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Llywodraeth Cymru Welsh Government

ORJIP Ocean Energy

Information Note: Environmental Monitoring Technologies and Techniques for Detecting Interactions with Marine Animals

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MarineSpace Making Sense of the Marine Environment™

CONTENTS

Information Note: Environmental Monitoring Technologies and Techniques for Detecting Interactions with Marine Animals and Habitats

1 INTRODUCTION

This series of technical, topic-specific Information Notes has been co-produced by the Welsh Consenting Strategic Advisory Group's Science and Evidence subgroup (SEAGP) in order to support the consenting of wave and tidal stream energy projects. The Information Notes have been developed to establish the current position of key stakeholders in Wales on the evidence available on interactions of wave and tidal energy technologies with the marine environment. They are designed to set out a starting point for applicants by providing an understanding of where consenting challenges might lie. The aim of the Information Notes is to support marine licence applications that are robust, proportionate and focused on assessing the key potential significant impacts and possible interactions between marine renewable energy (MRE) devices and the marine environment.

These Information Notes will support careful consideration of how, for a particular development, potential impacts that are considered low risk could be safely retired from further detailed consideration within Environmental Impact Assessments (EIA), where available evidence supports this approach. Ocean Energy Systems-Environmental (OES-Environmental) has set out a general process for risk retirement[1,2] but for developments in Welsh waters, risk retirement should always be discussed between developers and Natural Resources Wales (NRW) at the pre-application stage. In the context of these Information Notes, risk retirement implies that all potential impacts are included for consideration at the project scoping stage, and that following a review of the evidence some impacts may be 'scoped out' of any further detailed assessment to focus EIA on key significant impacts[3]. In all cases, potential impacts should be acknowledged in EIAs, with evidence-based justifications describing why particular impacts could be 'scoped out' of further detailed assessment.

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[1] https://tethys.pnnl.gov/events/oes-environmental-webinar-risk-retirement
[2] https://tethys.pnnl.gov/publications/state-of-the-science-2020-chapter-13-risk-retirement
[3] It should be noted that The Wildlife Trusts expressed concerns about the use of the phrase 'risk retirement' being applied in this context, particularly considering the uncertainties in impact assessment that are likely to arise with increasing scale of MRE developments.

Further information about this series of Information Notes, who these documents are for, how they were produced, and how they should be used can be found in the accompanying document *Information Notes: Background Information.* The *Information Notes: Background Information* documentation also contains information about the terminology used in this document.

1.1 ENVIRONMENTAL MONITORING TECHNOLOGIES AND TECHNIQUES FOR DETECTING INTERACTIONS – GENERAL

Interactions between the marine environment and MRE devices remain poorly understood, in part because of difficulties associated with observing interactions in highly energetic environments. For highly mobile marine animals such as seabirds, fish and marine mammals these difficulties are compounded by the rare nature of nearfield interactions between animals and MRE devices. These challenges require the design of monitoring equipment and associated systems that can survive in high energy marine environments, can manage power to operate instruments, and can collect, store, and (sometimes) analyse large amounts of data continuously (Hasselman et al. 2020).

Monitoring of MRE developments can suffer from the phenomenon of being "data rich - information poor" (DRIPy, Wilding et al. 2017). DRIPy data occurs where numerous parameters are monitored, and many data streams are collected without consideration of whether such data addresses key monitoring questions. Often this approach can result in monitoring programmes that are not proportionate for developers nor sufficiently focused to provide insight into environmental issues and reduce future consenting risk. To counteract this, the metrics and outcomes of monitoring programmes should be carefully selected to provide data that is targeted to a MRE development's key monitoring objectives. Wider-scale strategic monitoring programmes, on the other hand, should focus on providing data to inform assessment of ecosystem effects and provide insight into any non-linear effects[4] associated to stressors (Wilding et al. 2017). Examples of non-linear effects include those resulting in tipping points or thresholds for population viability, where a stressor (e.g. underwater noise) may have both acute and long-term impacts on a species, or when impacts vary over time because of seasonal effects. Monitoring, when it is required, should also be designed in such a way that it is sufficiently robust and understandable, to support consistent, transparent and timely decisions (Wilding et al. 2017).

Definitive guidance on how to undertake post-consent environmental monitoring for fish, seabirds, and marine mammals is not typically provided by regulators until an EIA has been carried out and key issues for monitoring have been identified. A wide suite of environmental monitoring technologies and techniques have been used for post-consent monitoring at MRE deployments to date. Commonly deployed instrumentation includes:

[4] A non-linear effect is an effect where there is not a direct, proportionate, or 'straight-line' relationship between the stressor and the effect.

- Passive acoustics – to characterise soundscapes and monitor for echolocating animals,
- Active acoustics – imaging sonars and echosounders to monitor for animal presence and behaviour, and
- Optical cameras – to monitor for animal presence and behaviour.

Instruments can be mounted on MRE devices, moored independently away from devices, or packaged together into integrated monitoring platforms (Hasselman et al. 2020).

Consents for marine renewable energy projects will generally include a condition that environmental monitoring is undertaken focussed on specific potential impacts. This is to ensure compliance with relevant legislations such as the Conservation of Habitats and Species Regulations 2017 (and the offshore equivalent) and for regulators to validate EIA assessments. Consent conditions normally include a requirement for the regulator to agree the details of an Environmental Monitoring Plan. The results of this monitoring will be used to inform developments that are delivered in phases, using an adaptive management approach to consenting. NRW has published guidance on the use of adaptive management for marine developments[5].

NRW is not prescriptive about monitoring technologies and techniques and has undertaken several reviews of the current state of the art over recent years. In 2021, the Welsh Government commissioned Swansea University to undertake a review of monitoring methodologies and technologies suitable for deployment in high energy environments in Wales, to monitor animal interactions with tidal energy devices[6], (Clarke et al. 2021a). NRW has also produced number of other reports providing insight and guidance on monitoring specific receptors, which are available on the NRW website[7].

