MARINET

Marine Renewables Infrastructure Network

Work Package 4: Research to innovate and improve infrastructures, technologies and techniques

D4.7 Best practice report on environmental monitoring and new study techniques

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About MARINET

MARINET (Marine Renewables Infrastructure Network for Emerging Energy Technologies) is an EC-funded consortium of 29 partners bringing together a network of 42 specialist marine renewable energy testing facilities. MARINET offers periods of free access to these facilities at no cost to research groups and companies. The network also conducts coordinated research to improve testing capabilities, implements common testing standards and provides training and networking opportunities in order to enhance expertise in the industry. The aim of the MARINET initiative is to accelerate the development of marine renewable energy technologies.

Companies and research groups who are interested in gaining access to test facilities free of charge can avail themselves of a range of infrastructures to test devices at any scale in areas such as wave energy, tidal energy and offshore-wind energy or to conduct specific tests on cross-cutting areas such as power take-off systems, grid integration, moorings and environmental issues. In total, over 700 weeks of access is available to an estimated 300 projects and 800 external users.

MARINET consists of five main areas of focus or 'Work Packages': Management & Administration; Standardisation & Best Practice; Transnational Access & Networking; Research; and Training & Dissemination. The initiative runs for four years until 2015.

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Legal Disclaimer

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Executive Summary

The need for environmental monitoring at marine renewable energy test centres is driven by legislative and research requirements related to environmental uncertainty surrounding offshore renewable energy developments. Uncertainty over the risks to marine wildlife posed by potential negative effects or impacts of marine renewable energy installations is a key factor which has the potential to limit the development of the marine renewable energy industry. A major problem with addressing this uncertainty is that there is as yet (at the time of writing) no available evidence base from which to estimate the risk of a marine renewable energy converter device having any adverse effects on the environment. A common regulatory approach therefore is to require project developers to develop a comprehensive monitoring plan or strategy which contributes to the evidence base and allows the risks to be better understood.

Work to date has identified priority areas in which further investigation is required in order to improve understanding of how marine renewable energy developments interact with the receiving environment. These priority areas are:

- Collision risk
- Barriers to movement displacement and/or habitat exclusion
- Noise (acoustic impacts on sensitive species)
- Effect of energy extraction on benthic and intertidal ecology
- Effect of electro-magnetic fields on sensitive species

Site selection for marine renewable energy test centres being designed for multiple use will identify the range of sensitivities at the site. The requirement and scope for any routine environmental monitoring, as envisaged for the testing of a range of types of devices, can then be established. Early initiation of this monitoring not only provides essential baseline data for the subject of the monitoring, but also establishes datasets that can be used periodically for site-wide analysis for potential impacts. This approach sees early agreement on the site-specific environmental uncertainties, which in turn forms the basis on which individual developers will be required to concentrate their environmental monitoring efforts.

Key to the success of undertaking such monitoring to support a greater understanding of the uncertainties is the ability to gather the required data in a robust manner, to the quality required in order to address the questions being posed. Gathering data to address the environmental uncertainties that apply to the marine energy sector has been hindered by the absence of appropriate technology for use in high energy marine environments. The absence of 'best practice' methods for gathering the necessary data can also lead to inconsistent approaches being used which, whilst facilitating innovation, can tend to limit the usefulness of these early-stage investigations aimed at informing on the knowledge gaps.

Specific tools and techniques, prioritised to address the main areas of concern, need to be developed for the environmental monitoring of marine energy converter devices. This report looks at the need for environmental monitoring at marine renewable energy test centres, describing the key environmental uncertainties surrounding offshore renewable energy developments, and strategies developed to address them. The report also discusses the equipment, protocols, and techniques being developed to facilitate environmental monitoring and being applied at marine renewable energy test centres to help address the environmental uncertainties.

European test centres should adopt a coordinated approach towards environmental monitoring of marine energy converter devices, and work towards development of a platform for sharing knowledge and undertaking collaborative projects. The findings from environmental monitoring at the European test centres should be connected and the pertinent findings summarised in a common location for existing and emerging test centres to utilise. Finally, in order to make the licensing process as streamlined as possible, the appetite amongst national regulators to develop a common approach to the licensing of prototype marine energy converter devices within Europe requires further investigation.

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1 INTRODUCTION

Marine renewable energy is an emerging sector with the first commercial scale devices currently under test at a few high-energy sites across Europe. At this early stage of the industry the extent to which these technologies interact with the surrounding environment is largely unknown. However, understanding these interactions will be essential to the acceptance and commercial development of these technologies.

In order to grant consent for an offshore renewable energy development (ORED), regulators have to be confident that projects will not have a significant adverse environmental impact. This requires a detailed understanding of the energy conversion device(s) and their potential for interaction with the receiving environment. The consenting process applied across Europe therefore requires developers to consider and document, prior to deployment, the risk of any potential effect or impact that a device might have on the environment, and to introduce appropriate mitigation measures that are aimed at minimising any potentially negative effects. For the wave and tidal[1] energy industries the lack of knowledge about the likelihood or extent of any potential effects clearly hinders robust risk assessment and mitigation. With 'survey, deploy and monitor' approaches being used in licensing the early deployments, the existence of truly representative baseline data and the availability of appropriate methodologies for observing and/or measuring potential effects or impacts are essential. Limitations in each of these areas introduce some significant challenges to gathering the knowledge required to progress to commercial deployments.

A significant proportion of wave and tidal developers are using the MARINET test sites (primarily the European Marine Energy Centre (EMEC), situated in the Orkney Islands, Scotland) to test and develop their pre-commercial devices. This creates a key role for test sites to encourage robust monitoring to be put in place, with the findings fed back into the different national regulatory processes. The independent nature of test centres allows them to be closely involved in discussions with regulators, industry, and academia in order to ensure that monitoring at the sites is used to best effect within the pertinent regulatory framework. This includes activities such as collective reviewing of the monitoring outputs by regulators and their relevant expert consultees, as increasing environmental information is gathered and reported. This ensures that the findings from the early-stage monitoring are fed back into the regulatory process as appropriate, leading to review of conditions placed by regulators on licences and, where appropriate, refinement of these conditions.

Marine renewable energy project developers must take environmental issues into consideration early in the design process, with the entire project lifecycle in mind (i.e. design, installation, operation, maintenance and decommissioning). By ensuring that monitoring is robust and of high quality, and is managed adaptively with regulatory input, the learning from these early-stage deployments could lead to better-informed risk assessments at the commercial licensing stage, and consequently to better informed, targeted and refined monitoring requirements for commercial deployments. This type of refinement would consequently introduce associated efficiencies, time saving for regulators, and cost reductions for all).

This document looks at the need for environmental monitoring, identifying the key environmental uncertainties surrounding OREDs, and explores the legislative and research drivers for monitoring to address these unknowns. It also considers the techniques and protocols which have been developed for environmental monitoring to date, and summarises monitoring activities being undertaken at marine renewable energy test sites across Europe. Section 4 describes new monitoring techniques being trialled at some of the MARINET facilities, and Section 5 provides recommendations for developing a coordinated approach to environmental monitoring across Europe.

Whilst the coverage of this document is European, other relevant research and monitoring initiatives are noted in Section 2.2.2).

The focus throughout is on wave and tidal stream energy developments and, while there is much that can be learned from experiences of offshore wind energy development, this area is largely outside the scope of this document. The

[1] Note that throughout this document use of the word 'tidal' refers to tidal stream, unless otherwise stated.

Appendices to this report provide specific environmental monitoring case studies – one for each of tidal, wave and offshore wind test sites.

The MARINET project includes the following real-sea test facilities for marine renewable energy:

- European Marine Energy Centre Ltd. - wave & tidal stream (Orkney)
- Belmullet Wave Energy Test Site (Ireland)
- Portaferry Tidal Test Centre (Northern Ireland)
- Nissum Bredning Wave Test Site - wave (Denmark)
- Galway Bay Wave Test Site - wave (Ireland)
- Tidal Testing Centre, Den Oever (Netherlands)
- Biscay Marine Energy Platform (BiMEP) - wave (Spain)

EMEC is (at the time of writing) the only grid-connected test centre for both wave and tidal energy converters. The majority of environmental monitoring associated with marine renewable energy developments has been focused around projects underway at EMEC, and therefore activities at EMEC are frequently cited as examples in this document. This is not intended to imply that these techniques or projects are any more valid or appropriate than those employed at other sites.

2 BACKGROUND TO ENVIRONMENTAL MONITORING

This section looks at the need for environmental monitoring at marine renewable energy test centres, describing the key environmental uncertainties surrounding OREDs and strategies developed to address them. This need is driven by the legislative and research drivers for environmental monitoring, which will also be discussed in this section.

2.1 ENVIRONMENTAL UNCERTAINTIES FOR WAVE AND TIDAL DEVICES

Uncertainty over the risk to marine wildlife posed by potential negative effects or impacts of marine renewable energy installations is a key factor which has the potential to limit the development of the industry. In order to address this uncertainty, developers are required to demonstrate that marine wildlife will not be adversely affected by installation activities and operational devices. Adequate mitigation solutions must be developed and put in place. For the first-stage device deployments, there is clearly no available evidence base from which to deduce 'no adverse effect', so a common regulatory approach is to require developers to develop a comprehensive monitoring plan or strategy which contributes to the evidence base and allows the risks to be better understood.

In Scotland, in order to assist the Regulator and developers in identifying the likely impacts of a development, the Scottish Government commissioned a project in March 2009 to evaluate the potential impacts of wave and tidal renewable energy devices on marine and coastal wildlife and habitats. The main output of this project was an Impact Assessment Tool (IAT) which can be used to interpret ecological data and information in order to address the potential vulnerability of species and habitats, and absorb technical information to identify stresses placed on the environment by any element of a development [1].

2.1.1 Key Uncertainties

The EU-funded Equitable Testing and Evaluation of Marine Energy Extraction Devices (EQUIMAR) project highlighted the main uncertainties regarding the potential effects of marine renewable energy developments [2] and proposed a route map to address these uncertainties [3]. The key environmental uncertainties identified were:

- Alteration in water circulation patterns
- Interference with benthic habitats
- Artificial reef effects
- Effects on water quality
- Noise disturbance
- Effects due to electro-magnetic fields
- Interference with marine animal movements
- Collision risk
- Socio-economic issues

Prior to this, the Scottish Government's Strategic Environmental Assessment (SEA) for Wave and Tide (Section E) [4] identified and grouped these uncertainties into the following three key priority areas for improving understanding of how marine developments interact with the environment:

- Collision risk, barriers to movement, and habitat exclusion
- Noise (acoustic impacts on sensitive species)
- Effect of energy extraction on benthic and intertidal ecology

In addition to the above three key areas of uncertainty, the potential effect of electro-magnetic fields (EMF) on marine wildlife caused by subsea electricity cables was also highlighted in the SEA.

