integrative Zoology*. 14, pp. 4–16.

Cole, E.L., Dodd, S.G., MacDonald, M.A., McCluskie, A. and Shepard, E.L.C. (2024) 'Guillemot and razorbill foraging ecology in relation to the Morlais Demonstration Zone, Anglesey, Wales.' *Menter Môn-Marine Characterisation Research Project (MCRP)* MCRP-SWAN-DOC-0002.

Copping, A.E., Freeman, M.C. and Gorton, A.M. (2018) 'Data Transferability and Collection Consistency in Marine Renewable Energy.' *Prepared for the U.S. Department of Energy under Contract* DE-AC05-76RL01830.

Copping, A.E., Hasselman, D.J., Bangley, C.W., Culina, J., Carcas, M. (2023) 'A Probabilistic Methodology for Determining Collision Risk of Marine Animals with Tidal Energy Turbines.' *Journal of Marine Science and Engineering*, 11, p. 2151.

Cornett, A., Cousineau, J. and Nistor, I. (2013) 'Assessment of hydrodynamic impacts from tidal power lagoons in the Bay of Fundy.' *International Journal of Marine Energy,* 1, pp. 33-54.

Cornett, A., Durand, N. and Serrer, M. (2010) '3-D Modelling and assessment of tidal current resources in the Bay of Fundy, Canada.' 3rd International Conference on Ocean Energy, 6 October, Bilbao. Available at: https://tethys-engineering.pnnl.gov/sites/default/files/publications/Cornett_et_al_ICOE_2010.pdf

Costagliola-Ray, M.M., Lieber, L., Nimmo-Smith, W.A.M., Masden, E.A., Caplat, P., Wilson, J. and O'hanlon, N.J. (2022) 'To fly or not to fly? Comparing vantage point and uncrewed aerial vehicle surveys for assessments of seabird abundance and fine-scale distribution.' *Environmental Impact Assessment Review*, 97, p. 106906.

Courtney, M.B., Flanigan, A.J., Hostetter, M. and Seitz, A.C. (2022) 'Characterizing Sockeye Salmon Smolt Interactions with a Hydrokinetic Turbine in the Kvichak River, Alaska.' *North American Journal of Fisheries Management*, 42, pp. 1054-1065.

Dai, P., Huang, Z. and Zhang, J. (2023) 'A modelling study of the tidal stream resource around Zhoushan Archipelago, China.' *Renewable Energy,* 218, p. 119234.

Elsouk, S., Santa Cruz, A. and Guillou, S.S. (2018) 'Review on the characterization and selection of the advanced materials for tidal turbine blades.' In *Proceedings of the 7th International Conference on Ocean Energy*, pp. 12-14.

Fair, L.F. (2003) 'Critical elements of Kvichak River sockeye salmon management.' *Alaska Fishery Research Bulletin,* 10(2), pp. 95-103.

FORCE (2019) 'SME Wraps Up PLAT-I Phase 1 Testing MarineEnergy.biz' [online] Available at: https://fundyforce.ca/news-and-updates/2019-06-07/sme-wraps-up-plat-i-phase-1-testing-marineenergy-biz Accessed 20/06/2024.

FORCE (2022) 'FORCE 2022 Project Update' [online] Available at: https://fundyforce.ca/document-collection/force-2022-project-update

FORCE (2023) 'Environmental Effects Monitoring Program Quarterly Report: April-June 2023' [online] Available at: https://fundyforce.ca/document-collection/environmental-effects-monitoring-program-quarterly-report-april-june-2023

FORCE (n.d.) 'Our Purpose and Mandate' [online] Available at: https://fundyforce.ca/about-us. Accessed 16/04/2024.

Frost, C. (2022a) 'Tidal stream cost reduction report.' ORE Catapult. Available at: https://cms.ore.catapult.org.uk/wp-content/uploads/2022/10/Tidal-stream-cost-reduction-report-T3.4.1-v1.0-for-ICOE.pdf

Frost, C. (2022b) 'Quantifying the benefits of tidal stream energy to the wider UK energy system.' ORE Catapult. Available at: https://cms.ore.catapult.org.uk/wp-content/uploads/2022/06/AI-paper-tidal-stream-benefits-to-the-wider-energy-system-v1.12.pdf

Furness, R.W., Wade, H.M., Robbins, A.M. and Masden, E.A. (2012) 'Assessing the sensitivity of seabird populations to adverse effects from tidal stream turbines and wave energy devices.' *ICES Journal of Marine Science*, 69(8), pp. 1466-1479.

Garavelli, L., Copping, A. E., Hemery, L. G., Freeman M. C., eds. (2024) 'OES-Environmental 2024 State of the Science report: Environmental Effects of Marine Renewable Energy Development Around the World.' Report for Ocean Energy Systems (OES). doi:10.2172/2438585

Germain, G. (2023) 'Experimental comparison of the flow-induced loading between a ducted bottom-mounted twin vertical axis tidal turbine at still and an unducted prototype.' In *Proceedings of the European Wave and Tidal Energy Conference*, 15.

Gill, A.B., Gloyne-Phillips, I., Kimber, J., and Sigray, P. (2014) 'Marine Renewable Energy, Electromagnetic (EM) Fields and EM-Sensitive Animals.' In: Shields, M., Payne, A. (eds) *Marine Renewable Energy Technology and Environmental Interactions*. Humanity and the Sea. Springer, Dordrecht, pp. 61-79.

Gillespie, D., Hastie, G., Montabaranom, J., Longden, E., Rapson, K., Holoborodko, A. and Sparling, C. (2023) 'Automated detection and tracking of marine mammals in the vicinity of tidal turbines using multibeam sonar.' *Journal of Marine Science and Engineering,* 11(11), p. 2095.

Gillespie, D., Palmer, L., Macaulay, J., Sparling, C. and Hastie, G. (2020) 'Passive acoustic methods for tracking the 3D movements of small cetaceans around marine structures.' *PLoS ONE*, 15(5), e0229058.