1.2 EVIDENCE SOURCES CONSIDERED BY SEAGP

SEAGP members were asked to apply their expertise and were encouraged to read the *Review of monitoring methodologies and technologies suitable for deployment in high energy environments in Wales, to monitor animal interactions with tidal energy devices* (Clarke et al. 2021a). SEAGP members were also asked to review the OES-Environmental Short Science Summary

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[5] https://naturalresources.wales/guidance-and-advice/business-sectors/marine/using-adaptive-management-for-marine-developments/?lang=en

[6] https://gov.wales/sites/default/files/publications/2021-07/monitoring-interactions-between-animals-and-tidal-energy-devices-report_0.pdf

[7] https://naturalresources.wales/guidance-and-advice/business-sectors/marine/marine-renewable-energy-developments/?lang=en

document on environmental monitoring of MRE developments[8] in advance of providing a response to an environmental monitoring technologies and techniques questionnaire. Respondents were also encouraged to consult the full chapter on environmental monitoring of MRE developments within the OES-Environmental 2020 State of the Science Report[9]. Additional key references are listed at the end of this document.

2 VIEWS OF NATURAL RESOURCES WALES ON ENVIRONMENTAL MONITORING TECHNOLOGIES AND TECHNIQUES

Information in this section was gathered in consultation with NRW benthic, fish, seabird, and marine mammal receptor specialists.

2.1 GENERAL PERSPECTIVES ON ENVIRONMENTAL MONITORING TECHNOLOGIES AND TECHNIQUES

For all species and habitats in question (receptors), the type of monitoring put in place will depend on the location of the development, type of devices to be installed and any associated potential impact pathways. NRW emphasise that a good baseline understanding of a site that provides insight into the current status of a receptor and predicted impact pathways of the development will help to inform proportionate and effective monitoring programmes, where they are necessary.

The monitoring techniques implemented at a development site should provide the data required to meet consent conditions and be proportionate to the magnitude of the potential impact. However, it should be noted the regulator will decide on the need (or not) for monitoring following an assessment of the evidence presented by developers in support of an application and in consultation with technical experts. NRW suggest that early engagement between developers and regulators, environmental organisations and other stakeholders is strongly recommended.

There are several challenges to the development of monitoring programmes in Wales. NRW identify that substantial uncertainty arises from limited array deployments in UK waters and limited experience in deploying associated monitoring systems. This is particularly true for Welsh waters, where limited single device deployments have occurred. However, many monitoring technologies have been applied at MRE developments in the UK and internationally although some environmental conditions can also make environmental monitoring difficult, for example highly turbid waters limiting the

[8] https://tethys.pnnl.gov/summaries/short-science-summary-environmental-monitoring
[9] https://tethys.pnnl.gov/publications/state-of-the-science-2020-chapter-10-environmental-monitoring

use of camera techniques and high potential for biofouling on equipment sensors.

2.2 SEABED HABITATS AND INVERTEBRATES

NRW expect that for seabed habitats and invertebrates, monitoring techniques and survey sites will be location and habitat specific. Ideally monitoring at all development scales should aim to identify any impacts (and recovery) from pressures associated with development activities compared with baseline assessments and control sites.

2.2.1 Priorities for monitoring

Key priorities for monitoring of seabed habitats and invertebrates will be habitats and species afforded protection by the Conservation of Habitats and Species Regulations 2017 (and offshore equivalent) found within a development's impact zone (as determined by physical processes monitoring). These habitats and species will be considered by regulators as part of any Habitats Regulation Assessment. Where there are uncertainties over impacts and/or recovery from temporary pressures, suitable monitoring is likely to be required to ensure there is no adverse impact on a protected habitats or protected species. In Wales, there is also a duty to maintain and/or enhance protected habitats and species in order to maintain the ecological coherence of the MPA network, and monitoring can help to ensure that this requirement is met. The location of a project will dictate whether habitats and species are within scope for assessments to ensure compliance with the relevant legislation.

2.2.2 Best practice and recommended monitoring techniques

NRW suggest that there is likely to be a difference in monitoring approaches for different types of devices, depending on the likely impact of the devices and associated infrastructure on benthic habitats and on the proximity of development to key receptors.

For the monitoring priorities outlined in Section 2.2.1, there are several resources providing information about best practice and recommended techniques for monitoring:

- NRW's benthic habitat assessments for marine developments guidance and advice[10],
- JNCC's Marine Monitoring Handbook[11],

[10] https://naturalresources.wales/guidance-and-advice/business-sectors/marine/benthic-habitat-assessments-for-marine-developments/?lang=en

[11] https://hub.jncc.gov.uk/assets/ed51e7cc-3ef2-4d4f-bd3c-3d82ba87ad95

- JNCC Recommended Operating guidelines and Standard Operating Procedures (SOP)[12],
- The North East Atlantic Marine Biological Analytical Quality Control Scheme (NMBAQC)[13] for benthic sample processing and analysis.

2.2.3 Post-consent monitoring

NRW suggest that benthic surveys (using video, diver, or grab samples), and multi-beam and/or sidescan sonar surveys (depending on the types of habitats or features that are likely to be impacted by the development) should be considered for post-consent monitoring purposes. Multi-beam and sidescan sonar surveys will be especially relevant for some reef communities and sediment habitats where hydrodynamic changes are likely to lead to scour or other changes in sediment dynamics.

NRW advise that acoustic methods would normally be used at the site characterisation and baseline survey stage and could be repeated periodically during longer-term monitoring programmes to help detect changes in seabed habitat extent or condition. These techniques are well-supported by the evidence base.