These key uncertainties (collision risk, barriers to movement, and habitat exclusion; noise; effect of energy extraction; and effect of EMF) together with strategies for addressing them are discussed in more detail below.

Collision risk, barriers to movement, and habitat exclusion

Although wave and tidal energy, and offshore wind energy extraction industries are often referred to collectively (e.g. 'Marine Energy', 'OREDs', much of the similarity lies in the marine environment itself, rather than in the particular stressor elements of individual devices. This means that the environmental and other risks and uncertainties that need to be addressed tend to be different when looking at detailed device-specific impacts across the different sectors. However, there are some issues of concern that are common across the sectors and it can be helpful to view those issues collectively.

On this 'collective' basis, we can say that the potential for underwater interactions between sensitive marine wildlife species (i.e. marine mammals, fish, and diving birds) and operational devices may be summarised as:

- Collision risk (physical damage/death)
- Barriers to movement (disruption to migration routes and other transit pathways)
- Habitat exclusion and species displacement (displacement/exclusion of species from feeding and breeding grounds due to presence of device/noise).

These issues are generic areas of key concern for regulators and their advisors, although the extent to which they are related to the different industry sectors varies. For example, 'collision risk' is generally perceived to be more of a risk from tidal energy generation devices than wave devices, and this is largely due to the type of fauna present at typical deployment sites and the nature of the moving parts (exposed blades) associated with these devices. The characteristics of specific deployment sites will also have an effect of the extent to which any of these issues is likely to have an effect on marine wildlife. For example, avoidance reactions to underwater noise at relatively low levels may be more acute for species travelling regularly through narrow tidal channels due to the physical conditions of such sites. Whilst an issue (such as collision risk) may be considered more of a potential risk for a particular sector (tidal energy developments), it is important to remember that these are also potential issues for other sectors (wave energy developments) in particularly sensitive areas.

Whilst the bulk of this report considers the potential risks that may be due to the devices themselves, it is also important to remember throughout project planning that all activities associated with a particular project may also pose a threat to sensitive species by potentially presenting barriers to movement and exclusion from habitat (e.g. due to physical presence of support vessels and noise from installation, maintenance or decommissioning processes). Whilst such effects would be most likely to be transient and therefore temporary, they should nevertheless be considered in a project-wide assessment of risks.

Acoustic impacts on sensitive species

The potential for wave or tidal energy conversion devices to generate acoustic output during operation, and any noise produced as a result of associated marine activities, might potentially lead to displacement (see above) or physical damage to organs of sensitive marine wildlife species. There is also the potential for such output to cause disturbance to behaviour: for example, cetaceans use sound for navigation, prey detection and communication – all of which may also be affected by noise from marine renewable energy developments. Figure 1 below shows the frequency overlap for the hearing range of marine species and known anthropogenic noise (adapted from [5]).

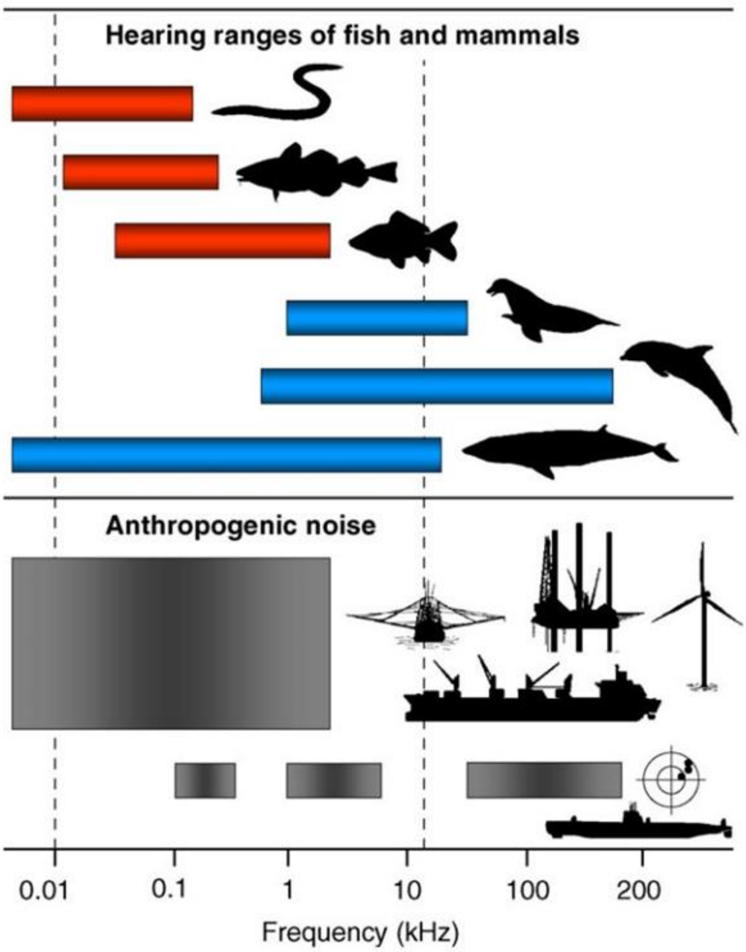

Figure 1: Schematic showing hearing range of fish and marine mammals relative to known frequencies of anthropogenic noise

Effect of energy extraction on benthic and intertidal ecology

The potential effects of OREDs on benthos due to installation activities and removal of energy are varied and to a large extent remain unknown. Structural installation and shifting of sediments may cause alterations and changes to benthic communities or to individual species, with non-mobile and suspension-feeding species being particularly susceptible. Furthermore, the construction of foundations and installation of mooring lines associated with marine renewable devices effectively introduces hard substrata on the ocean floor, attracting specific benthic species and causing changes in the habitat. Given the importance of the benthos on the marine ecosystem, the following correlations should be taken into consideration when attempting to understand consequences on benthic communities [6]:

- Spatial demands by sediment shifts → reduction of benthic association or of single species
- Introduction of hard-substrata, different hydrodynamic conditions → changes in composition of species
- Presence of electrical cables → rise in temperature and abundance of benthic communities.

In general most of the potential impacts associated with OREDs are likely to be similar to those associated with more mature industries (such as oil and gas) however some impacts will be specific to marine renewable devices. The potential impacts that OREDs may have on benthos and benthic habitats are summarised in Table 1 below [7][8].

Impact	Source	Phase			Device type				
		Construction	Operation	Decommissioning	Floating WEC	Sea based WEC	Tidal Turbine	Fixed Wind	Floating Wind
Direct loss of seabed area	Device footprint	✓	✓		✓	✓	✓	✓	✓
Contamination	Accidental spillage		✓	✓	✓	✓	✓	✓	✓
Smothering effects	Excavation, piling, dredging	✓	✓	✓		✓	✓	✓	✓
Scour/loss of substrate	Device structure	✓	✓	✓	✓	✓	✓	✓	✓
Introduction of non-native/ invasive species	Device transport and vessels from other areas	✓	✓	✓	✓	✓	✓	✓	✓
Vibration/noise	Piling, drilling, acoustic surveys	✓	✓	✓	✓	✓	✓	✓	✓
Impedance of current flow	Tidal turbine presence		✓				✓	✓	
Change in current regime	Tidal turbine presence		✓				✓		
Change in wave regimes	WEC wave shadowing		✓			✓			
Physical disturbance	Moorings, anchor lines, chains and construction debris	✓	✓	✓	✓	✓	✓	✓	✓

Table 1: Predicted impacts for benthic communties due to construction and operation of OREDs [7][8]

Electro-magnetic field effects

Little is known about how the EMF from subsea electricity cables or active devices might potentially impact marine wildlife, but a concern is that it could cause displacement, reduction of reproductive abilities and/or interruption of migratory routes for fish and shellfish species. The Scottish Government's SEA for Wave and Tide (Section C) [9] concludes that although detectable by electro/magneto-sensitive species, electric and magnetic fields generated by the operation of wave and tidal energy converter devices are likely to be small and within the variation range of naturally occurring fields. Marine flora and macro-invertebrates are not sensitive to electric or magnetic fields and therefore no impacts from the installation or operation of tidal and wave energy converter devices are expected.

The significance of potential effects cannot be quantified on the basis of current information. Many species known to be electro- and/or magneto-receptive are of conservation concern or are vulnerable to the effects of human activity, and developers are required to assess the potential impacts of their proposals on these species [10]. The significant increase in OREDs within specific coastal areas is of concern if these species are affected. The Collaborative Offshore Wind Research into the Environment (COWRIE) initiative suggests two approaches to further understand the effects of EMF from sub-sea electricity cables [11]. The first is to build on the EMF sensor technology that has been developed through COWRIE projects to provide suitable equipment and protocols for determining the EMF emitted and its variability in relation to power production, and the second is to undertake controlled studies of different cable configurations and specifications to more fully understand the characteristics and extent of the electromagnetic environment associated with offshore wind farm sub-sea cables both individually and in multiple arrays. The US-DOE and Marine Scotland Science are undertaking a variety of laboratory studies to further understand how marine species are affected by EMF.

Offshore wind installations typically involve burying the subsea electricity cables at a depth of around 1 metre, which should reduce or eliminate the effect of EMF. It should also be noted that some near-shore wave energy converter (WEC) technologies utilise high pressure pipelines to pump pressurised water ashore, with actual electricity generation occurring on the land. In such developments there would be no EMF effect on marine species.

2.1.2 Approach to Addressing these Uncertainties

The approach taken to address these environmental uncertainties at test sites will differ from those designed for use at 'virgin' commercial sites in that some of the monitoring required will be carried out only once at the outset of establishing the test site. For example, site selection for multi-use test sites should identify the range of sensitivities at the site. An initial assessment will then inform on whether routine monitoring is required, or whether it can be ruled out in future for a particular issue, at that particular site. This approach to environmental monitoring is a major attraction of using test sites – i.e. sensitivities will have been addressed at the outset, even though they will require periodic reassessment. This in effect results in a subset of environmental uncertainties (the site-specific sensitivities) on which individual developers will be required to concentrate their monitoring efforts.

Addressing these environmental uncertainties by gathering data from the initial deployments has been hindered in part by the absence of appropriate technology for use in the high energy marine environments and the fact that there is not always agreement on, nor comparative testing of, the best approaches to gathering the data required to inform on the knowledge gaps. This has led to a number of approaches being used to collect data to inform the adaptive environmental management processes. Section 3.2 of this report describes protocols available at the time of writing for monitoring marine wildlife, while some common approaches to addressing environmental uncertainties highlighted in the previous section are described below.