Gillespie, D., Palmer, L., Macaulay, J., Sparling, C. and Hastie, G. (2021) 'Harbour porpoises exhibit localized evasion of a tidal turbine' *Aquatic Conservation: Marine and Freshwater Ecosystems*, 31(9), pp. 2459-2468.

Hammar, L., Andersson, S., Eggertsen, L., Haglund, J., Gullström, M., Ehnberg, J., *et al*. (2013) 'Hydrokinetic Turbine Effects on Fish Swimming Behaviour.' *PLoS ONE*, 8(12), e84141. https://doi.org/10.1371/journal.pone.0084141

Harland, E. (2013) 'Fall of Warness Tidal Test Site: Additional Acoustic Characterisation.' *Scottish Natural Heritage Commissioned Report No. 563*.

Hasselman, D.J, Hemery, L.G., Copping, A.E., Fulton, E.A., Fox, J., Gill, A.B. and Polagye, B. (2023) ''Scaling up' our understanding of environmental effects of marine renewable energy development from single devices to large-scale commercial arrays.' *Science of The Total Environment*, 904.

Hawkins, A. D. and Popper, A. N. (2017) 'A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates.' *ICES Journal of Marine Science*, 74(3), pp. 635–651.

Hastie, G., Mackey, B., and Du Fresne, S. (2010) 'Summary report on the variation in sonar target detections between night and day', SMRU LIMITED. Available at: https://www.marinedataexchange.co.uk/details/TCE-1928/2008-2009-smru-seagen-strangford-lough-sonar-monitoring-of-marine-mammals-around-seagen

Hastie, G., Montabaranom, J., Sparling, C. and Gillespie, D. (2023) 'WP2 Active Sonar Fieldwork Report.' *Menter Môn Marine Characterisation Research Project (MCRP)* MCRP-SMRU-DOC-0011.

Heal, M., Hoover, B.A. and Waggitt, J.J. (2021) 'Using rangefinder binoculars to measure the behaviour and movement of European Shags *Phalacrocorax aristotelis* in coastal environments.' *Bird Study,* 68(1), pp. 135-140.

Horning, M., Haulena, M., Tuomi, P.A., Mellish, J.A.E., Goertz, C.E., Woodie, K., Berngartt, R.K., Johnson, S., Shuert, C.R., Walker, K.A. and Skinner, J.P. (2017) 'Best practice recommendations for the use of fully implanted telemetry devices in pinnipeds.' *Animal Biotelemetry*, 5, pp. 1-15.

Horne, N., Schmitt, P., Culloch, R., Wilson, B., Houghton, J.D., Dale, A. and Kregting, L. (2023) 'Comparability of outputs between traditional and simulation-based approaches to collision risk modelling.' *Journal of Marine Science and Engineering*, 11(12), p. 2359.

Horning, M. *et al*. (2019) 'Best practice recommendations for the use of external telemetry devices on pinnipeds.' *Animal Biotelemetry*, 7(1), pp. 1-7.

Igiugig Village Council, Ocean Renewable Power Company (2022) '2021 Fish Monitoring report.' Igiugig Hydrokinetic Project FERC Project No. P-13511. Available at: https://tethys.pnnl.gov/project-sites/rivgen-power-system

Jackson, D. and Whitfield, P. (2011) 'Guidance on survey and monitoring in relation to marine renewables deployments in Scotland' Volume 4. Birds. Unpublished draft report to Scottish Natural Heritage and Marine Scotland. Available at: https://tethys.pnnl.gov/sites/default/files/publications/SNH-2011-Volume-4.pdf

Janik, V.M., Zein, B. and Götz, T. (2023) 'Work Package 8 – Acoustic Deterrents Final Report, Dec 2023' *Menter Môn-Marine Characterisation Research Project* (MCRP) MCRP-SMRU-DOC-0014.

JNCC (2005) 'UK Common Standards Monitoring Guidance for Marine Mammals.' Available at: https://hub.jncc.gov.uk/assets/58eb48d9-2523-4397-93df-77e21a8ac51d

Kastelein, R.A., Bunskoek, P., Hagedoorn, M., Au, W.L.W. & de Haan, D. (2002) 'Audiogram of harbour porpoise *(Phocoena phocoena)* measured with narrow-band frequency-modulated signals.' *Journal of the Acoustical Society of America*, 112(1), pp. 334-344.

Keenan, G., Sparling, C., Williams, H. and Fortune, F. (2011) 'SeaGen Environmental Monitoring Programme: Final Report.' Report by Royal Haskoning. Report for Marine Current Turbines (MCT). Available at: https://tethys.pnnl.gov/sites/default/files/publications/Final_EMP_report_SeaGen.pdf

Khare, V., Khare, C., Nema, S. and Baredar, P. (2019) 'Chapter 2 - Introduction of Tidal Energy', in Khare, V., Khare, C., Nema, S. and Baredar P. (eds) *Tidal Energy Systems*, Elsevier, pp. 41-114

Kongsberg (2010) 'Technical Report – Measurement' *Operational Underwater Noise, SeaGen Unit* for Marine Current Turbines Ltd. Available at: https://www.marinedataexchange.co.uk/details/TCE-1929/2010-kongsberg-maritime-ltd-seagen-strangford-lough-operational-underwater-noise---seagen-unit

Li, W., Lin, Y.G., Liu, H.W., Ma, S. (2008) 'Research on horizontal-axis marine current turbine.' In: 1st national symposium on ocean energy in Hangzhou, pp.81-90.