Changes in hydrodynamics are closely linked with potential impacts on benthic habitats so the two receptors need to be considered jointly. Although it may not be required to inform consents, monitoring and research around small developments and across different device types would help to inform understanding of the potential impacts of changes to hydrodynamics as developments increase in size. For large arrays, there may be more uncertainty over the impacts predicted by modelling work, in which case it would be suitable to undertake monitoring to capture long range impacts.

2.2.4 Opportunities for innovation

There is a growing interest in the use of environmental DNA (eDNA) analysis for monitoring. Although NRW consider this to be an interesting approach alongside traditional analysis of species presence and abundance, the associated evidence base is considered to be poor. This technique is also limited by the number of species for which sequences are available in DNA barcode reference libraries (Jeunen et al. 2019). Efforts should be made to implement eDNA analysis alongside traditional techniques in order to grow the reference database.

[12] Available by searching JNCC's Resource Hub: https://hub.jncc.gov.uk/
[13] http://www.nmbaqcs.org/

2.3 FISH

2.3.1 Priorities for monitoring

NRW identify the following as key priorities for monitoring of effects on fish across the MRE project development cycle, from construction through decommissioning:

- Spatial and temporal information on use of the site by fish,
- Fish interaction with tidal turbines,
- Fish behaviour around tidal turbines.

NRW note that the risk to fish associated with installations of devices with fewer, or no moving parts would be reduced, although there may still be effects associated with changes in fish behaviour.

NRW consider that risks to fish associated with MRE development is likely to increase with the scale of the development. Barrier effects may also increase risk associated with large arrays, as visual, auditory, or hydrological cues may cause fish to avoid the array and possibly the wider area. Depending on the array location, barrier effects from a MRE development could interfere with migration patterns or cause displacement from an area. NRW considers there is a particular risk to protected diadromous fish where developments are situated closer to the coast, estuaries and to rivers where there is likely to be increased densities of these fish. Barrier and displacement effects from MRE developments are highlighted as being challenging to capture using the monitoring techniques outlined in the next section (2.3.2).

2.3.2 Best practice and recommended monitoring techniques

For the monitoring priorities outlined in Section 2.3.1, NRW suggest several recommended techniques for monitoring MRE developments:

- A combination of fish surveys and acoustic fish telemetry primarily for diadromous fish, but potentially also for protected marine fish,
- Remote sensing cameras or acoustic cameras,
- High frequency fish telemetry tags.

NRW advise that some protected fish species such as diadromous fish are scarce in the marine environment so capturing behaviour using these technologies is likely to be difficult.

NRW considers that the evidence base supporting the use of telemetry (tagging), and acoustic arrays and acoustic sensors and tags as part of MRE monitoring strategies is very good. The evidence base is adequate for active acoustic monitoring, eDNA, capture surveys, and device-mounted video monitoring. However, NRW consider the use of seabed and benthic surveys, off-

device video monitoring (e.g. baited video), and integrated monitoring platforms to be poorly supported by evidence.

It should be noted that NRW consider the evidence base supporting the application of these techniques and technologies to monitoring fish around MRE developments in Welsh waters to be poor, as there have been very few MRE developments to date.

2.3.3 Post consent monitoring

NRW suggest that the following techniques could be implemented in post-consent monitoring programmes:

Single device development:
- Active acoustic monitoring
- On-device video monitoring

Small array development:
- Telemetry (tagging)
- Acoustic arrays and acoustic sensors/tags
- Active acoustic monitoring
- On-device video monitoring

Large array development:
- Telemetry (tagging)
- Acoustic arrays and acoustic sensors/tags
- Active acoustic monitoring
- Capture surveys (e.g. fish trawls)
- Seabed/benthic surveys (video, diver, grab samples, etc)
- On-device video monitoring
- Off-device video monitoring (e.g. baited video, video surveys)

NRW recognise that some conditions could make the application of these monitoring technologies in Welsh waters more challenging, including high turbidity and biofouling. Additionally, NRW note that fish are a very diverse group and advise that some techniques may be more effective than others for particular fish species. The monitoring techniques applied should therefore be informed by the specific fish species, MRE device type, and the development location.

The scale of the development will also inform the project monitoring objectives. For example, for larger arrays, risk associated with fish behavioural change occurring at a distance from the development also becomes important and should be addressed through monitoring.

2.3.4 Strategic monitoring needs

NRW acknowledge that primary data and evidence related to the spatial and temporal use of Welsh waters by fish may be more appropriate for strategic monitoring by government or an agency than by individual developers. For example, data collection on migratory routes and marine habitat use by diadromous fish in Welsh waters is a high priority evidence need which poses constraints on MRE consenting in Welsh waters. Collecting this data requires a strategic approach because efforts must cover a large spatial area and data collection must occur over several years, requiring extensive resources.

NRW has published two Science Reports (552 & 553) on collecting evidence for diadromous fish in Welsh waters (Clarke et al. 2021b, Clarke et al. 2021c). NRW suggest that strategic surveys on marine fish spawning and nursery grounds to update and expand on data in Ellis et al. 2012 and Coull et al. 1998 would help to inform environmental risks from MRE projects, and that other marine industries would also benefit from this evidence.

2.4 SEABIRDS

2.4.1 Priorities for monitoring

NRW identify the following as key priorities for monitoring of effects on seabirds:

- Pre-application surveys to provide a baseline for identification of potential effects as a project is developed,
- Evidence of underwater interactions in proximity to tidal turbines, including species identification and any evidence of collision during device operation,
- Seabird distribution and behaviour during device operation.

2.4.2 Best practice and recommended monitoring techniques

For developments of all scales, NRW recommend that developers should generally undertake two years of baseline surveys, although this will be dependent on the development scale and risk associated with a particular development. For locations in or adjacent to MPAs, baseline data will be particularly important to understand how seabirds use different locations at sea at different times of the year.