Collision risk, barriers to movement, and habitat exclusion

On-going monitoring of how fish, marine birds and marine mammals interact with operational devices in terms of collision risk, barriers to movement, and habitat exclusion/species displacement is normally required by regulatory authorities when ORED proposals include the potential for such effects. Undertaking project-specific monitoring, particularly for the early stage device deployments, provides much-needed data which will help to assess the extent of any actual effect or impact. Such data from early-stage projects is essential in helping to determine vulnerability of the different potentially sensitive species to the potentially harmful effects. Gathering monitoring data from these deployments also facilitates the assessment of the effectiveness of other mitigation measures used to reduce potential effects. Examples of such mitigation measures might include choice of installation period (i.e. avoiding sensitive times), device design, varying turbine spacing, and increasing the visibility of devices.

Typical approaches to monitoring for collision between marine wildlife and marine renewable energy devices include use of underwater video cameras, strain gauges, acoustic detection of impact events, blade examination, and active sonar. Studies carried out at EMEC using these approaches have met with mixed success, and further work is required to refine and develop these methods. The environmental monitoring work-stream of the ETI-funded Reliable Data Acquisition Platform for Tidal (ReDAPT) project [12] was set up to use a combination of these methods to monitor marine wildlife interactions with an operating tidal turbine installed at the EMEC tidal test site.

Acoustic effects on sensitive species

It is important that pre-installation assessment of ambient underwater noise is undertaken in order to produce information with which context can be given to any increase in noise levels due to marine renewable energy device installation and operation. Assessment/monitoring of noise from device operation should also be undertaken, as it should for device installation and decommissioning operations if they are considered to be noisy operations. Acoustic monitoring should take account of differing site conditions and bathymetry as well as device type and design, with a view to specifically including assessment of any components (e.g. chain mooring lines) that might be expected to be particularly noisy elements. Such assessments could be expected to inform any requirement for monitoring of noise effects on marine mammals, birds and fish, and help inform on-going monitoring and review of the effects of noise on these organisms.

There is a need for robust equipment and methods for gathering and analysing underwater acoustic data to be developed, and several approaches are being taken to achieve this (see section 4.3). EMEC has carried out acoustic baseline measurement studies at all of its test sites [13][14][15][16][17], and these data, methodologies and equipment are available to developers for use in their own device-specific studies.

Effect of energy extraction on benthic and intertidal ecology
In order to properly assess the effect of OREDs on the benthic environment, it is essential that a broad-scale baseline characterisation of the seabed environment of any proposed development footprint is undertaken prior to any work commencing. This initial site characterisation will inform the regulatory view on how sensitive the area is, and therefore on whether, and how much, future benthic monitoring should be undertaken.

Any monitoring plan that is developed should take into account any potential for spatial, temporal and seasonal variations. At this stage a single sampling station is likely to be sufficient since the main purpose is to define the benthic habitats and their spatial extent (using a suitable spatial frequency). It is important to identify any correlation between stressor elements of a project proposal and possible impacts, since different elements will potentially put different environmental pressure on the benthic communities. Project variables will be largely around the type of marine renewable energy device(s) being installed so that, for example, monopiles for wind and tidal energy turbines may have a different effect on a benthic ecosystem compared to moored wave energy converters, due to the introduction of hard substrate in the environment.

General methods for monitoring include acoustic surveys (aimed at identifying presence and strata of benthic communities), grab and trawl methods (designed to adequately sample the benthos near the development and analyse its composition and spatial dispersion), and remote visual observation (use of a Remote Operated Vehicle (ROV) for species identification). Targeted surveys, aimed at identifying single benthic communities to understand the specific role of a given species within the habitat, can also be useful. Cumulative and combination of impacts should be considered for EIA and Special Areas of Conservation (SAC) assessment.

2.1.3 Receptor-specific Monitoring Methods

Methods for monitoring marine mammals
Monitoring methodologies designed to gather information to aid understanding of the potential impact of OREDs on marine mammals are varied and serve different purposes according to the scope of the survey and the site characteristics. Monitoring methods include desk studies, visual observation, and acoustic surveys. Table 2 below presents an overview of the methodologies developed for monitoring marine mammals at the impact assessment stage.

Monitoring Objective	Monitoring Method							
	Vantage point	Video range	Boat based Line Transectº	Aerial line transect	Autonomous Acoustic Monitoring	Photo ID	Telemetryº	Stranding schemes
Species present	✓◆		✓◆	✓◆	✓	✓	◆	◆
Density/abundance	✓◆		✓◆	✓◆	✓	✓◆	✓	
Productivity	◆			◆				
Distribution	✓◆	✓	✓◆	✓◆	✓		✓◆	
Behaviour	◆	✓	◆				◆	
Injury/mortality		✓					◆	✓◆
Communication/ masking					✓			
Barrier effects	✓							
SAC connectivity						✓◆	✓◆	

Table 2: Monitoring methods for impact assessment of marine mammals close to OREDs. º Applicable to monitoring basking sharks. ✓ Indicates methodologies for cetaceans and ◆ methods for seals [18][19]

Methods for monitoring marine birds

Various monitoring methodologies can be applied to the monitoring of avian species, including desk studies, aerial and boat surveys. Entities such as the Joint Nature Conservation Committee (JNCC) in the UK provide training on monitoring of seabirds. Generally baseline monitoring of avian fauna is undertaken for a minimum of two years. Initial assessments of bird populations will need to guide any detailed monitoring plan, and approaches will vary depending on the sensitivity of species and any protected status. Boat surveys, if required, should generally be carried out at least once a month to provide spatial, temporal and seasonal variation of the species; whilst at least eight campaigns per year are required for aerial surveys as outlined in Table 3 below [20].

Year Period	Description	Approximate dates
1	Mid-winter	January and February
2	Late winter	February and march
3	Early Breeding season	April - mid May
4	Mid breeding season	Mid May - mid June
5	Late breeding season	Mid June - end July
6	Post breeding//moult	August to mid September
7	Autumn	Mid September - October
8	Winter	November and December

Table 3: Periods of the year for aerial marine bird survey [20]

Three general survey methods can be used for baseline characterization of birds at site: land based survey from a vantage point, boat-based transect and aerial-transect surveys. The choice of method employed often depends on the size of the development, as well as their distance from shore, and the frequency and range of surveys will be influenced by the overall strategy and adequacy of any single method. Non-generic surveys have been developed in order to assess the behavioural response of particular species and to evaluate interconnectivity with breeding areas. Generic and non-generic methods developed for the baseline characterisation of birds colonies at a given site are presented in Table 4 below [8][20].

Primary assessment type	Monitoring Objective	Monitoring methods					
		On land vantage	Boat Based Surveys	Aerial Surveys	Radar	Remote Tracking	Electronic tagging
EPS licence, appropriate assessment and EIA	Species present	<1.5 km	>1.5 km	>1.5 km			
	Density/abundance	<1.5 km	>1.5 km	>1.5 km			
	Habitat use	<1.5 km	>1.5 km	>1.5 km			
AA only	Connectivity				*	*	*

Table 4: Monitoring methods for characterisation of avian fauna close to OREDs [8][20]

In general the same methods employed for baseline assessment of birds population, distribution and abundance at a given site are also often employed for monitoring the impacts due to construction and operation of the development. This ensures that the data are directly comparable and maximises the likelihood of any direct cause-effect relationship that might exist between the renewable energy development and avian fauna being detected.

Methods for monitoring fish

Monitoring methodologies designed to understand the potential impact of OREDs on marine fishes are varied and different according to the aim of the survey and the site characteristics. Some monitoring methodologies which can be applied to fish monitoring are [21]:

- Desk study of all elements below (e.g. review/analysis of existing records/data)
- Underwater video and stills photography
- Grab sampling
- Acoustic Ground Definition System
- Sidescan sonar
- Fisheries Liaison; Landings data; Effort data
- Socio-economic evaluations

2.2 DRIVERS FOR ENVIRONMENTAL MONITORING AT TEST CENTRES

2.2.1 Regulatory

The marine renewable energy industry is relatively new compared to other established marine and energy industries, and has had to rely on existing legislation, drawn up with other marine and energy applications in mind. Regulators must, of course, ensure compliance with all applicable legislation, and take whatever measures are necessary to ensure compliance. In a new sector, where there is no available evidence-base, the method used by regulatory authorities to ensure compliance normally entails the placing on conditions (for monitoring) on project licences. Various countries are now developing legislation which can be applied to marine renewable projects, with offshore wind at a more mature stage of legislative development than wave and tidal.

While there is a lack of uniformity in interpretation for similar laws between the different European countries, all are derived from and must meet the requirements of the EU Directives which apply to offshore wind, wave and tidal energy. The aim of these Directives is to contribute towards ensuring bio-diversity through the conservation of natural habitats and of wild fauna and flora in the territory of the EU Member States. Measures taken pursuant to these Directives must be designed to maintain or restore, at favourable conservation status, natural habitats and species of wild fauna and flora of Community interest. The marine renewable energy industry is a new player in this field and must demonstrate what effect it will have on the environment.

Statutory drivers for undertaking environmental monitoring include national and international Environmental Impact Assessment (EIA) legislation, national and international conservation legislation and agreements, and environmental liability legislation. Such legislation affords protection to marine mammals, basking sharks and birds as well as benthic habitats and species.

Although there is a lack in legislation on EIA for marine renewable energy projects, it is reasonable to presume that related legal instruments will be updated as the wave and tidal energy industry develops. Therefore, regulation on EIA (see below) will become an essential element for allowing large-scale marine renewable energy schemes [22].

In countries where regulation on marine renewable energy schemes has already been implemented, and since it is generally assumed that marine renewable energy is a “clean energy”, the legal requirements for a complete EIA may be less demanding (e.g. Portugal), may not be required (e.g. Denmark) or may be required for some projects depending on its characteristics (e.g. UK – for commercial deployments and prototype deployments over 1MW; Spain, if the authorities deem it necessary; France for those projects exceeding a 2.5 MW production and having a subsea cable) [23].

Three principal factors illustrate how developed the regulatory/legislative frameworks are in each country:

- Is a Strategic Environmental Assessment (SEA) in place for wind, wave and tidal?
- Is a Marine Spatial Plan (MSP) in place?
- Does the country have a streamlined or ‘one stop shop’ system for marine consenting?

In its European offshore renewable energy roadmap published in 2011, the EU-funded Offshore Renewable Energy Conversion Platform Coordination Action (ORECCA) project identified that some countries (such as Scotland and Ireland) are more advanced in addressing these factors, while others (notably the UK, France, Norway, Portugal and Spain – which all have MARINET test facilities) needed to continue to progress in this regard in order to realise the large opportunities presented by the sector [24]. Some progress has been made, with the UK now having a 'one-stop-shop' system in place for marine licensing.