Long, C. (2018) 'No evidence of long-term displacement of key wildlife species from wave and tidal energy testing.' In *4th Asian Wave and Tidal Energy Conference, Taipei, Taiwan.*

Long, C. 2017. 'Analysis of the possible displacement of bird and marine mammal species related to the installation and operation of marine energy conversion systems'. Scottish Natural Heritage Commissioned Report No. 947. Available at: https://www.nature.scot/sites/default/files/2017-06/Publication%202017%20-%20SNH%20Commissioned%20Report%20947%20-%20Analysis%20of%20the%20possible%20displacement%20of%20bird%20and%20marine%20mammal%20species%20related%20to%20the%20installation%20and%20operation%20of%20marine%20energy%20conversion%20systems.pdf

Longden, E. and Hastie, G. (2024) 'WP13 Seal Tagging Final Report March 2024.' *Menter Môn-Marine Characterisation Research Project* MCRP-SMRU-DOC-0017.

MacAulay, J., Gillespie, D., Rapson, K., Montabaranom, J., Sparling, C., and Gordon, J. (2023) 'WP1b: Measuring dive profiles using Passive Acoustic Monitoring.' *Menter Môn-Marine Characterisation Research Project (MCRP)* DOC-MCRP-SMRU-DOC-0008.

Mackey, B., Mackay, A., Northridge, S. and Philpott, E. (2010) 'Monitoring of Harbour Porpoise *(Phocoena phocoena)* in Strangford Lough with focus on the Narrows (April 2006 – Oct 2009)', SMRU LIMITED. Available at: https://www.marinedataexchange.co.uk/details/TCE-1916/2006-2010-smru-seagen-strangford-lough-monitoring-of-harbour-porpoise-in-strangford-lough-with-focus-on-the-narrows

Marine Data Exchange (2023) '2017-2022, Nova Innovation, Ynys Enlli, Bird and Marine Mammal Survey.' [online] Available at: https://www.marinedataexchange.co.uk/details/TCE-3691/2017-2022-nova-innovation-ynys-enlli--bird-and-marine-mammal-survey. Accessed: 06/02/2025.

Martin, J., Sabatier, Q., Gowan T.A., Giraud, C., Gurarie, E., Calleson, C.S., Ortega-Ortiz, J.G., Deutsch, C.J., Rycyk, A., and Koslovsky, S.M. (2015) 'A quantitative framework for investigating risk of deadly collisions between marine wildlife and boats.' *Methods in Ecology and Evolution*, 7(1), pp. 42-50.

Martin-Short, R., Hill, J., Kramer, S.C., Avdis, A., Allison, P.A., and Piggott, M.D. (2015) 'Tidal resource extraction in the Pentland Firth, UK: Potential impacts on flow regime and sediment transport in the Inner Sound of Stroma.' *Renewable Energy*, 76, pp. 596-607.

Meza, C. and Rojas, R. (2020) 'Pan American Marine Energy Conference (PAMEC 2020): Book of abstracts.' doi: 10.18845/mct.v22i1.2020.

McCann, D.L and Bell, P.S. (2017) 'Observations and tracking of killer whales *(Orcinus orca)* with shore-based X-band marine radar at a marine energy test site.' *Marine Mammal Science*, 33(3), pp. 904-912.

McMillan, J.M., Lickley, M.J., Karsten, R. and Haynes, R. (2008) 'The potential of tidal power from the Bay of Fundy.' *SIAM Undergraduate Research Online*, 1, pp. 20-37.

Møhl, B. (1968) 'Auditory sensitivity of the Common seal in air and water.' *Journal of Auditory Research*, 8, pp. 27-38

Moreau, M., Germain, G., Maurice, G., Richard, A. and Coquet, R. (2021) 'HydroQuest: Feedback from Paimpol-Bréhat and validation of the design method.' *Conference: 14th European Wave and Tidal Energy Conference*, At: Plymouth, UK.

Morlais Energy (2024a) 'Tidal Energy' [online] Available at: https://www.morlaisenergy.com/en/about-us/tidal-energy. Accessed 09/12/2024.

Morlais Energy (2024b) 'The Morlais story' [online] Available at: https://www.morlaisenergy.com/en/about-us/the-morlais-story. Accessed 08/07/2024.

Nedwell, J.R. and Brooker, A.G. (2008) 'Measurement and assessment of background underwater noise and its comparison with noise from pin pile drilling operations during installation of the SeaGen tidal turbine device, Strangford lough.' Subacoustech Report No. 724R0120 to COWRIE Ltd. ISBN: 978-0-9557501-9-9. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Nedwell-Brooker-2008.pdf

Nedwell, J.R., Turnpenny, A.W.H., Lovell, J., Parven, S.J., Workman, R., Spinks, J.A.L and Howell, D. (2007) 'A validation of the dB_{ht} as a measure of the behavioural and auditory effects of underwater noise.' Subacoustech Report Reference: 534R1231, Published by Department for Business, Enterprise and Regulatory Reform. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Nedwell-et-al-2007.pdf

Norris, J. (2009) 'European Marine Energy Centre: the development of a targeted environmental monitoring strategy and the streamlining of marine renewables consents in Scotland'. In *Proceedings of the 8th European Wave and Tidal Energy Conference, Uppsala, Sweden* (pp. 1057-64).

Norris, J.V., and Droniou, E. (2007) 'Update on EMEC activities, resource description, and characterisation of wave-induced velocities in a tidal flow.' In *Proc. 7th European wave and tidal energy Conference, Porto, Portugal.*

Nuuttila, H.K. and Mendzil, A. (2014) 'Development of marine mammal observation methods for vantage Point surveys in Ramsey sound.' *SEACAMS Project Report*, p. D75.

Ocean Energy Systems Environmental (OES) (2022) 'Marine Renewable Energy: An Introduction to Environmental Effects.' Available at: https://tethys.pnnl.gov/sites/default/files/summaries/MRE_Brochure-Printable.pdf

Ocean Energy Systems (OES) (2023) 'Tidal Current Energy Developments Highlights'. [online] Available at: https://tethys-engineering.pnnl.gov/sites/default/files/publications/oes-2023-tidal-current-energy-spreads.pdf. Accessed 18/04/2024.

Ocean Science Consulting (2024) 'WP3&4 Final Report.', *Menter Môn-Marine Characterisation Research Project* (MCRP) MCRP-OSC-DOC-0005.