Boat-based surveys are preferred for inshore areas as they tend to provide better coverage over a small area and they are better able to observe seabird abundance and behaviour throughout the tidal cycle. NRW note that aerial surveys may be more appropriate for developments further offshore.

2.4.3 Post-consent monitoring

NRW suggest that the following methods for post-consent monitoring could be considered for seabirds at all scales of projects:

- Visual surveys of seabirds (boat-based surveys are preferred over fixed vantage point surveys),
- On-device video monitoring,
- Integrated monitoring platforms,[14]

The supporting evidence base is considered to be good for visual surveys of abundance and aerial surveys. It is also considered to be good for seabird telemetry studies, although this technique is more likely to be implemented in academic studies rather than in association with post-consent monitoring by developers.

In Welsh waters, NRW considers that there are multiple challenges to deploying monitoring equipment that will provide information that reduces uncertainty around seabird collision risk. At present, very little monitoring information has been produced that can identify seabird species underwater and recognise nearfield behaviour and potential collisions with devices. Although integrated monitoring platforms, video monitoring and active acoustic technologies have all been trialled as technologies for MRE monitoring, NRW consider that the existing evidence base for these technologies remains poor.

There are several key challenges that would influence the effectiveness of some monitoring technologies in Welsh waters. For example, NRW advise that high turbidity will affect the quality of video monitoring data and that for both video monitoring and sonar it is rarely possible to identify particular seabird species. There may also be access challenges at seabird breeding colony locations for tagging birds as part of tagging studies. Tagging studies are also limited by the number of birds (proportion of the colony) that can be tagged and that often it is seabirds from the edge of colonies that are captured for tagging. These individuals' behaviours may not be representative of the most successful seabirds in that colony (that are often found in more central positions).

2.4.4 Strategic monitoring needs

NRW suggest that information on baseline abundances of seabirds could be gathered strategically by government agencies. This information could then be used by developers to inform collision risk modelling for seabirds.

[14] Several integrated monitoring platforms are described in Section 10.4 of the OES-Environmental State of the Science chapter on Environmental Monitoring Technologies and Techniques for Detecting Interactions of Marine Animals with Turbines (Hasselman et al. 2020, https://tethys.pnnl.gov/sites/default/files/publications/OES-Environmental-2020-State-of-the-Science-Ch-10_final_hr.pdf)

2.5 MARINE MAMMALS

Although general advice is provided in the sections below, NRW expect that monitoring of marine mammals around MRE developments will be specific to the development location and the type of MRE device. Monitoring requirements may be more stringent for deployments that are situated in the vicinity of an MPA. This is because deployments near MPAs are likely to be associated with greater densities of protected marine mammals and so are associated with greater consenting risk.

NRW advise that the scale of a development is directly related to the associated risks to marine mammals, which will influence monitoring requirements for marine mammals. Although some monitoring has been carried out around single devices and small arrays, the degree to which a larger array will result in a barrier effect (such as avoidance behaviour), rather than an increased collision or entanglement risk (from animals transiting the array) is uncertain.

2.5.1 Priorities for monitoring

NRW identify the following as key priorities for monitoring of effects on marine mammals:

- Collisions and avoidance rates under various conditions of tidal flow,
- Underwater noise,
- Population movement around sites to assess barrier effects and/or behavioural disturbance.

Technologies and techniques to enable collision detection and in particular species identification in the event of a collision are still in the early stages of development, although these are key monitoring priorities for marine mammals.

NRW note that there is significant uncertainty around the effects of long-term use of acoustic deterrent devices (ADDs) on cetaceans such as bottlenose dolphins, Risso's dolphins, and harbour porpoise. Should ADDs be used in MRE developments, monitoring should be carried out to address concerns about the effects of long-term displacement of animals from large areas.

2.5.2 Best practice and recommended monitoring techniques

NRW suggest that the following guidance on marine mammal site characterisation and underwater noise measurement should be considered to inform marine mammal monitoring strategies at MRE development sites:

- Guidance to inform marine mammal site characterisation requirements at wave and tidal stream energy sites in Wales[15]. Note that this document is primarily focused on surveys for EIA, rather than post-consent monitoring,
- National Physical Laboratories Good Practice Guide No. 133 – Good Practice Guide for Underwater Noise Measurement[16],
- International Standards Organisation ISO/TC 43/SC3: Underwater Acoustics[17].

2.5.3 Post-consent monitoring

Several technologies and techniques are available for monitoring marine mammals. Each technology or technique has specific advantages and limitations and should be discussed with NRW when planning post-consent monitoring strategies. NRW recommend that developers should implement the following techniques where appropriate in post-consent monitoring programmes for developments at all scales:

- Telemetry (tagging),
- Acoustic arrays and acoustic sensor/tags,
- Passive acoustic monitoring,
- Active acoustic monitoring,
- Integrated monitoring platforms[18],
- Collision sensors on blades.

The specific technologies implemented and methods for implementation at a specific development may vary according to the type of device.

The location of a development will also be important, as NRW advise that the effectiveness of a particular monitoring technique will depend to some extent on environmental conditions. For example, waters with strong currents can cause substantial flow noise for bottom mounted hydrophones; high amounts of suspended matter in the water column will increase backscatter (signal noise) for active acoustics; and high turbidity will reduce visibility for video monitoring.