Brief summary of legislation

Regardless of size or whether or not an EIA is required, all marine renewable energy projects deployed in European Waters must give consideration to two principal pieces of EU environmental legislation aimed at protecting vulnerable sites, habitats and species, which form the cornerstone of Europe's nature conservation policy, and to national enactments of that legislation. These two EU legislative measures are EC Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Flora and Fauna (the 'Habitats Directive') [25] and EC Directive 79/409/EEC on the Conservation of Wild Birds (the 'Birds Directive') [26].

The Habitats Directive aims to protect some 220 habitats and approximately 1,000 species listed in the directive's Annexes. Annex I covers habitats, Annex II covers species requiring designation of Special Areas of Conservation, Annex IV covers species in need of strict protection, and Annex V covers species whose taking from the wild can be restricted by European law. These are species and habitats which are considered to be of European interest, following criteria given in the directive. The Birds Directive aims to protect all European wild birds and the habitats of listed species.

In addition to the above two Directives, the Marine Strategy Framework Directive (MSFD) [27] was formally adopted by the EU in July 2008. The MFSD is complementary to and provides an over-arching framework for the Habitats Directive and the Birds Directive. The MSFD outlines a transparent, legislative framework for an ecosystem-based approach to the management of human activities which supports the sustainable use of the marine environment. The overarching goal of the Directive is to achieve 'Good Environmental Status' (GES) across Europe's marine environment by 2020. The MSFD does not state a specific programme of measures that Member States should adopt to achieve GES, except for the establishment of Marine Protected Areas (MPAs).

Natura 2000 [28] is a European wide network of protected areas developed under the Habitats Directive and the Birds Directive. Natura 2000 is the centrepiece of EU nature & biodiversity policy and is an internationally important network of areas designated to conserve natural habitats that are in danger of disappearance in their natural range, have a small natural range, or present outstanding examples of typical characteristics of the biogeographic region and species that are rare, endangered, vulnerable or endemic within the European Community. The aim of the network is to assure the long-term survival of Europe's most valuable and threatened species and habitats.

Some OREDs are also subject to EC Directive 85/337/EEC (the 'EIA Directive') [29]. This Directive requires an EIA to be completed in support of an application for development of certain types of project, as listed under Annexes I and II of the Directive. Wave, tidal and offshore wind energy developments are listed under Annex II of this Directive as "Industrial installations for the production of electricity, steam and hot water". National authorities have the discretion to decide whether or not an EIA is required for projects listed under Annex II, and this is done by the "screening procedure", which determines the effects of projects on the basis of thresholds/criteria or by a case by case examination. The EIA Directive is likely to be applicable to the vast majority of offshore renewable energy developments and an EIA, written up in the form of an Environmental Statement (ES), will be required in support of most proposed developments.

The final report of WP2 of the Intelligent Energy Europe (IEE) funded Streamlining of Ocean Wave Farms Impact Assessment (SOWFIA) project [30] identified the EIA process as a potential barrier to the development of wave energy development. The report highlights criticisms of the process, with findings suggesting that there is widespread inconsistency in the manner in which the EIA Directive is applied to developments across different EU Member States in terms of information required and related monitoring requirements, and that the process was overly burdensome on small-scale developers who may be deploying only one or a limited number of device units.

The SOWFIA project also compiled information on the consenting of wave energy projects in selected countries of the EU [31].

The EU is in the process of proposing changes to the EIA Directive (in consultation – due 2015) which are intended to lighten unnecessary administrative burdens and make it easier to assess potential impacts, without weakening existing environmental safeguards. The EU-funded Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact (EQUIMAR) project recommends that the list of potential impacts/uncertainties should be continuously evaluated and updated in light of on-going research, and that legislation should allow for amendment of protocols as and when uncertainties are resolved [23]. This approach, known as Adaptive Management, should be incorporated in the legal framework of marine renewable energy schemes.

Consenting process at test centres

Whilst EU environmental legislation requirements for marine renewables and offshore wind is constant, each country has its own national legislation which informs national consenting regimes and there is no EU-wide consent for deployment of marine renewable energy devices at this time. Various countries are at different stages of developing their consenting processes, and test centres have been set up with different functions (e.g. to test offshore wind, wave, tidal; to test different scales of devices and/or associated infrastructure) and as such the focus and range of testing capabilities of test centres will differ.

Test centres enjoy a unique position in the marine renewable energy industry: they can act as impartial facilitators to catalyse solutions to industry-wide issues; they can channel central funds into addressing key uncertainties for the good of multiple developers and wider industry; and through maintaining close liaison with regulators, academia and other experts, issues of primary concern can be identified. Test centres can also help to shape the consenting regime and provide a valuable learning ground for developers going through the environmental appraisal process.

A key aim for test centres should be to have in place streamlined consenting requirements, making it simpler for developers to deploy devices/infrastructure/components than in the regular marine environment. This provides a time/cost advantage for developers at this important pre-commercial stage, but this must be balanced by the need to instil environmental awareness and learning in developers who at early stages of device development tend to be more focussed on technological aspects and a swift route to deployment. Such a simplified route to consent can only be achieved through inspiring regulator confidence in how the test centre manages operations at its sites, and the likely scale of device impacts on a well-characterised receiving environment. It is also important that potential impacts are considered for each monitoring phase of the project lifecycle (namely site characterisation; mitigation; adaptive management; and decommissioning) and appropriate environmental monitoring applied.

Although the consenting processes at test centres across Europe will vary, the information required to support application for consents is similar. In broad terms, the following stages will apply:

- Scoping/screening – initial information dissemination and consultation with key stakeholders.

- Recommendations for baseline monitoring – site-wide or project-specific
  (In addition, developer/test centre may wish to carry out local resource assessment monitoring).

- Feedback from scoping and data from baseline monitoring used to inform EIA/ES (and other supporting documentation which may be required for consent application).

- Consent application (will include mitigation/impact monitoring; on-going baseline monitoring).

The consenting process at EMEC is discussed in detail in Appendix 1 of this report, although at the time of writing it was undergoing further development to introduce additional efficiencies.

Overview of survey, deploy and monitor approach
Whilst environmental risk assessment addresses the *potential* for positive and negative impacts on elements of the receiving environment, it is widely recognised that there are still knowledge gaps that relate to how marine devices *actually* affect sensitive species (including, but not limited to, European Protected Species). In this context, in Scotland, Marine Scotland worked closely with its statutory environmental consultee Scottish Natural Heritage (SNH) in developing a pragmatic approach to licensing at test sites, which is commonly referred to as the 'Survey, Deploy and Monitor' approach [32]. This process acknowledges that developers will utilise the best available technology at their disposal to put in place a range of sensors or other data collection mechanisms that provide data, the interpretation of which is likely to inform on the extent of any interactions. Developers reflect these decisions in a Project Environmental Monitoring Plan (PEMP), which typically forms an annex to the supporting environmental documentation that accompanies licence applications. The PEMP reflects agreements that have been reached between the developer and the Regulator, regarding the mechanism for establishing on-going assessment and adaptive management of the monitoring (including scheduling) as the project proceeds. The EMP would typically state, for example, a maximum number of tidal cycles from deployment, after which analysis of the data collected would be discussed with the Regulator or its appointed advisors. Further action, including the on-going scheduling of future assessments, typically depends on the outcome of the initial analysis and develops in an adaptive manner.

The 'survey, deploy, and monitor' approach is a risk management process with the purpose of applying an appropriate and proportionate approach to licensing which depends upon the circumstances surrounding the proposed marine renewable energy development. The approach is based on three main factors:

1. Environmental Sensitivity (of the proposed development location)
2. Scale of Development
3. Device (or Technology) Classification

The focus of this approach is on the extent of site characterisation surveys and device testing that is appropriate to inform the consenting process, in relation to the perceived relative environmental risk posed by the development. Reduced data presentation or collection requirements, in relation to lower risk proposals, should facilitate earlier consenting decisions and more rapid build out of overall low risk projects. Impact monitoring, post-construction, of test devices or arrays is likely to be a condition on most consents granted, not least so as to provide the information necessary to support subsequent applications for further, perhaps medium or high risk, schemes.

Through this policy, the extent of site characterisation monitoring and the role of pre-deployment testing requirements will be identified, appropriate to the overall risk of the project inferred from its size, location, and technology. It is recognised, however, that there will be circumstances where these three parameters alone do not adequately define the risk posed to a particular receptor or receptors, and the licensing process(es) may require greater understanding of potential impacts than will be furnished through these provisions. A flexible approach to application of the policy will therefore almost certainly be needed, using the policy as a guide, rather than applying it rigidly in every situation, and thereby ensuring that statutory licensing requirements are still met.

2.2.2 Research

Test centres have a key role to play in facilitating applied, industry-relevant and regulatory-driven research at test sites rather than research driven by academic interest alone. In reality, of course, a regulatory driver will become an industry driver, since regulatory permission will always be required for all deployments. At this early stage of the development of the industry, the main research driver related to regulation is the need to understand more about the potential for environmental effects of marine renewable energy devices on the receiving environment. The main research driver related to environmental monitoring that is required to increase this understanding is the need to develop new, robust and comparable techniques for gathering the necessary data, where these techniques are not available.

As an example of how a test centre can do address this need, EMEC has established the EMEC Developers' Research Forum (DRF), open to all developers testing, or intending to test, at EMEC. In this forum the full range of research relating to the marine renewable energy sector is discussed among developers testing at the EMEC test centres. These discussions are always had in the full knowledge of the regulatory requirements and areas of concern (with which EMEC keeps up to date via its equivalent liaison group with the Regulatory Authority and statutory consultees). It is also important in the development of new research proposals to maintain a close awareness of other relevant research underway. As part of its normal research-related activities EMEC seeks to maintain a close awareness of research being conducted both nationally and internationally, in respect of which EMEC is actively engaged in a wide variety of projects which are applicable to multiple developers can then be formulated and presented as funding proposals.

One of the recommendations of the ORECCA project [24] was that test centres should become not only R&D centres for devices, but also for environmental effects. EMEC is an example of a test centre that does this as well as developing other industry-relevant research projects.

International research
The International Council for Exploration of the Sea (ICES) Study Group on Environmental Impacts of Wave and Tidal Energy (SGWTE) second update report presents a summary of research relating to environmental interactions of wave and tidal energy developments being carried out in EU-member countries [33].

The International Energy Agency Ocean Energy Systems initiative (IEA-OES) [34] provides a framework to research breakthrough technologies, fill existing research gaps, build pilot plants and carry out deployment or demonstration programmes in order to support energy security, economic growth and environmental protection. To date IEA-OES has established five annexes, including one on Assessment of Environmental Effects and Monitoring Efforts for Ocean Wave, Tidal, and Current Energy Systems (Annex IV) which published its final report in January 2013 [35]. A key output of the Annex IV project is a publically available, searchable knowledge base of environmental effects information known as Tethys [36].