O'Doherty, T., O'Doherty, D.M. and Mason-Jones, A. (2018) 'Tidal energy technology.' *Wave and Tidal Energy*, pp. 105-150.

Office of Energy Efficiency & Renewable Energy (2022) 'U.S. Department of Energy Announces $35 Million in Funding to Advance Tidal and River Current Energy Systems.' [online] Available at: https://www.energy.gov/eere/articles/us-department-energy-announces-35-million-funding-advance-tidal-and-river-current. Accessed 30/05/2024.

Offshore Energy (2024) 'Substation construction for Morlais tidal energy project wraps up'. [online] Available at: https://www.offshore-energy.biz/substation-construction-for-morlais-tidal-energy-project-wraps-up/#:~:text=Completion%20of%20the%20substation%20means,Wales%20on%20October%2020%2C%202023. Accessed 08/07/2024.

Onoufriou, J., Russell, D.J.F., Thompson, D., Moss, S.E. and Hastie, G.D. (2021) 'Quantifying the effects of tidal turbine array operations on the distribution of marine mammals: Implications for collision risk.' *Renewable Energy*, 180, pp. 157-165.

ORPC Maine (2013) 'Cobscook Bay Tidal Energy Project: 2012 Environmental Monitoring Report.' Report by Ocean Renewable Power Company (ORPC). FERC PROJECT NO. P-12711-005. Available at: https://tethys.pnnl.gov/sites/default/files/publications/ORPC_FINALenvironmentalreport_Mar2013.pdf

Paboeuf, S., Yen Kai Sun, P., Macadré, L.M. and Malgorn, G. (2016) 'Power performance assessment of the tidal turbine sabella D10 following IEC62600-200.' In *International Conference on Offshore Mechanics and Arctic* Engineering, 49972, p. V006T09A007. American Society of Mechanical Engineers.

Palagyi, T., Rice, A.N. and Palmquist, K. (2024) 'Use of Passive Acoustic Monitoring to Track Marine Mammals at Offshore Windfarm Sites.' In *International Oil Spill Conference*, 1, p. 329s3.

Palmer, L., Gillespie, D., MacAulay, J.D.J., Sparling, C.E., Russell, D.J.F. and Hastie, G.D. (2021) 'Harbour porpoise *(Phocoena phocoena)* presence is reduced during tidal turbine operation.' *Aquatic Conservation: Marine and Freshwater Ecosystems*, 31(12), pp. 3543-3552.

Qin, H. (2023) 'China's ocean power stations set to go commercial'. [online] Available at: https://chinadialogueocean.net/en/climate/chinas-ocean-power-stations-set-to-go-commercial/#:~:text=One%20project%20near%20Xishan%20Island,largest%20individual%20tidal%20stream%20unit.&text=As%20of%202021%2C%20China%20ranked,stream%20generation%2C%20behind%20the%20UK. Accessed: 18/04/2024.

Ramos, V., Carballo, R., Álvarez, M., Sánchez, M. and Iglesias, G. (2013) 'Assessment of the impacts of tidal stream energy through high-resolution numerical modeling.' *Energy*, 61, pp. 541-554.

Ramos, V., Carballo, R., Sanchez, M., Veigas, M. and Iglesias, G. (2014) 'Tidal stream energy impacts on estuarine circulation.' *Energy Conversion and Management*, 80, pp. 137-149.

Ridgway, S. H. and Joyce, P. L. (1975) 'Studies on seal brain by radiotelemetry.' *Rapports et procès-verbaux des réunions*, International Council for the Exploration of the Sea,169, pp. 81-91.

Risch, D., van Geel, N., Gillespie, D. and Wilson, B. (2020) 'Characterisation of underwater operational sound of a tidal stream turbine.' *Journal of the Acoustical Society of America,* 147(4), pp. 2547–2555.

Risch, D., Marmo, B., van Geel, N., Gillespie, D., Hastie, G., Sparling, C., Onoufriou, J. and Wilson, B. (2023) 'Underwater Noise of Two Operational Tidal Stream Turbines: A Comparison.' In *The Effects of Noise on Aquatic Life: Principles and Practical Considerations,* pp. 1-22. Cham: Springer International Publishing.

Robbins, A. (2012) 'Analysis of Bird and Marine Mammal Data for Fall of Warness Tidal Test Site, Orkney.' *Scottish Natural Heritage Commissioned Report No. 614.*

Roberts, A., Thomas, B., Sewell, P., Khan, Z., Balmain, S. and Gillman, J. (2016) 'Current tidal power technologies and their suitability for applications in coastal and marine areas', *Journal of Ocean Engineering and Marine Energy*, 2, pp. 227–245.

Rossington, K. and Benson, T. (2020) 'An agent-based model to predict fish collisions with tidal stream turbines.' *Renewable Energy*, 151, pp. 1220-1229.

Russell, D. J. F., Hastie, G. D., Thompson, D., Janik, V. M., Hammond, P. S., Scott-Hayward, L. A. S., Matthiopoulos, J., Jones, E. L., and McConnell, B. J. (2016) 'Avoidance of wind farms by harbour seals is limited to pile driving activities.' *Journal of Applied Ecology*, 53(6), pp. 1642–1652. doi:10.1111/1365-2664.12678.

Russel, D.J.F. and McConnell, B. (2014) 'Seal at-sea distribution, movements and behaviour.' SMRU, Scottish Oceans Institute, University of St Andrews. Report to the UK Department of Energy and Climate Change.

Sabella (2020) 'Monitoring around tidal turbines Sabella D10 example'. Available at: https://tethys.pnnl.gov/sites/default/files/events/Sabella_by_Diane_Dhome.pdf

SAE (2023) 'MEYGEN.' [online] Available at: https://saerenewables.com/tidal-stream/meygen/. Accessed 11/04/2024.