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[15] https://naturalresourceswales.gov.uk/media/681871/guidance-to-inform-marine-mammal-site-characterisation-requirements-at-w.pdf
[16] https://www.npl.co.uk/special-pages/guides/gpg133underwater
[17] https://www.iso.org/committee/653046/x/catalogue/p/1/u/0/w/0/d/0
[18] Examples of integrated monitoring platforms are reviewed in section 10.4 of Hasselman et al. 2020, available online at: https://tethys.pnnl.gov/sites/default/files/publications/OES-Environmental-2020-State-of-the-Science-Ch-10_final_hr.pdf

NRW highlight that different locations may present different marine mammal ecology (species, seasonality and behaviours), which should also be considered when planning post-consent monitoring strategies.

Very few monitoring technologies have been trialled in Welsh waters. Although many monitoring methods for marine mammals have been tested rigorously and evidenced in the literature, they will have inherent weaknesses and NRW advise that it is important to consider these alongside the development location and scale when developing monitoring programmes. For each method, technique, or technology, NRW highlight the following considerations:

- **Visual surveys** of abundance can only be carried out in daylight hours and in good weather. Poor animal detection rates in small areas can be problematic for analysis.
- **Aerial surveys** are considered to be effective and are useful when surveying large geographical areas. However, they require daylight and good weather conditions, and can be prohibitively expensive. Aerial surveys will only detect animals when they are on the sea surface, and there may be identification biases towards species that are larger and spend greater amounts of time on the sea surface. There may also be analytical differences between digital and visual aerial surveys.
- **Telemetry** has been used to understand seal distribution and behaviour around MRE developments (e.g. MeyGen), although it has not been demonstrated for cetaceans.
- **Active acoustic monitoring** also has precedent for marine mammal monitoring, although identification of species can be challenging unless combined with other monitoring methods.
- **Device-mounted video monitoring** techniques are considered to be well-evidenced for marine mammals, but NRW highlight that they are likely to be difficult to apply in Welsh waters where water column visibility is poor.
- The use of **integrated monitoring platforms** is supported by evidence, and these platforms have been trialled in UK waters at several locations. However, NRW note that the success rates of these platforms have not been particularly well documented, and that the robustness of such platforms can be an issue for long-term deployments.

Large arrays may require different monitoring strategies or techniques than smaller arrays because they may extend across areas with different densities of species of interest and different physical environmental characteristics. NRW advise that monitoring such arrays would likely require multiple deployments of monitoring instruments to cover such variability across the development site, and that these deployments should reflect densities and behaviour patterns of the species of interest.

2.5.4 Reducing uncertainty in monitoring marine mammals

To date there have not been any large array deployments in UK waters which has led to some uncertainty as to how environmental monitoring could be carried out at such developments. However, NRW suggest that at present, it is assumed that techniques tested on smaller developments will likely be suitable for upscaling. When the opportunity arises, this assumption should be validated in practice.

NRW also suggest that developers could help to reduce uncertainty associated with environmental monitoring methods by trialling monitoring technologies at a similar location to the proposed development site or at the deployment site itself. Where developments plan to expand from small to large arrays, monitoring techniques and technologies could be trialled on a smaller number of turbines before up-scaling. Developers could also become involved in academic research initiatives to support the development of new monitoring technologies and approaches.

2.5.5 Strategic monitoring needs

NRW identify that there is a requirement for strategic monitoring of marine mammal management unit (MU)-scale population sizes and distributions to better understand animal linkages with MPAs, to improve advice on mortality limits, and to map areas of high animal density. Although project-level baseline surveys would still be required, this MU-scale data would provide important context for an assessment.

3 PERSPECTIVES FROM ENVIRONMENTAL ORGANISATIONS

The Royal Society for the Protection of Birds (RSPB) and The Wildlife Trusts (TWT) were consulted on monitoring technologies and techniques for detecting interactions between MRE devices and marine animals. Both organisations highlight that they would provide advice on the type of monitoring that would be expected for developments as part of a consultation on an application, however, they also encourage the development of a more strategic approach to monitoring across the sector that promotes transferability in the monitoring methods used and data that is collected.

RSPB and TWT note that MRE is at an earlier stage of development than the offshore wind industry, for example. As protocols, techniques, and approaches to monitoring are still developing for the MRE sector, it is important that feedback from individual projects informs advice for future developments through open and transparent sharing of data.

By undertaking high quality monitoring activities at smaller development scales, RSPB and TWT suggest that developers can help to produce important outcomes and know-how to inform the consenting of future, larger projects.

3.1 PRIORITIES FOR MONITORING

RSPB highlights the importance of understanding the reactive behaviour of seabirds to MRE devices, as this will influence and inform understanding of collision risk. Understanding how seabirds use flow features (such as upwellings, eddies, and wakes), and whether their diving behaviour takes them closer to submerged devices will also influence estimation of potential collision risk. RSPB note that the attraction of seabirds to MRE devices (whether because of prey aggregation or as a resting location) is accounted for within collision risk models, so any monitoring on seabird attraction to MRE devices will also provide information that could reduce uncertainty.

Monitoring the displacement of seabirds is also important to RSPB, who suggest that this issue could be addressed in pre and post device installation surveys of seabird abundance.

For wide-ranging species, population-scale monitoring is crucial, although such monitoring could be approached in a strategic way, as NRW suggest in Section 2. TWT suggest that a strategic programme similar to the Crown Estate's Offshore Wind Evidence and Change Programme[19] be established to identify and fund evidence projects and strategic monitoring programmes, feeding into strategic planning requirements.

3.2 MONITORING TECHNOLOGIES AND TECHNIQUES

RSPB acknowledges that there are current challenges with monitoring occurrences of animal collision with MRE devices. They note that video monitoring can sometimes be difficult because of turbidity issues and biofouling on equipment. Sensors in tidal turbine blades are suggested as a possible source of information about collision, although they may not be available in many devices and there is some uncertainty about if and how a collision with an animal would be identified.

Sonar and other acoustic methods are likely to develop further in the future, but like NRW, RSPB highlights that there are currently challenges associated with identifying animals to species level.