European level research
In Europe, the European Energy Research Alliance (EERA) aims to strengthen, expand and optimize EU energy research capabilities through the sharing of world-class national facilities in Europe and the joint realisation of pan-European research programmes (EERA Joint Programmes). The EERA Joint Programme on Ocean Energy [37] includes research into environmental impact as a key research theme. An aim of this research activity is to initiate the production of guidelines and protocols for the environmental assessment of wave and tidal technologies. This work will be based on existing protocols such as those developed during the EQUIMAR project [38].

The SOWFIA project [39] aims to achieve the sharing and consolidation of pan-European experience of consenting processes and environmental and socio-economic impact assessment best practices for offshore wave energy conversion developments. Studies of wave farm demonstration projects in each of the collaborating EU nations are contributing to the findings. The study sites comprise a wide range of device technologies, environmental settings and stakeholder interests.

The Marine Energy in Far Peripheral and Island Communities (MERiFIC) project [40] seeks to advance the adoption of marine energy across the two regions of Cornwall and Finistère and the island communities of le Parc Naturel Marin d'Iroise and the Isles of Scilly. Project partners will work together to identify the specific opportunities and issues faced by peripheral and island communities in exploiting marine renewable energy resources with the aim of developing tool kits and resources for use by other similar communities. Work package 3 of the MERiFIC project will develop a comprehensive baseline of marine energy resource data for the cross border region of Cornwall and the Isles of Scilly and Finistère. The main aim of this work package is to provide a comparison and protocol of measurement techniques and terminology within the cross border region. A literature review of the environmental impact of marine renewable energy has been undertaken as part of this work [41].

Research in the UK
In the UK, the environmental research needs for the marine renewable industry have been captured under the banner of the Marine Renewable Energy Knowledge Exchange (MREKE) programme [42]. The aim of this programme

is to enable a better understanding of the risks and benefits of deploying renewable energy arrays in the marine environment, and to ensure an environmentally sustainable future for the marine renewable energy sector.

The Offshore Renewables Joint Industry Programme (ORJIP) [43] is managed by the Carbon Trust and funded by The Crown Estate, the Department of Energy and Climate Change (DECC), and Marine Scotland with the aim of reducing consenting risks for offshore wind and marine energy projects. As part of this initiative a short focused project was commissioned by The Crown Estate (*Pentland Firth and Orkney Waters Enabling Actions Report: Consolidation of wave and tidal EIA / HRA issues and research priorities* – technical report to The Crown Estate issued by Aquatera Ltd, in draft at time of writing) with the following aims:

- Produce a consolidated up-to-date list identifying the key strategic environmental issues facing the wave and tidal energy sectors.
- Identify the priority research gaps relevant to wave and tidal energy demonstration scale arrays and then outline potential approaches to fill these gaps.
- Identify strategic research priorities which any coordinated approach to addressing them could focus on.

The outputs from this project will inform and focus any coordinated approach to research that is developed via ORJIP.

In Scotland, the Scottish Marine Renewables Research Group (SMRRG), a partnership initiative between Marine Scotland and SNH [43], focuses research on Scotland's seas. It oversees projects that are funded by the Scottish Government and SNH, aimed at better understanding the potential environmental impacts of marine renewable energy developments. The SMRRG research agenda is driven by the knowledge gaps identified from the Strategic Environmental Assessment (SEA) and raised subsequently, and therefore also seeks to address issues that are of regulatory concern.

In Wales, the Marine Renewable Energy Strategic Framework (MRESF) project investigated the potential marine renewable energy resource of Welsh Territorial Waters and included studies to increase the knowledge base for key data gaps surrounding the environmental uncertainties associated with marine renewable energy developments [45]. This project gathered data during 2009-2010 and reports available from the MRESF website include:

- Desktop Review of Marine Mammals and Risks from Underwater Marine Renewable Devices in Welsh waters
- Studies of Marine Mammals in Welsh High Tidal Waters
- Desktop Review of Birds in Welsh Waters and Preliminary Risk Assessment from Underwater Marine Renewable Devices in Welsh Waters
- Assessment of Risk from Underwater Marine Renewable Devices in Welsh Waters - Field Methodologies and Site Assessments

Research in Ireland

In Ireland, the Marine Institute’s National Marine Research Strategy, Sea Change [46], presents a national agenda comprising science, research, innovation and management, aimed at a complete transformation of the Irish maritime economy. This strategy includes a research programme looking at renewable ocean energy, focusing on offshore wind and wave.

Research in Spain

Spain’s Ministry of Science and Innovation is backing the Ocean Lider Initiative [47], the main aim of which is to develop the technologies needed to set up integrated installations that can harness marine energy. The project, which involves 19 companies and 25 research centres, has received grants from the Spanish Centre for the Development of Industrial Technology (CDTI) and the State Fund for Local Investment.

This project includes a work-package looking at research in models, protocols, guidelines, methodologies, tools and new technologies that enable a proper assessment of environmental impacts associated with marine renewable developments.

Research in France

The French Research Institute for Exploitation of the Sea (IFREMER) undertakes targeted applied research to address the questions posed by society (including climate change effects, marine biodiversity, pollution prevention, and seafood quality). IFREMER is a public institute of an industrial and commercial nature, supervised jointly by the Ministry of Higher Education and Research and the Ministry of Ecology, Sustainable Development and Energy.

3 ENVIRONMENTAL MONITORING AT MARINET TEST SITES

This section discusses the equipment and protocols being developed to facilitate environmental monitoring at ORED test sites. A summary of monitoring in progress at the various marine renewable energy test centres is also provided.

3.1 AVAILABLE EQUIPMENT

Monitoring of the marine environment, particularly for the detection of interactions between new wave and tidal energy generation technologies, poses novel challenges which can demand bespoke equipment and sensor solutions. Effort is being directed at turning off-the-shelf products into instruments which are fit for purpose in high energy marine environments, and an increasing range of sensors and equipment is becoming available as technology companies innovate to fill this market gap. In a similar trend to the marine energy converter systems (MECS) whose operating environment the sensors are designed to measure, it is expected that the range of monitoring equipment will continue to increase for some time yet before convergence on the most effective solutions.

Challenges facing the collection of information to inform environmental uncertainties in the marine environment include:

- The costs of deploying/recovering monitoring equipment at sea are high, with any unscheduled downtime due to bad weather conditions adding to these costs significantly (e.g. cancellation costs for vessel/crew hire etc).

- Existing sensors for data collection in the marine environment (wave-rider buoys, acoustic doppler current profilers (ADCPs), etc) were developed for long-range high level oceanographic purposes and are not suitable for highly defined resource characterisation at the level of detail required for the emerging marine renewable industries.

- Other monitoring equipment must be extremely robust and fit for purpose in order to survive the harsh conditions. Many off-the-shelf sensors have been developed for other purposes and are being used as best available, but are not really good enough to do the job (i.e. there is a need to develop a bespoke range of sensors to address the full range of measurement activities required by the marine renewable energy sector).

MARINET deliverable D4.8 provides an introduction to equipment and measurement techniques used to monitor environmental activities and processes in the marine environment, and presents a list of measuring equipment and survey techniques in use by the MARINET project partners. MARINET deliverable D4.8 also explains the importance of considering the spatial and temporal scales when selecting monitoring and measurement techniques. Reference tables showing techniques which can be used to measure physical parameters and biological parameters are included in D4.8. Further information on the various monitoring techniques which are suitable for use with environmental compartments is available in the full D4.8 report.

The principal outcome of MARINET deliverable D4.8 is a common information source in the form of a database of available techniques and equipment, accessible via the MARINET website. The database identifies 27 techniques used for environmental monitoring and measurement employed by the MARINET consortia partners at the time of preparation. The majority of techniques have multiple equipment options, and include information about sites where the techniques have been used, together with operating principles, parameters measured, associated methodologies, typical operating range and sampling frequency. The main conclusion from D4.8 is that each test centre is developing its own solutions, and there is no consistency or common approach being taken. This is to be expected at this emergent stage of the marine renewable energy industry.

In Scotland, there has been discussion at the regulatory level regarding the need for consistency in monitoring equipment and methods in order to enable effective comparison of results across studies. On the one hand, comparability can be a real help to comparative assessment of different methods and project reports yet, on the other hand, there is a reluctance to introduce requirements for specific methods and equipment due to the risk of potentially inhibiting innovation in these areas. While regulators cannot endorse any specific manufacturer's equipment, and there is recognition that a balance must be achieved between consistency in methodologies and innovation, there is a strong regulatory push for development of fit-for-purpose monitoring equipment and techniques. In this respect test centres are well-placed to play a strong role in the facilitation of development and testing of equipment in realistic high-energy marine environments. For example, the 'Drifting Ears' drifting hydrophone system, originally designed by the Scottish Association for Marine Science (SAMS) and EMEC, was further developed to withstand conditions experienced at the EMEC tidal test site (see Section 4.3). Test centres are also well-placed to host and potentially validate testing conducted by equipment developers and MECS developers.

3.2 Available Methodologies

This section incorporates information from the MARINET deliverable D4.17 (Report on Environmental Monitoring Protocols) and is based on the "Guidance on survey and monitoring in relation to marine renewables deployment in Scotland" developed by SNH [48] and on "Guidelines for data acquisition to support marine environmental assessment of offshore renewable energy projects" developed by the UK Centre for Fisheries and Aquaculture Science (CEFAS) [8], which have provided in depth reviews and analysis of protocols for environmental monitoring. These documents highlight the key points of environmental protocols which are under development for monitoring the impact of marine renewable energy developments on the marine environment.

These recent guidance documents produced by SNH and CEFAS indicate that there is a general lack of knowledge about procedures for monitoring impacts of marine renewable energy structures on the marine environment. As a consequence the guidance focuses predominantly on the following four key environmental receptors, which is also a reflection of their importance as amongst the key receptor groups for which monitoring is difficult:

- Marine Mammals (cetaceans and seals)
- Seabirds (migratory and diving)
- Benthic Ecology
- Fish

Monitoring methods and protocols may differ according to whether they are designed to be implemented in the baseline site characterisation stage or as an impact assessment study. Protocols available for monitoring these key environmental receptors are discussed below.

3.2.1 Marine Mammals

As discussed in section 2.1.1, the principal issues of regulatory concern with marine mammals are displacement due to physical presence of devices and the potential for physical harm due to collision with underwater moving parts. Such displacement or harm may be caused by a number of potential mechanisms, including (but not limited to) acoustic output of devices or vessels, and processes involved in installation and maintenance activities. Table 5 below provides an overview of methodology and equipment typically used for the monitoring of marine mammals.