Salmon, A., Meadows, B., Kilcher, L. and Hirsch, B. (2022) *Igiugig's Journey Towards Sustainability* (No. NREL/BR-5700-83816). National Renewable Energy Lab.(NREL), Golden, CO (United States). Available at: https://www.nrel.gov/docs/fy23osti/83816.pdf

Samedy, V., Wach, M., Lobry, J., Selleslagh, J., Pierre, M., Josse, E. and Boët, P. (2015) 'Hydroacoustics as a relevant tool to monitor fish dynamics in large estuaries.' *Fisheries Research*, 172, pp. 225-233.

Savidge, G. *et al*. (2014) 'Strangford Lough and the SeaGen Tidal Turbine.' In M. A. Shields and A. I. L. Payne (eds.), *Marine Renewable Energy Technology and Environmental Interactions,* pp. 153–172. Springer Netherlands; doi:10.1007/978-94-017-8002- 5_12.

Scottish Natural Heritage (2016) 'Assessing collision risk between underwater turbines and marine wildlife'. SNH guidance note.

Serin, E. (2023) 'What is tidal stream energy?' [online] Available at: https://www.lse.ac.uk/granthaminstitute/explainers/what-is-tidal-stream-energy/. Accessed 17/04/2024.

Smith, K. (2021) 'Shetland Tidal Array Monitoring Report: Subsea video monitoring'. Nova Innovation Ltd. EnFAIT-0364 Version 4.0. Available at: https://marine.gov.scot/sites/default/files/enfait-0364_subsea_video_monitoring_report_v4.0_final.pdf

Smith, K. (2024) 'Shetland Tidal Array Monitoring Report July 2023 to June 2024.', STA013, Revision_01

Smith, K. and Simpson, N. (2018) 'EnFAIT Enabling Future Arrays in Tidal', EnFAIT-EU-0035 -Y1 Environmental Monitoring Report. Version 1.0. Available at: https://tethys.pnnl.gov/sites/default/files/publications/Smith_and_Simpson_2018.pdf

Smith, K., Date, H. and Waggitt, J. (2021) 'Shetland Tidal Array Monitoring Report: Vantage point surveys.' EnFAIT-0347 Version 5.0. Available at: https://marine.gov.scot/sites/default/files/enfait-0347_sta_vp_report_final.pdf

Sparling, C., Lonergan, M., and McConnell, B. (2018) 'Harbour seals *(Phoca vitulina)* around an operational tidal turbine in Strangford Narrows: No barrier effect but small changes in transit behaviour.' *Aquatic Conservation: Marine and Freshwater Ecosystems,* 28(1), pp. 194–204. doi:10.1002/aqc.2790.

Sparling, C., Lonergan, M., Isojunno, S. and McConnell, B. (2010) 'Using telemetry to investigate the effect of SeaGen on harbour seal behaviour and movement at Strangford Lough, Northern Ireland'. SMRU LIMITED. Available at: https://www.marinedataexchange.co.uk/details/TCE-1927/2006-2010-smru-seagen-strangford-lough-using-telemetry-to-investigate-the-effect-of-seagen-on-harbour-seal-behaviour-and-movement

Strangford and Lecale AONB (2024) 'Strangford Lough Marine Protected Area'. [online] Available at: https://strangfordlough.org/landscape-heritage/strangford-lough-marine-protected-area/#:~:text=Marine%20Protected%20Area-,Strangford%20Lough%20Marine%20Protected%20Area,of%20important%20habita-ts%20and%20species. Accessed 06/12/2024.

Tethys (2019) 'Strangford Lough - MCT (SeaGen)'. [online] Available at: https://tethys.pnnl.gov/project-sites/strangford-lough-mct-seagen. Accessed 22/03/2024.

Tethys (2020) 'PLAT-I 4.63 Tidal Energy'. [online] Available at: https://tethys.pnnl.gov/project-sites/plat-i-463-tidal-energy. Accessed 20/06/2024.

Tethys (2021) 'Roosevelt Island Tidal Energy (RITE) Project Pilot'. [online] Available at: https://tethys.pnnl.gov/project-sites/roosevelt-island-tidal-energy-rite-project-pilot. Accessed 16/04/2024.

Tethys (2023a). 'Nova Innovation - Shetland Tidal Array'. [online] Available at: https://tethys.pnnl.gov/project-sites/nova-innovation-shetland-tidal-array. Accessed 10/04/2024.

Tethys (2023b) 'EMEC Fall of Warness Grid-Connected Tidal Test Site'. [online] Available at: https://tethys.pnnl.gov/project-sites/emec-fall-warness-grid-connected-tidal-test-site. Accessed 29/05/2024.

Tethys (2023c) 'Cobscook Bay Tidal Energy Test Site'. [online] Available at: https://tethys.pnnl.gov/project-sites/cobscook-bay-tidal-energy-project. Accessed 16/04/2024.

Tethys (2024a). 'MeyGen Tidal Energy Project'. [online] Available at: https://tethys.pnnl.gov/project-sites/meygen-tidal-energy-project. Accessed 11/04/2024.

Tethys (2024b) 'Sabella D10 Tidal Turbine at Ushant Island'. [online] Available at: https://tethys.pnnl.gov/project-sites/sabella-d10-tidal-turbine-ushant-island. Accessed 14/06/2024.

Tethys (2024c) 'Fundy Ocean Research Center for Energy (FORCE) Test Site'. [online] Available at: https://tethys.pnnl.gov/project-sites/fundy-ocean-research-center-energy-force-test-site. Accessed 16/04/2024.

Tethys (2024d) 'About Tethys'. [online] Available at https://tethys.pnnl.gov/about-tethys. Accessed 30/05/2024.

Tethys (2024e) 'Igiugig RivGen® Power System'. [online] Available at: https://tethys.pnnl.gov/project-sites/rivgen-power-system. Accessed 22/05/2024.

Tethys Engineering (2024) 'Kite'. [online] Available at: https://tethys-engineering.pnnl.gov/technology/kite. Accessed 19/09/2024.