RSPB suggest that tagging of animals, while strongly evidenced and demonstrated in many applications, may not always be appropriate for MRE monitoring because of the associated cost and limitations in the numbers of animals that can be tagged. Where tags are used, it will be important to carefully consider several key parameters including tag size, battery requirements, methods of data acquisition (remote download, or recapture), and the complexity of data required. RSPB advise that pressure sensors and accelerometers integrated into tags could help to improve data by providing

[19] https://www.thecrownestate.co.uk/en-gb/what-we-do/on-the-seabed/offshore-wind-evidence-and-change-programme/

information about animal dive profiles that would feed into collision risk modelling.

TWT would encourage ongoing monitoring of underwater noise impacts on species and populations at both project and strategic levels, and also highlight the importance of regularly monitoring the status of benthic species assemblages found at MRE development locations. More broadly, data collection and monitoring practices should be open and transparent, and data should be made available to validate modelling and environmental assessments, to enable learning between projects and to facilitate the development of best practice.

3.3 OPPORTUNITIES FOR INNOVATION

There is a clear need for innovation in monitoring technologies for MRE devices and developments. RSPB notes that there are few suitable 'off the shelf' technologies available at present, and that investment to support technology design and development is crucial. It will also be important to engage professionals outside of the MRE sector to develop new ideas and deliver new and innovative technologies.

TWT highlight the development of 'smart monitoring' technologies for offshore wind turbines, where monitoring technologies such as motion-activated cameras, are contained within the turbine. Similar technologies could be applied within the MRE sector.

4 PERSPECTIVES FROM INDUSTRY

It is important that developments progress in tandem with well-designed monitoring programmes in order to generate knowledge and reduce uncertainty associated with MRE developments. Without MRE devices in the water to monitor it will be difficult to improve monitoring programme design and develop technologies that meet both industry and regulatory needs or improve the evidence base on effects.

4.1 PRIORITIES FOR MONITORING

Monitoring priorities for MRE developments in Wales, from an industry perspective, include:

- Developing proportionate monitoring programmes with clear objectives that are strongly associated with the outcomes of the consenting process and that distinguish between statutory monitoring (to inform management) and voluntary monitoring (to de-risk future projects),
- Monitoring key receptor (birds, fish, and marine mammals) interactions with operational tidal energy convertors to validate the outcomes of EIA.

Some industry members also suggest that underwater noise monitoring could also be a priority. An important challenge in monitoring nearfield interactions

between highly mobile animals and MRE devices is the rare nature of animal encounters. This can often lead to the creation of large amounts of data punctuated by very few observations of animal interactions, making it very difficult to analyse and generate conclusions on animal presence or behaviour around MRE devices.

Although far field displacement of animals from a MRE site is recognised to be a key environmental challenge, industry highlight that it will be very difficult to separate the effects of small-scale MRE developments on populations from other large-scale environmental changes stemming from interannual or decadal ocean variability and climate change. As such, displacement effects could be better addressed through strategic monitoring programmes.

In Wales, opportunities to monitor MRE developments at any scale have been limited. There may be additional monitoring requirements for large arrays, as no arrays have been deployed in Welsh waters and few arrays have been deployed globally. Some impacts that are considered less important for single devices and small arrays may become of more concern as projects grow in scale. Industry members recognise that the evidence base must keep pace with the scale of development, and so suggest that in some cases investment in monitoring effects that may not be critical for early projects could help to de-risk future, larger-scale developments.

4.2 POST-CONSENT MONITORING

It is expected that the following technologies may be included in post-consent monitoring plans for single devices:

- Visual surveys of animal abundance,
- Passive acoustic monitoring,
- Active acoustic monitoring,
- Integrated monitoring platforms.

For small and large array developments, it is anticipated that additional technologies may be included in monitoring programmes such as telemetry, acoustic arrays and acoustic sensors or tags, ADCP measurements, eDNA, and seabed and benthic surveys. Monitoring non-conventional turbines such as tidal kites may be more challenging given their movement in the water column. The objectives and techniques for monitoring wave energy devices will be different than for tidal stream energy devices because their associated impact pathways will differ.

Industry members consider there is adequate evidence to support the use of these technologies at MRE development sites, but each monitoring methodology will have strengths and weaknesses (many of which are highlighted in Clarke et al. 2021a). Monitoring programmes for MRE developments should be sense checked by specialists and expert consultees, in order to ensure that they are

practicable and proportionate, and that they will produce data to address priority monitoring objectives.

Industry also recognises there are challenges for monitoring systems associated with the extreme, highly energetic environments at MRE sites. Any new monitoring systems may need to undergo short-term trials at project development sites or in more accessible locations such as the Marine Energy Test Area (META) to verify the equipment's performance and survivability, reducing risk at full-scale deployments.

4.3 STRATEGIC MONITORING NEEDS

The Welsh Government's Sector Locational Guidance[20] has identified sites that offer good wave and tidal stream resource, while also having the least constraints for development. It is suggested that for these sites, strategic baseline data collection on key receptors would help individual developers to make informed decisions on project design and monitoring requirements. Ultimately, the availability of strategic baseline data at sites identified for MRE development could reduce project and environmental risk and also facilitate consenting.

A common issue for industry is that data collected by individual developers for specific projects is not shared for the benefit of the wider industry. Where developments are in-part publicly funded through grants, it would be appropriate for results to be shared (providing that sensitive IP is not disclosed).

4.4 CHALLENGES FOR DEVELOPERS AND OPPORTUNITIES FOR INNOVATION

The cost associated with addressing environmental monitoring requirements can be prohibitively expensive as a result of the equipment needed to operate in a challenging marine environment, and the duration over which monitoring needs to occur. Industry members suggest that it would be helpful to understand the appropriate timelines for development of environmental monitoring plans for developments in Wales, for example whether developers should engage with regulators on environmental monitoring at an early stage, or later, when EIAs are nearly complete. It is important that the sector collectively consider solutions to share the risks and benefits of environmental monitoring across stakeholders. Ultimately, this should help to streamline the consenting process and enable deployments of devices around which monitoring can occur.