Method	Metric	Equipment required	Survey design	Suggested monitoring interval	Analysis of change
Vantage Point	Presence/ absence; Distribution; Relative abundance; Habitat use; Behaviour.	Binoculars/ telescope; Theodolite; Inclinometer; Video-range.	Suitable elevated vantage point; Visual observation - continuous scan; Even sampling of	Seasonally and annually if natural variability to be established; At least one in each	Very wide range of metrics may be gathered, so very dependent upon questions being

			spatial and/or temporal factors influencing detection; May need to be calibrated with line transect visual surveys.	development phase.	asked and data being collected.
Autonomous Acoustic Data Loggers	Presence/ absence; Impact detection.	AADL e.g. CPOD, Hydrophone system; Batteries; Boat-winch; Moorings.	Gradient/BACI design.	Continuous (need regular servicing).	Regression analyses.
Passive acoustic tracking.	Habitat use; Behaviour.	Acoustic transmitting tags; Underwater acoustic modem aboard a boat.		Continuous.	Marine mammal behaviour over large spatio-temporal scales (departures, arrivals and occupancy times).
Line transect visual surveys	Relative abundance; Density; Abundance;	Platform; Inclinometer (aerial); Reticle binoculars (ship); Angleboard (ship); Data recording software and laptop.	Randomly located lines; Various layouts (zig-zag, parallel).	Seasonally and annually if natural variability is to be established; At-least one in each development phase; Intensive surveying within short periods may be more appropriate than regular surveying over extensive periods or throughout the year.	Baseline: Distance; Sampling analyses; Statistical tests between point estimates e.g. Z-test; Regression analyses.
Photo-ID	Presence/absence; Abundance; Connectivity.	Small manoeuvrable Boat; Digital SLR & 200+MM autofocus lens; GPS; Note-taking materials.	None specific – but area covered must be sufficient to sample population in question.	Population estimates may require 2 days per month or more concerted effort during shorter periods; Question dependent.	Matching & grading Photographs; Matching across Catalogues; Estimator for abundance e.g. Petersen.
Carcass recovery	Species present; Cause of death; Movement /behaviours; Time-energy budget.	Trained observers; Equipment for moving animals; Vets.	Established stranding Network.	Dedicated monthly coastline surveys or before and after activities/ phases of key interest (e.g. construction?).	Species composition over time; Cause of death over time; in conjunction with development phases.
Active Sonar * and Underwater Photography	Approach distance to Devices (TECs, WECs); Impacts; Behaviour.	In development.	N/A.	N/A.	Statistical analyses.

Table 5: Methods available for monitoring potential impacts of OREDs on cetaceans. The methods employed will be dependent on the approach chosen for the specific site. *Active sonar methods are still under development. [18][19].

The SNH monitoring guidelines [18], [19] provide detailed information on how to carry out monitoring programmes as presented in Table 5 above. Further information on equipment is available in the annexes of the CEFAS guidelines [8]. Review of studies carried on marine mammals, especially in relation to offshore wind farms related impacts can be found in literature: such as the Danish [49], UK/COWRIE [50] and the German review of experiences on environmental monitoring [51]. Detailed information on monitoring activates of the impacts on marine mammals due to the presence of tidal stream turbine can be found in Keenan et al., [52]; whilst issue and gaps related monitoring activities have been discussed in depth in the IEA-OES Annex IV final report [35]. Further information on marine mammal monitoring and impacts is discussed in [53][54][55][56].

3.2.2 Seabirds

The extent to which a particular species could be affected by OREDs depends on the importance of the geographical area to the species and their vulnerability to the construction and operation phase of the development. In particular it is important to understand how the development could affect the foraging and breeding of seabirds which will affect their abundance and distribution over time.

Table 6 below presents an overview of the methodologies developed for monitoring marine birds at the impact assessment stage.

Method	Metric	Equipment required	Survey design	Suggested monitoring interval	Analysis of change
ESAS boat-based surveys transect.	Distribution, abundance and behaviour of seabirds; Seasonal changes.	Survey vessel with suitable observation deck 5-25 m above sea level; Binoculars; GPS unit; compass; Note: 1. Binoculars are used to identify birds only and not to detect birds. 2. Vessel speed of 10 knots ideal (range 5-15 knots).	Array of parallel transects, sampled approx. monthly through year, but according to needs.	Variable. Annually at first, every 5 years after 3rd operating year.	Visual and statistical comparisons of distribution and abundance.
Aerial transect surveys, direct observation method	Distribution and abundance of seabirds; Seasonal changes.	Fixed wing light Aircraft; Binoculars; GPS unit; Compass.	Array of parallel transects, sampled approx. monthly through year, but according to needs.	Variable. Annually at first, every 5 years after 3rd operating year.	Visual and statistical comparisons of distribution and abundance.
Aerial transect surveys, digital imaging method	Distribution, abundance and behaviour of seabirds; Seasonal changes.	Binoculars; Spotting scope; Compass; Equipment to measure distance /angle of declination.	Various: snapshot scans, flying bird watches, focal bird watches; Sampling approx. monthly through year, but according to needs.	Variable. Annually at first, every 5 years after 3rd operating year.	Visual and statistical comparisons of distribution and abundance.
Shore-based VP surveys	Distribution, abundance and behaviour of seabirds; Seasonal and interannual changes.	Binoculars; Spotting scope; Compass; Equipment to measure distance /angle of declination.	Various: snapshot scans, flying bird watches, focal bird watches; Sampling approx. monthly through year, but according to needs.	Variable. Annually at first, every 5 years after 3rd operating year.	Visual and statistical comparisons of distribution and abundance.
Cliff-nesting raptors	Breeding territory, occupancy, and productivity of eagles and peregrine.	Binoculars; Spotting scope.	Complete survey of areas of interest; Usually 2-3 visits in breeding season (March-July).	Annually.	Comparison of occupancy and productivity rates.
Seabird colony counts	Number of breeding seabirds.	Binoculars; Spotting scope;	Census of areas of interest; Protocol	Usually less than annually, depending	Comparison of numbers and

		Digital camera; Reference photos of colony geography.	varies with Species; Usually based on one carefully timed visit; Additional visit may be needed to measure productivity.	on needs; 5-year interval likely to be appropriate.	productivity.
WeBS and NEWS type surveys	Numbers of waders and water-birds present along defined stretches of coast and inshore waters.	Binoculars; Spotting scope; GPS unit; Field maps.	Total counts of predefined stretches, usually monthly.	Variable.	Comparisons of distribution and abundance with time and regional /national trends.
Telemetry tagging of individual birds	Data on ranging, site connectivity, barrier effects and foraging behaviour.	Telemetry tags (many different designs) and tracking equipment; Equipment to catch and handle birds.	Tailored to project needs.	Usually conducted as one-off study; Repeating after an interval of several years could provide evidence of response to development infrastructure including with time habituation.	Comparison of behaviour through time and in relation to proximity of development.
Radar	Activity and travel routes of flying birds.	Specialist radar Equipment.	Tailored to project needs.	Usually conducted as one-off study. Repeating after an interval of several years could provide evidence of habituation to development infrastructure.	Comparison of behaviour preconstruction with post construction through time and in relation to proximity of development.
Collision monitoring	Estimates of collision mortality.	Protective gloves for handling dead birds.	Systematic searches of depositional shores for corpses. PM of corpses for evidence of trauma.	Variable.	Trends in numbers of dead birds found and attributed cause of death.

Table 6: Monitoring methods for characterisation of marine birds close to OREDs [20]

3.2.3 Benthic Ecology

A variety of methods have been developed for the baseline and impact monitoring of benthic habitats. Different methods can been applied and adapted to the specific marine renewable energy technology based on the expected impact pathways. An overview of methods available for the survey of benthos is presented in Table 7 below.

Methods	Metric	Equipment Required	Survey design	Monitoring interval	Analyses of changes
Acoustic survey	Substrate distribution; Habitat/ community distribution.	AGDS; sidescan sonar; Multibeam sonar.	Overlapping parallel tracks.	One pre-installation then every 2-5 years.	Visual comparison of seabed maps; GIS spatial analysis.
Drop-down video/ photography	Distribution of habitats/communities /biotopes.	Drop-down imaging system.	Grid arrangement; Random sampling; Stratified random sampling; Transect sampling.	One pre-installation then annually.	Chi-square or Wilcoxon signed rank; Test comparison of biotope composition of site; Simple visual comparison of

					biotope frequency data.
	Presence of specified species; Maintained presence of priority species at specific locations.	Drop-down imaging System.	Random sampling; Stratified random Sampling; Transect sampling; Directed visual Sampling.	One pre-installation then annually.	Comparison of proportional occurrence; Simple confirmation of presence.
ROV video/ photography	Presence of specified species.	ROV.	As for drop-down video.	As for drop-down video.	As for drop-down video.
Grab sampling	Species abundance per unit area; Species richness; Diversity indices.	Van Veen grab; Day grab; Hamon grab.	Grid arrangement; Random sampling; Stratified random Sampling; Transect sampling.	Annually, but at least two at pre-installation to establish natural variability.	Analysis of Variance (ANOVA).
	Community Composition.	Van Veen grab; Day grab; Hamon grab.	Grid arrangement; Random sampling; stratified random sampling; Transect sampling.	Annually, but at least two at pre-installation to establish natural variability.	Ordination (MDS, PCA) ANOSIM.
Diver core sampling	Species abundance per unit area; Species richness; Diversity indices.	SCUBA; Diver deployed cores.	Random sampling; stratified random sampling; Transect sampling.	Annually, but at least two at pre-installation to establish natural variability.	ANOVA.
	Community Composition.	SCUBA; Diver deployed cores.	Grid arrangement; Random sampling; stratified random sampling; Transect sampling.		Ordination (MDS, PCA) ANOSIM.
Diver video/ photography	Broad community character and substrate condition.	SCUBA; Underwater video or stills camera.	Location directed.	One pre-installation, then every 3-6 months (or synchronise with other diving tasks).	Simple visual comparisons.
Diver transects (visual survey)	Semi-quantitative species abundance (MNCR Phase 2 surveys) ; Biotope presence and distribution.	SCUBA; Underwater video or stills camera (optional).	Transects; Stratified random sampling; Directed 'spot dives'.	One pre-installation, then a minimum of two per year.	Direct comparison of community attributes (semi-quantitative abundance, biotope presence.
Diver quadrats	Species abundance (individual abundance or % cover).	SCUBA; Quadrat.	Replicated samples from plots arranged along transects.	At least one pre-installation, then a minimum of two per year.	Ordination (MDS) ANOSIM, SIMPER.
	Species richness/ Diversity.	SCUBA; Quadrat.	Replicated samples from plots arranged along transects.	At least one pre-installation, then a minimum of two per year.	ANOVA.
	Abundance of selected conspicuous species.	SCUBA; Quadrat.	Replicated samples from plots arranged along transects.	At least one pre-installation, then a minimum of two per year.	ANOVA.
Intertidal survey	Presence and spatial distribution of intertidal communities/biotopes; Beach profiles.	Tape measure/ transect line.	Vertical shore transect.	One pre-installation survey then annually.	Simple comparison of spatial arrangement of biological zonation relative to tidal height.