Tollit, D., Joy, R., Wood, J., Redden, A., Booth, C., Boucher, T., Porskamp, P. and Oldreive, M. (2019). 'Baseline Presence of and Effects of Tidal Turbine Installation and Operations on Harbour Porpoise in Minas Passage, Bay of Fundy, Canada.' Available at: https://www.thejot.net/article-preview/?show_article_preview=1071

United Nations/Framework Convention on Climate Change (2015) 'Adoption of the Paris Agreement.' 21st Conference of the Parties, Paris: United Nations. Available at: https://unfccc.int/sites/default/files/english_paris_agreement.pdf

Verdant Power (2020) 'Roosevelt Island Tidal Energy Environmental Assessment Project.' Prepared for NYSERDA. Available at: https://www.nyserda.ny.gov/-/media/Project/Nyserda/Files/Publications/Research/Environmental/21-03-Roosevelt-Island-Tidal-Energy-Environmental-Assessment-Project.pdf

Williamson, B., Blondel, P., Armstrong, E., Bell, P.S., Hall, C. Waggitt, J.J. and Scott, B.E. (2016) 'A Self-Contained Subsea Platform for Acoustic Monitoring of the Environment Around Marine Renewable Energy Devices–Field Deployments at Wave and Tidal Energy Sites in Orkney, Scotland.' *IEEE Journal of Oceanic Engineering,* 41(1), pp. 67-81.

Williamson, B., Fraser, S., Blondel, P., Bell, P.S., Waggitt, J.J. and Scott, B.E. (2017) 'Multisensor Acoustic Tracking of Fish and Seabird Behavior Around Tidal Turbine Structures in Scotland.' *IEEE Journal of Oceanic Engineering*, 42(4), pp. 948-965.

Wills, T. (2020) 'Construction Method Statement Shetland Tidal Array (as extended)'. Nova Innovation Ltd. Available at: https://marine.gov.scot/sites/default/files/enfait-0322-sta_as_extended_-_construction_method_statement_v2.0_0_-_redacted.pdf

Zhang, D., O'Conner, N.E., Simpson, A.J., Cao, C., Little, S. and Wu, B. (2022) 'Coastal fisheries resource monitoring through A deep learning-based underwater video analysis.' *Estuarine, Coastal and Shelf Science*, 269, p. 107815.

Zhang, L.X., Tang, S.J., Hao, Y. and Pang, M.Y. (2018) 'Integrated energy and economic evaluation of a case tidal power plant in China.' *Journal of cleaner production*, 182, pp. 38-45.

Zheng, J., Dai, P., and Zhang, J. (2015) 'Tidal Stream Energy in China.' *Procedia Engineering*, 116, pp. 880 – 887.

Zhu, W.Q., Xu, M.Q. and Zhang, X.M. (2012) 'Study on the key technologies of horizontal axis surface tidal current generating.' *Acta Energiae Solaris Sinica*, 33, pp. 1067-1072.

Zhu, Y., Jia, L., Duan, C., Sun, X. and Guo, W. (2017) 'Status of testing field for ocean energy generation.' *Journal of Modern Power Systems and Clean Energy*, 5(2), pp. 160-168.

Abbreviations

ADCPs: Acoustic Doppler Current Profilers

ADDs: Acoustic Deterrence Devices

ADV: Acoustic Doppler velocimeter

AfL: Agreement for Lease

AIS: Automatic Identification System

AONB: Area of Outstanding Natural Beauty

C-POD: Cetacean Porpoise Detector

CIs: Confidence Intervals

CREEM: Centre for Research into Ecological and Environmental Modelling

CRM: Collision Risk Models

DART: Drifting Acoustic Recorded and Tracker

Defra: Department for Environment, Food and Rural Affairs

DOE: U.S. Department of Energy

EEMP: Environmental Effects Monitoring Program

EIA: Environmental Impact Assessment

EMEC: European Marine Energy Centre

EMF: Electromagnetic Fields

EMP: Environmental Monitoring Program

EnFAIT: Enabling Future Arrays in Tidal

EPS: European Protected Species

ERM: Encounter Rate Model

ETDs: External Telemetry Devices

FEPA: Food and Environment Protection Act

FORCE: Fundy Ocean Research Centre for Energy

GAM: Generalised Additive Model

GEE: Generalised Estimating Equations

GHGs: Greenhouse Gases

GPS: Global Positioning System

GSM: Global System for Mobile Communication

HATT: Horizontal Axis Tidal Turbines

ICE: European Intelligent Community Energy

IR: Infra-Red Camera

IVC: Igiugig Village Council

JNCC: Joint Nature Conservation Committee

KFIM: Kinetic Hydropower Turbine System-Fish Interaction Model

LAT: Lowest Astronomical Tide

LSE: Likely Significant Effect

MBES: Multibeam Echosounder

MCRP: Marine Characterization Project

MCT: Marine Current Turbines Ltd.

MCZ: Marine Conservation Zone

MDE: Marine Data Exchange

MDZ: Morlais Demonstration Zone

ML: Machine Learning

MMMP: Marine Mammal Mitigation Plan

MMO: Marine Mammal Observer

NENU: Northeast Normal University

NERC: Natural Environment Research Council

NENU: Northeast Normal University

NOC: National Oceanography Centre

OES: Offshore Engineering Society

ORJIP OE: Offshore Renewable Energy Joint Industry Programme for Ocean Energy

ORPC: Ocean Renewable Power Company

ORPG: Ocean Renewable Power Generation

PAM: Passive Acoustic Monitoring

PBR: Potential Biological Removal

PEMP: Project Environmental Monitoring Plan

PNNL: Pacific Northwest National Laboratory

PSD: Power Spectral Density

PTS: Permanent Threshold Shift

PVA: Population Viability Analysis

RGB: Red, Green, Blue

RITE: Roosevelt Island Tidal Energy

RMEE: RITE Monitoring of Environmental Effects

RPM: Rotations Per Minute

SAB: Surface Active Behaviour

SAC: Special Area of Conservation

SAM: Static Acoustic Monitoring

SMRU: Sea Mammal Research Unit

SNH: Nature Scot (Formerly Scottish Natural Heritage)