There are opportunities for the MRE sector to adapt monitoring approaches and technologies from other sectors. Industry members identify monitoring electromagnetic field emissions as a key example, where substantial effort has

[20] https://gov.wales/sector-locational-guidance-project

been invested to understand this effect in the offshore wind energy sector and both similar monitoring approaches and outcomes could be applied to MRE. There may also be an opportunity to take a similar approach to the marine aggregates industry, where developers collectively contribute to a fund that is used to address strategic data gaps. Industry members suggest that greater recognition of the value of marine environmental datasets and data products across the maritime sector could provide a further incentive for advancement of technologies for gathering data at MRE developments.

The development of widely available and standardised monitoring technologies and techniques at a sectoral level is preferred to the development of customised approaches for individual projects. Industry perceives that there is not always sufficient resource (financial, time, or knowledge) available to developers or their partners to develop bespoke MRE monitoring technologies, and environmental monitoring is often not considered to be a key deliverable for projects. The requirement to develop, test, and implement monitoring technologies would fall disproportionately on first-mover developers, with substantial financial and time implications. Instead, industry members suggest that strategic, collaborative efforts and focused financial input from stakeholders (industry, researchers, regulators) across the wider marine sector could accelerate monitoring technology development and provide opportunities for the MRE sector and for marine engineering as a whole.

5 SUMMARY AND RECOMMENDATIONS

The design of robust and effective environmental monitoring technologies for MRE developments remains a considerable challenge. Monitoring strategies must be targeted in order to gather data that address the required monitoring objectives of each development and consent requirements, although there is also an expectation that such data contributes to filling broader evidence gaps and improving our overall understanding of the environmental effects of MRE developments to feedback into the consenting process. Developing and implementing environmental monitoring technologies and techniques is also resource intensive, given the specific challenges associated with deploying equipment in high-energy wave or tidal energy environments.

Uncertainty about the effectiveness of monitoring technologies when deployed at full-scale MRE sites is currently a source of risk for both NRW and industry. NRW wish to see evidence to support the use of particular technologies and approaches to monitoring, while industry requires investments in monitoring technologies to be proportionate and well justified.

Researchers continue to develop a number of new monitoring technologies, such as the application of eDNA analysis for benthic species surveys and sensors to detect collisions between animals and devices. Monitoring approaches could also be adapted from other sectors. However, very little technology is available 'off the shelf', and stakeholders agree that concerted

collaborative efforts to develop and test novel technologies that can be applied across the sector should be supported by adequate funding.

5.1 RECOMMENDATIONS

- Developers are encouraged to engage as early as possible with NRW (regulatory and advisors) and environmental organisations to establish what environmental monitoring may be required at a proposed development site. In doing so, it will be important to clearly distinguish the requirement for pre-application surveys from post-consent monitoring requirements and to define how each will contribute to any adaptive management approaches.
- While monitoring strategies will generally be tailored to each development site, there is guidance that can provide developers with information about what monitoring approaches could be expected. Combined with early conversations with NRW at the pre-application stage, this could help to alleviate some project risk.
- New technologies or monitoring approaches should undergo trials before being applied to larger scale projects to demonstrate survivability and validate data collection, transfer, storage, and analysis processes. In this way, adaptive management approaches could also be applied to establishing best practice approaches for monitoring.
- Financial investment in collaborative efforts to develop monitoring technologies that benefit the sector is needed. This may be done strategically at government level or could be incorporated into a research programme where funding is made available to partnerships of industry and academic organisations.

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APPENDIX A MONITORING TECHNIQUES AND TECHNOLOGIES IN PREVIOUS MARINE ENERGY PROJECTS: LICENSING DOCUMENTS AND CONSENT CONDITIONS

Project Name	Location	Technology	Consenting Status	How collision risk is addressed	EIA/ HRA/ Other	Consent conditions
MeyGen	Scotland	Tidal Stream Array	Constructed	Active Acoustic Monitoring (AAM) - Active acoustics (sonar) to track marine mammals using 2 x Tritech Gemini multi-beam sonars (720 kHz) fixed on a High Current Underwater Platform (HiCUP).	PEMP	
MeyGen	Scotland	Tidal Stream Array	Constructed	Passive Acoustic Monitoring - 3 tetrahedral hydrophone clusters, positioned on the legs of the Turbine Support Structures (TSS). In combination the 3 clusters enable detection, identification of species and 3D tracking around rotor swept area and out to several tens of metres of echo locating cetaceans (e.g. harbour porpoise and dolphins).	PEMP	
MeyGen	Scotland	Tidal Stream Array	Constructed	Harbour Seal Telemetry - Deployment of UHF/GPS tags, that relay locations in real time to shore stations, and UHF / TDR tags, that relay depth data in real time to shore stations.	PEMP	

Project Name	Location	Technology	Consenting Status	How collision risk is addressed	EIA/ HRA/ Other	Consent conditions
MeyGen	Scotland	Tidal Stream Array	Constructed	FLOWBEC Platform	PEMP	
MeyGen	Scotland	Tidal Stream Array	Constructed	The MeyGen Advisory Group has been set up to ensure that appropriate and effective monitoring of the impacts of the MeyGen Tidal Energy Project Phase 1 are undertaken.	s.36 consent and marine licence conditions	To satisfy the requirements of the related section 36 ("s.36") consent and marine licence conditions.
Morlais	Wales	Tidal Stream Demo Zone	Consented	Construction and post-construction monitoring surveys covering marine mammal monitoring; scour monitoring; cable burial risk assessment; bathymetric surveys and Acoustic Doppler Current Profiler (ADCP) surveys.	Marine Licence Decision	Licence conditions will be required to ensure that construction and post-construction monitoring surveys cover marine mammal monitoring; scour monitoring; cable burial risk assessment; bathymetric surveys and Acoustic Doppler Current Profiler (ADCP) surveys.