	Selected species abundance.	Tape measure/ transect line; Quadrats.	Replicate quadrats within selected zones.	One pre-installation survey then annually.	ANOVA.
	Maintained presence of priority species at specific locations.	GPS.	Visual location and repeated observation.	One pre-installation survey then annually.	Simple confirmation of maintained presence (may require additional information on condition.

Table 7: Survey methods for monitoring benthic communities in the proximity of OREDs [7][8]

3.2.4 Fish

Monitoring methodologies and strategies designed to understand the potential impact of OREDs on fish are varied and differ according to the aim of the survey and the site characteristics.

An overview of fishing monitoring activities related to OREDs is presented in [49][57]. Studies into the assessment of fish population at the BIMEP wave energy site have recently begun [58] and research into the potential use of wave energy test sites as nursery grounds for lobster commenced at EMEC in 2011 [59]. Table 8 below provides an overview of some methods employed for monitoring fish at marine renewable energy test centres.

Method	Metric	Equipment required	Survey design	Suggested monitoring interval	Analysis of change
Passive acoustic tracking.	Habitat use; Behaviour.	Acoustic transmitting tags; Underwater acoustic modem aboard a boat.	At the site, 2m high seabed landers carry data-logging acoustic receivers. Suitable number (hundreds) of fish tagged with acoustic transmitters	Continuous. Data uploaded remotely every few months.	Fish behaviour over large spatio-temporal scales (departures, arrivals and occupancy times).
Active acoustic tracking (e.g. FLOWBEC).	Habitat use; Behaviour; Abundance; Morphology of turbulence.	Active sonar; Echo-sounders/fish finders.	Data logging active sonar equipment installed within a self-contained platform.	Continuous over a 2-week period.	Identification of pelagic and demersal fish species; Determine predator-prey interactions in different wave/tidal conditions.
HD wide angle cameras.	Presence/absence; Diversity; Abundance.	HD wide-angle cameras.	Cameras deployed upon seabed and mid-water column located along the zone of interest.	Continuous.	Census of mobile species diversity and abundance.
Integrated camera and ADCP (OpenHydro and Imperial College study, EMEC)	Presence; Abundance.	Integrated video camera techniques with ADCP methods.	Camera fixed on MECS structure; ADCP deployment in vicinity of MECS; Data split into hour segments for each day; Randomised photographs created, fish identified and counted and then averaged.	Continuous.	Assess abundance responses of *P. pollachius* to a deployed tidal turbine; Assess abundance responses in relation to temporal scales: hour, day and year; Assess abundance response in relation to important abiotic

					variables such as flow velocity.
Release of juvenile lobster; Tagging and v-notching of crab and lobster	Habitat use; Abundance.	Fishing vessels and standard creel gear.	Rearing and release of juvenile lobster; Limited catch, tag/v-notch, record and release over summer months; Real catch data from regular fishing in the Scientific Monitoring Zone.	Recapturing expected 2016-18, dependant on further project funding.	Local population dynamics and movement patterns of lobsters; Synthesis of potential effect of inshore wave energy developments on the local creel fishery.
Visual surveys of basking sharks [4]	Abundance.	Optics.	Land-based or boat-based surveys.	Monthly.	Abundance.
Acoustic monitoring array (unique in UK)	Long-term space use.	Individual seabed landers with acoustic transceiver with spherical detection volume of ~700m.	As in QBEX project Module 1; Monitors movements of acoustic transmitter-tagged animals.	Sub-minute scale for up to 5 years. Can be limited by how long tags stay on animals.	Individual spatial changes that when collated across individuals gives precise measurement of spatial re-distributions (fluxes) of key species between test and control sites; Because of the long-term nature of this monitoring, daily, seasonal and annual changes in re-distributions at the site will be quantified.
	Wider scale dispersal outside the MREI (test) and adjacent (control) areas; Pressure (depth) and temperature from miniature electronic data loggers.	Animal-attached data storage tags.	As in QBEX Module-1.		
HR Wallingford HAMMER model to incorporate behavioural response of marine species to noise from marine renewable energy devices (MRED) during construction and operation					

Table 8: Methodologies for monitoring fish activities at OREDs [57][59][60]

3.3 Monitoring Underway

This section presents details (current at the time of writing) of monitoring data being collected to inform and address the key environmental uncertainties discussed in section 2.1.1.

3.3.1 Marine Mammals

Table 9 below presents the marine mammal monitoring activities undertaken at test centres and some commercial deployments, based on information acquired by the SOWFIA Project [61].

Test centre	Monitoring requirements	Sampling stations and time period	Used methodologies
AMETS (Ireland)	Data collected to satisfy EIA.	October 2009-September 2010.	Seasonal vessel-based line transects; Towed hydrophone surveys; Static acoustics and monthly land-based observations.
Galway Bay (Ireland)	-	-	Desktop review and collation of existing information on marine mammals that occur in the area.
EMEC (Orkney, Scotland, UK)	Required by Licensing Authority.	Fall of Warness tidal test site, July 2005 - present. Billia Croo wave test site, March 2009 - present.	Weekly surveys from onshore single vantage point using visual observation methodology approved by Marine Scotland. MMO monitoring from jack up barge during developer installation operations using visual observation technique following EMEC MMO protocol. Also boat-based underwater noise monitoring for cetacean impact. Boat-based marine mammal observations using a visual survey technique following the EMEC MMO protocol (agreed and approved by the Regulator & Statutory Environmental Advisors) during various developers' marine works activities.
Wave Dragon (Wales, UK)	Acoustic monitoring required for EIA.	N/A.	Desk based study collating existing information on marine mammals. Acoustic marine mammal monitoring.
Wave Hub (Cornwall, UK)	Applied and fundamental research by the University of Exeter.	Monthly boat-based surveys, August 2008 - present and continuing.	Opportunistic sightings of marine mammals on boat-based point counts of birds at 9 points located in a grid over the Wave Hub, and 10 points in increasing distances away from the Wave Hub in an easterly and westerly direction. Also continuous acoustic data on marine mammal occurrence & behaviour for same time period.
	Data collected to satisfy EIA.		Desk based study of Cornwall Wildlife Trust sightings database. Acoustic detection of cetaceans in vicinity of the Wave Hub (TPOD).
Pico (Portugal)		May & September 2010.	Acoustic marine mammal monitoring only.
Ocean Plug – Portuguese Pilot Zone (Portugal)	Data collected to satisfy the geophysical and environmental characterisation of the site required in the legislation.	2011.	Boat based and aerial surveys.
Commercial Deployment	**Monitoring requirements**	**Sampling stations and time period**	**Used methodologies**
Aquamarine Power (Lewis, UK)	Not known.	Not known but monitoring started in 2010.	Visual observations, methodology unknown.
Pelamis Farr Point (Scotland, UK)	Monitoring required for EIA.	For future.	Pre-scoping process included creation of a metadata catalogue of all known available data and information sources with respect to relevant environmental sensitivities within the proposed area. Surveys for marine mammals are required for

			the EIA (yet to be carried out).
Pentland Firth, UK	Currently just scoping project.	Desk-based study.	Seal habitat use based on current data collected by SMRU (aerial & ground counts of hauled out seals and telemetry).
Sotenas (Sweden)		2012 - present.	Acoustic marine mammal monitoring only.
Peniche (Portugal)			No known marine mammal monitoring carried out.
Ocean Plug – Portuguese Pilot Zone (Portugal)	Data collected to satisfy the geophysical and environmental characterisation of the site required in the legislation.	2011.	Boat based and aerial surveys.
Reunion	Required by national, European and International law.	January 2012-present.	Acoustic marine mammal monitoring only.
Runde (Norway)			No known visual or acoustic data collection for marine mammals.
SEM-REV (France)			No known visual or acoustic data collection for marine mammals.

Table 9: Summary of marine mammal monitoring activity at marine energy test centres and some commercial deployments [61]

3.3.2 Seabirds

Table 10 below presents the marine bird monitoring activities undertaken at test centres and some commercial deployments, based on information acquired by the SOWFIA Project [61].

Test centre	Monitoring requirements	Sampling stations and time period	Used methodologies
AMETS (Ireland)	Data collected to satisfy EIA.	2009 - 2010.	Monthly land based visual methods for shore and open water bay habitats, for terrestrial habitats at the landfall site and on Inishglora Island (<3km from the AMETS). Monthly sea based surveys for area surrounding test site (~180km^2) using the European Seabird at Sea standard method.
Wave Hub (Cornwall, UK)	Applied and fundamental research by UNEXE.	2008 - present.	Near-monthly point counts conducted at 19 sampling stations stretching east-west across the Wave Hub development zone.
Wave Hub, (Cornwall, UK)	Data collected to satisfy EIA.	2004 - 2005.	300m line transects to ascertain bird density by month (one year's survey effort).
EMEC (Orkney, Scotland, UK)	Required by Licensing Authority.	2005 - present for tidal test site. 2009 - present for wave test site.	Multiple methods (site dependent); approved by Marine Scotland (Regulator).

Ocean Plug – Portuguese Pilot Zone (Portugal)	Data were collected to satisfy the geophysical and environmental characterisation of the site required in the legislation.	2004 - 2007 (data from Marine Important Bird Areas monitoring). 2010 - 2012 (data from Future of the Marine Atlantic Environment project). 2011 (data collected during the geophysical and environmental characterisation campaigns of the site).	Multiple methods used.
Commercial Deployment	**Monitoring requirements**	**Sampling stations and time period**	**Used methodologies**
Western & Northern Scotland	Applied and fundamental research. In fulfilment of MaREE.	2011 - present.	Visual surveys, tagging and tracking of individual birds.
Runde (Norway)	Unknown.	2009 - 2010.	Unknown.
Pentland-Orkney	Scoping data with respect to Scottish marine environment.	Desk-based studies.	Techniques review.

Table 10: Summary of marine bird monitoring activity at marine renewable energy test centres and some commercial deployments [61]

Further information about the potential impacts of marine renewable installations on marine birds has been collected, primarily through offshore wind energy programmes [48][49][50]. Detailed descriptions of protocols can be found in [20][53][56].