SPA: Special Protection Area

SPL: Sound Pressure Level

TAST: Targeted Acoustic Startle Technology

TEC: Tidal Energy Converter

TGU: Turbine Generator Unit

T-PODs: Timing Porpoise Detectors

TRL: Technology Readiness Level

TSE: Tidal Stream Energy

TTS: Temporary Threshold Shift

UHF: Ultra High Frequency tags

VATT: Vertical Axis Tidal Turbines

VP: Vantage Point surveys

WPs: Work Packages

ZJU: Zhejiang University

Glossary and definition list

Acoustic Deterrent Device: A device that transmits sound into the surrounding water to deter marine mammals from approaching.

Acoustic monitoring survey: A survey that monitors wildlife and the acoustic environment by measuring sound waves underwater.

Analogue- Digital converter: An electronic device or circuit that converts continuous analog signals, such as voltage or current, into discrete digital values which can then be analysed.

Array: A collection of tidal stream turbines at sea, and the cables linking them together.

Avoidance: Behaviour of an animal responding to and moving away from a turbine.

Avoidance responses: Either avoiding passing close to a turbine, or passing close to a turbine but taking last-second action to avoid colliding.

Background underwater noise: Ambient noise generated from sources such as wind and rain on the ocean surface or sediment scraping along the sea floor.

Backscatter: Reflection of a signal (such as sound waves or light) back in the direction from where it originated. A stronger return signal indicates a hard bottom such as coral or rocks. A weaker return signal indicates a soft bottom such as mud.

Barrier effect: When infrastructure blocks the movement of species.

Baseline Survey: Describes the environment before construction so it can be compared to data collected post construction.

Benthic: Zone at the bottom of a body of water.

Biofouling: The accumulation of microorganisms and macroorganisms on wet surfaces.

Boat-based visual surveys: Observations from a boat travelling along transects (lines of travel on which scientific information is recorded).

Cetaceans: Dolphins, porpoises, and whales

Collision: When an animal comes in contact with the moving parts of a turbine.

Control areas: Provide reference points so that the area impacted by a tidal turbine can be compared to the 'normal' environment.

dB_{ht} criteria: The dB_{ht} species represents the decibels above the hearing threshold and provides a measurement of sound that allows the comparison of the effects of noise on a range of species. It should be noted that the use of dB_{ht} criteria is no longer considered n advisable method to apply in underwater noise assessments.

dB_{ht} species-specific metric: Frequency weighting technique for determining the level of sound relative to hearing threshold (ht). The dB_{ht} (Species) metric has in the past been used as a means of objectively evaluating or predicting the expected effects of noise on a wide range of species.

Displacement: When a species moves to a new area due to unfavourable conditions.

Disturbance: When an activity causes a species to stop acting in a natural way.

Drag Anchors: This is a typical anchor you would see on a ship, usually used in softer soil conditions and when dragged along the seabed gets anchored as it 'digs in'.

Dual-Frequency Identification Sonar observation monitoring: Uses high (1.8 MHz) or low (1.1 MHz) frequency sound waves to produce high resolution underwater images. It combines high frequency sound waves, an acoustic lens, and high-resolution transducer array.

Echolocation: A biological active sonar used by several animal groups, both in the air and underwater, used to locate and identify objects or communicate.

Echosounder: Transmits sound pulses downward into the water column by a transducer. The echo reflected from the bed is received by the echo sounder. The time interval between the emission of the sound pulse and its return as an echo is used to estimate the depth of the water.

Elasmobranchs: A subclass of cartilaginous fish, including sharks, rays, skates, and sawfish.

Electromagnetic fields: A field produced by moving electric charges, most relevant are hose produced by sub-sea power cables.

Encounter: When an animal is in the proximity of a tidal turbine and has potential to collide with the turbine.

Encounter rate: The rate at which marine mammals and birds have potential to collide with a tidal turbine.

Environmental Impact Assessment: A tool used to assess the significant effects of a proposed project on the environment.

Environmental Management Plan: Set of mitigation, monitoring and institutional measures to be taken during the design, construction and operation (including post construction) stages of the project.

Environmental Statement: The report on the Environmental Impact Assessment (EIA) for a proposed development project.

Export cable: The cable linking a tidal stream turbine to land and the National Grid.

External Telemetry Devices: Collect information about movement patterns, physiology and ecology of marine mammals when they cannot be directly observed.

Evasion: When an animal changes its behaviour to escape contact with a turbine.

Generalised Additive Model: A Generalised Additive Model (GAM) is a modelling technique which allows analysis of complex non-linear relationships between continuous explanatory variables and the response variable.

Gravity anchors: This type of anchor uses weight – could be concrete, or just a pile of heavy chain, to restrict movement of the device.

Gravity foundation: Large concrete structure that sits on the seabed and rely on their weight to provide stability for marine structures.

Green hydrogen: Where water is split into hydrogen and oxygen using energy from renewable energy sources.

Haul out: When seals come onto land to rest or breed.

Hydrophone: A microphone designed to be used underwater for recording or listening to underwater sound.

Intertidal: The intertidal zone or foreshore is the area above water level at low tide and underwater at high tide.

Kinetic Hydropower Turbine System-Fish Interaction Model (KFIM): Provides a picture of the presence and abundance of fish targets and their movements relative to a turbine field.

Lagrangian Drifters: Oceanographic instruments comprised of a float secured to a drogue which has an acoustic recorder and hydrophone attached to them with the purpose of measuring underwater sound.

Land-based Vantage Point surveys: Monitoring looking out to sea from a high vantage point on land scanning the survey area at regular intervals.

Load factor: Measures efficiency of energy usage; a high load factor indicates more efficient energy usage.