Project Name	Location	Technology	Consenting Status	How collision risk is addressed	EIA/ HRA/ Other	Consent conditions
Morlais	Wales	Tidal Stream Demo Zone	Consented	Monitoring scheme to assess navigational safety.	Marine Licence Decision	To ensure navigational safety, licence conditions will require an Aids to Navigation Plan (AtNP) to be developed, submitted to and approved by NRW PS prior to commencement of licensed activities.
Morlais	Wales	Tidal Stream Demo Zone	Consented	Requirements for Advisory Groups for Morlais to inform approach to monitoring and review of monitoring data.	Demonstration Zone Order	To satisfy the requirements of the related section 36 ("s.36") consent and marine licence conditions.
Hywind Scotland	Scotland	Floating Offshore Wind	Consented	Vessel traffic will be monitored on Automatic Identification System (AIS) during construction and operation of the Wind Turbine Generator (WTG) Units to assess the effect the Project has on passing traffic.	EIA	

Project Name	Location	Technology	Consenting Status	How collision risk is addressed	EIA/ HRA/ Other	Consent conditions
Hywind Scotland	Scotland	Floating Offshore Wind	Consented	GLS Logging for the ability to quantify variation in diver wintering distribution and activity among seabird colonies.	PEMP	
Hywind Scotland	Scotland	Floating Offshore Wind	Consented	Seabed monitoring during O&M using ROV's and video recording was planned to monitor potential scouring	PEMP	
Kincardine	Scotland	Floating Offshore Wind	Consented	Collison sensors in WTG blades to monitor collision risk (acoustic sensors installed inside the WTG blades), cameras/radar (eight HD cameras installed on the 2 MW turbine using the DTBird system) for detecting collisions and species identification.	PEMP	Section 36 Condition 22
Kincardine	Scotland	Floating Offshore Wind	Consented	Noise monitoring was undertaken using the Scottish Association for Marine Science (SAMS) own designed Drifting Ear. Load cells and periodic maintenance ROV surveys primarily used for monitoring the integrity of the inter-array cables, mooring lines and anchors. ROV surveys also offered the opportunity to monitor the presence of ghost fishing nets lodged on the mooring system.	PEMP	Section 36 Condition 23

Project Name	Location	Technology	Consenting Status	How collision risk is addressed	EIA/ HRA/ Other	Consent conditions
DeltaStream	Wales	Tidal Stream Energy Demonstration Array	Consented	The deployment of temporary moorings for flow monitoring devices to enable accurate flow measurement during design work, installation and planning of marine operations. Taken place for short durations, at various times over the project development stage leading up to deployment and operation.	Environmental Scoping Report	
DeltaStream	Wales	Tidal Stream Energy Demonstration Array	Consented	Baseline data collection using fixed point surveys and opportunistic transect surveys will be used to obtain site specific data on species presence, abundance and habitat use. This will be achieved through vantage point surveys as the predominant survey methodology with acoustic (such as CPOD or similar) and/or vessel transect surveys providing supplementary data.	Environmental Scoping Report	

Project Name	Location	Technology	Consenting Status	How collision risk is addressed	EIA/ HRA/ Other	Consent conditions
META	Wales	Wave and Tidal Demo Zone	Consented	A primary monitoring tool available to Marine Energy Wales (MEW) Operational Manager was the META Consents Register that was prepared post-consent and provided a log of all consents and associated conditions to be adhered to during installation, operation and maintenance, and decommissioning activities.	EMP	
Nova Innovation Blue Mull Sound	Scotland	Tidal Stream Array	Consented	Manual monitoring of seabirds consisting of a Nova Innovation member of staff directly overseeing the operation of the turbine and environmental monitoring. Automated environmental monitoring will comprise impact sensors and motion-triggered video capture to detect and review any collisions.	EMMP	
Nova Innovation Blue Mull Sound	Scotland	Tidal Stream Array	Consented	Video monitoring to observe interactions of the turbine with wildlife; to identify interaction between wildlife and the rotor; to understand the nature of the interaction, and identify whether an animal has been harmed.	EMMP	

Project Name	Location	Technology	Consenting Status	How collision risk is addressed	EIA/ HRA/ Other	Consent conditions
Beatrice	Scotland	Offshore Wind	Consented	Digital aerial surveys of the offshore wind farm and the waters extending to the Caithness Coast during the core seabird breeding season months. Deployment of GPS Tags of adult great black-backed gulls and herring gulls breading in the ECC SPA.	PEMP	Section 36 Condition 27 & 28
Beatrice	Scotland	Offshore Wind	Consented	Drop Down Video (underwater camera) photography to assess the location and extent of potential Annex 1 habitats.	PEMP	Section 36 Condition 19 (PEMP), 27 (CaP)
Beatrice	Scotland	Offshore Wind	Consented	The primary method for monitoring scour and local sediment deposition was through visual inspections using Remotely Operated Vehicles (ROV). Geophysical surveys included use of multi-beam echo sounder and side scan sonar equipment to provide high resolution bathymetry and data on seabed features.	PEMP	Section 36 Condition 19 (PEMP)
Moray Offshore Renewables (Moray East)	Scotland	Offshore Wind	Consented	Geophysical survey - Multi-beam Echo Sounder, Side Scan Sonar, Sub-Bottom Profilers and Magnetometers/Gradiometer.	PEMP	

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