Lowest Astronomical Tide: The lowest level that can be expected to occur under average meteorological conditions and under any combination of astronomical conditions.

Marine fauna: Animals that live in the ocean or rely on the ocean for all or part of their lives. Marine fauna are highly diverse and range in size from microscopic zooplankton to the blue whale.

Marine Mammal Monitoring Protocol: Document listing appropriate mitigation measures during offshore activities that are likely to produce underwater noise, potentially causing injury or disturbance to marine mammals. Also refers to the act of having marine mammal observers watch for marine mammals during construction, and if one is spotted then constructions stops until the marine mammal has left.

Marine mammals: Classified into four different taxonomic groups: cetaceans (whales, dolphins, and porpoises), pinnipeds (seals, sea lions, and walruses), sirenians (manatees and dugongs), and marine fissipeds (polar bears and sea otters).

Migration: Seasonal movement of species from one region to another.

Mitigation measures: Methods to prevent, reduce or control negative environmental effects of a project.

Monopile: A single large pile is drilled/hammered into the seabed and the turbines are mounted to it - often used in offshore wind.

Mooring cables: The chain/cables that connect the device to the anchors to keep it in place. Can be a single cable (this would allow full rotation of the device around the anchor) or up to 6 cables.

Multibeam survey: Method which maps the seafloor and detects objects in the water column or along the seafloor using acoustic waves.

M-weighting systems: The first frequency weighting functions proposed for marine mammals were termed "M" functions (for marine mammals). The M-weighting functions de-emphasize frequencies that are near the upper and lower limits of the estimated hearing range of each type of hearing group (mysticetes/low-frequency cetaceans, mid-frequency cetaceans, and high-frequency cetaceans, pinnipeds under water, and pinnipeds in air).

Nacelle: The centre of the turbine.

Neap tidal cycles: High tides are a little lower and low tides are a little higher than average caused by the sun and the moon at right angles to each other.

Net-Zero: A target to reduce human-caused emissions to as close to zero as possible. Any remaining emissions must be balanced by storing carbon.

Passive Acoustic Monitoring: Uses mounted hydrophones to detect echolocating marine mammals.

Parametric bootstrapping: Bootstrapping methods are a numerical approach to generating confidence intervals that use either resampled data or simulated data to estimate the sampling distribution of the maximum likelihood parameter estimates.

Permanent Threshold Shift: When the ability of a marine mammal to hear is reduced permanently resulting in permanent hearing loss.

Pile driving: The process of installing a pile into the sediment for the foundations of marine infrastructure.

Piled/drilled anchors: This type of anchor is drilled into the seabed - typically used where the ground is harder/rock.

Pinniped: A carnivorous aquatic mammal such as a seal.

Pin piling: Involves drilling a pile with a small diameter.

Potential Biological Removal level: The maximum number of animals, not including natural deaths, that may be removed from a marine mammal stock while allowing the population to maintain or recover to its optimum sustainable population size.

Power Spectral Density: Any quantity expressed as a contribution per unit of bandwidth. An example is sound exposure spectral density, expressed in units of Pa^2 •s/Hz.

Precautionary principal: Describes measures that are put in place to reduce the impact of an activity to an acceptable level. Where this can't be achieved, the development activity is stopped until a resolution is reached.

Quantitative data: Numbers-based, countable, or measurable data.

Seabed morphology: The shape and structure of the seabed and its features.

Seal haul out sites: Areas where seals rest on land for sleep, breeding etc.

Slack tides: The point in the tidal cycle where the tidal stream has the lowest velocity.

Small cetaceans: Dolphins, porpoises, and small toothed whales.

Snapshot scans: Method to record birds or marine mammals in motion, flagging records of flying birds if they were within a theoretical box at the moment of the snapshot.

Species characterisation netting: Provides data on species abundance, particularly for fish species near tidal turbines. This supports data collected by dual frequency identification.

Species density: The number of species present in a given area.

Spring tides: High tides are a little higher and low tides are a little lower than average which happens when the Earth is between the moon and the sun.

Static Acoustic Monitoring System: These are moored subsurface hydrophones that detect, store, process (and in some cases remotely transmit) underwater sound. There are two forms of systems: broadband acoustic spectrum recorders, which can monitor ambient/anthropogenic noise and marine mammals and systems that monitor marine mammals alone.

Technology Readiness Level: Describes the technical maturity of a technology and is measured on a scale of one to nine, from the research phase (one) to full scale deployment (nine).

Telemetry tracking: Position measured by a tag attached to a mammal which can provide information on location and seasonal behaviour.

Temperature rise to within 1.5 degrees Celsius: The 1.5 degrees Celsius target was based on assessments of the impacts of climate change at different levels of warming. It was found that at 1.5 degrees Celsius, extreme heat is significantly less common and intense in many parts of the world than at 2 degrees Celsius.

Temporary Threshold Shift: A temporary hearing loss caused by anthropogenic noise.

TETHYS: Knowledge hub launched in 2011 by the Pacific Northwest National Laboratory (PNNL) to facilitate the exchange of information and data on the environmental effects of marine and wind energy technologies; and serve as a commons for marine and wind energy practitioners and therefore enhance the connectedness of the renewable energy community.

Tidal Energy Converter: A machine that concentrates energy from moving masses of water, specifically tides.

Tidal Stream Energy Resource: An area available that provides a fast enough tidal current that energy can be harnessed from.

Tidal range: The difference in height between high and low tide.

Transect: Line on which scientific data is recorded.

Vantage Point survey: A survey from a fixed location with a high point of view, to achieve a greater view over the study area.

X-band marine radar facility: X-band radar systems scan the ocean surface in real time at high temporal (1–2s) and spatial (5–10m) resolution. An area of sea surface of several square kilometres can therefore be continuously monitored.

X-band radar: Can be mounted on vessels or offshore structures to measure waves and currents along with ship traffic.

Correct as of April 2025, unless otherwise stated.

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