3.3.3 Benthic Ecology

Table 11 below presents details of benthic monitoring activities undertaken at test centres, based on information acquired by the SOWFIA Project [61].

Test centre	Monitoring requirements	Sampling stations and time period	Used methodologies and results
AMETS	Required under EIA.	Twenty five stations were sampled in July and November 2010 at the two test site areas and along the cable route.	Four grab samples were taken at each station, one of them was used for particle size analysis and organic content and three were preserved for macro-faunal identification, using standard procedures (NMBAQC). Sediments were classified as infra-littoral or circa-littoral fine sands.
	Survey was part of survey of Ireland's seabed area, data was used in EIA.	All test centre area.	Bathymetric survey undertaken in 2008 by Marine Institute and supplementary shallow water surveys conducted by IMAR survey in 2009.
	Required under EIA.	The two test site areas, the cable route and a buffer zone either side of the cable route.	Dropdown video survey and dive surveys. The video imagery was reviewed to assess the habitats and biotopes present. All species observed were recorded and an estimate was made of their abundance on a DAFOR scale.
Bimep	Benthic characterisation has been made under the required EIA. Data on benthic communities were collected.	Three stations on intertidal hard substrate were sampled in March 2008; Eight sub-tidal stations (4 on soft-bottom substrate and 4 on hard-bottom substrate) were sampled in	Desk based study using literature published on the subject for the or nearby the deployment area. The replicates of $0.0625m^2$ and 0.15m depth were taken for each station. Replicates were sieved and preserved

		April 2008; The sampled areas correspond to the two cable route alternatives.	for the species identification and quantification. Transects were filmed to complement sample collection data. Community structural parameters have been determined through the application of diversity indices.
EMEC	Benthic characterisation of the sites was required for initial setup of sites. Marine Licence conditions required developers to undertake ROV surveys of device deployment location (as of January 2013 this is no longer a requirement for deployment at EMEC).	Eight tidal test berth and six wave test berths; Survey of berths, cables, and device deployment locations pre- and post-installation; Post-decommissioning surveys.	ROV survey; still photography; Report of benthic characterisation available to clients; ROV surveys: ROV video footage, still photographs and reports. N.B. these surveys are no longer required as a licence condition.
Ocean Plug	A geophysical and environmental characterisation report is required; however no data on benthic communities have been collected. Shape files on the composition of superficial seabed sediments are available.		
SEM-REV	Benthic characterisation has been made under the required EIA. Data on benthic communities were collected.	Six stations were sampled along the cable route and deployment area in June 2009.	Samples were collected with grabs from a ship equipped with a crane and a winch. Two replicates of $0.25m^2$ were collected for each station. The sediments composition was characterised: dominant particle size in each station. Characterisation of species composition and abundance of infauna (organisms living within the substratum) and epibenthos (organisms living on the surface of the substratum).
Wave Hub	Benthic classification and biodiversity assessment.	Two sites each at the North, Centre and South of the station were surveyed during November 2010 and January 2011.	Baited remote underwater videos (BRUVs) were deployed at each site for a bottom recording time of 1hr 20 mins to 1hr 30 mins. For each camera drop, benthic composition was categorised using EUNIS classification. Sessile species were identified. Mobile species were identified and counted with time when first appearing in the footage being recorded.

Table 11: Summary of benthos survey activity at marine energy test centres [61]

Reviews giving further information on benthos monitoring in the proximity of marine renewable energy installations is available in [47][48][50] whilst detailed monitoring information can be found in [62] and [63].

3.3.4 Fish

Table 12 below provides details of fish-related monitoring being undertaken at marine energy test sites.

Test centre	Monitoring requirements	Sampling stations and time period	Used methodologies and results
EMEC	Study to determine the likely influence of a small-scale refuge area on local lobster population abundance and availability, and to explore the potential for using such an area to augment local lobster stocks by using them as nursery grounds for the release of hatchery-reared juveniles.	EMEC Billia Croo wave test site, 2011-2012.	Novel application of tagging procedure to tag very early stage juvenile lobster (stage 8). The study concluded that the area within the EMEC wave test site at Billia Croo provides suitable feeding and refuge habitat for lobster, and has the potential to act as a nursery area to both the local fishery and to the

			Orkney Islands as a whole. Further work is required to monitor the progress of tagged juvenile lobster released at the test site.
Wave Hub	QBEX project: Quantifying benefits and impacts of fishing exclusion zones around Marine Renewable Energy installations	Novel technologies will be used to determine the spatial movements of fish and shellfish across a wide-range of spatio-temporal scales (spanning metres to 100s of kilometres and minutes to years).	The project will seek to quantify the extent to which 'spillover' of bioresource abundance, i.e. fish and invertebrate species, enhances adjacent areas as a consequence of fishing exclusions within and around marine renewable energy installations. Methods include Acoustic tracking of fish to record behaviour. Fish-borne data storage tags to determine movement patterns. Static gear deployments for multi-season crustacean surveys.

Table 12: Summary of fish monitoring at marine energy test centres

4 NEW STUDY TECHNIQUES AND NOVEL APPLICATIONS

This section explores the techniques being developed to help address the environmental uncertainties arising from OREDs and describes the application of these techniques at marine renewable energy test centres.

4.1 UNDERWATER SONAR

Recent research has shown that a new generation of imaging sonar systems have the capacity to produce acoustic images of marine mammals, and may provide a basis for monitoring close range interactions between marine mammals and marine energy converter systems [64]. If it was possible to use sonar systems in three dimensions for this purpose, such a system would be of key importance in reducing the uncertainty of whether or not marine mammals approach close to OREDs and if so, whether they can take appropriate avoidance action around operational devices. This section describes the use of underwater sonar as a key component of EMEC's integrated environmental monitoring project (see Appendix 1) underway at its tidal test site.

4.1.1 Background

The accelerated development of active sonar systems for the defence sector and for fisheries research and management could provide a technology suitable for use in the underwater monitoring of interactions between marine mammals and marine renewable energy devices. This technology involves actively generating an acoustic signal which is projected towards, and reflected by, a target. Analysis of the reflected signal can lead to detailed information on the characteristics (size, shape, substance) of the target, and is used in, for example, fish counting equipment. However, an assessment of commercially available systems concluded that the high level of turbulence typically found in high tidal flow environments puts the use of such sonar beyond the technical capabilities of current off-the-shelf systems. Despite this, it is anticipated that such technical issues are likely to be relatively minor, and could be remedied if technical R&D was committed from the sonar manufacturers involved [65].

It is important to note that the resolution of any sonar is unlikely to be able to determine with certainty whether a physical interaction occurs between a marine mammal and a marine renewable energy device. However, the use of other technologies, such as underwater video, hydrophones, or strain gauges/accelerometers mounted on the rotors of tidal devices, may potentially provide a valuable partner technology to confirm interactions with marine mammals and build confidence in the output of the new application of active sonar technology [65].

Other projects using active sonar to monitor marine wildlife behaviour include the NERC-funded Flow, Water Column & Benthic Ecology 4D project (FLOWBEC) [66] which aims to increase ecological understanding of the mobile predator use of high energy sites and to identify and quantify which type of habitats they use in these areas, particularly for foraging. The FLOWBEC sonar platform allows the interaction of fish, diving seabirds and marine mammals with marine renewable devices to be imaged, and the acoustic environment analysed. The platform is based on a Simrad EK60 multi-frequency echosounder (38, 120 and 200kHz) used for target identification, abundance estimates, and measures of the morphology of turbulence, together with an Imagenex Delta T multi-beam sonar (260kHz) pinging at several frames per second for target tracking and behavioural analysis. The project also uses a fluorometer to measure chlorophyll, and an ADCP for measuring local current, temperature and depth. All instruments are supported on a frame of nominal weight 4000kg in air, 2500kg in water and nominal dimensions 3.2m long x 2.9m wide and 0.9m high, with rechargeable battery units capable of powering the instruments and associated controllers for up to 2 weeks. The entire structure is self-contained with no external cables for communications or power [67].

A key aim of the integrated environmental monitoring project underway at EMEC is to utilise a 3-D active sonar system mounted in a seabed monitoring pod to monitor marine mammals, large fish, diving birds, and possibly other marine species in the vicinity of an operating tidal energy converter device.

4.1.2 Technology

An independent audit of the EMEC active sonar unit being used in its integrated environmental monitoring pod confirmed that there were, at the time of writing, no off-the-shelf sonar systems which would provide the required imaging in high-energy tidal flow environments. The proposed solution under the EMEC project utilised a high-frequency wide-band system based on Ultra Electronic's existing Artemes Forward Look Sonar (FLS). This system can be configured as a gap filling sonar, obstacle avoidance sonar, and as a standalone forward looking detection and classification sonar, with variations operating at centre frequencies from 60kHz to 550kHz. The unit contains two horizontal receiving arrays, vertically separated to allow vertical localisation of targets (i.e. to provide depth information for any target).

4.1.3 Methodology

The study is being conducted in a number of phases: (1) initial build and deployment of the active sonar system within the sea-bed pod (complete); (2) calibration of the active sonar system (complete); (3) enhancement of signal processing algorithms to overcome the degradation of sonar performance due to the extreme environmental factors (underway at time of writing); and (4) development of algorithms to aid discrimination between biological and other targets detected by the sonar and to determine the species of persistent targets interacting with the turbine (planned future activity at the time of writing).

Due to the unknown effect of the sonar on marine wildlife, licence conditions for operating the sonar were imposed by the Regulator (Marine Scotland), requiring that initial operating cycles should be of short duration and synchronised with land-based wildlife observation periods in order to identify any visual evidence of disturbance to marine mammals in the area. After a period of three months' of operation, a report was submitted to the Regulator showing that no obvious negative effects due to operation of the sonar were observed. Periods of sonar operation will extend subject to regulatory approval and as confidence in absence of negative impacts on the environment increases.

On-going use of the active sonar system will be scheduled to coincide with at least one of land-based wildlife observations or passive acoustic monitoring. In addition, visual evidence from an underwater camera mounted on the operating turbine will be compared with wildlife observation data and the sonar data to enable fine-tuning of tracking algorithms based on species behaviours.

4.1.4 Calibration

The active sonar system was calibrated by towing a reference target behind a vessel following a pre-determined path through the test site to confirm that the sonar correctly assesses range and bearing to a target, and to measure the unknown parameters in the sonar equation required to determine the Target Strength of that target. Analysis of the results confirmed that the Transmission Loss experienced in the Fall of Warness environment can be predicted using a relatively sophisticated propagation model. However, simple models such as spreading loss plus absorption are not reliable in such shallow water.

4.1.5 Analysis

Initial analyses of data collected from the active sonar system confirm that fluctuations in the received signals due to turbulence are present, and that these effects cause imperfections in the sonar images. Despite this, images clearly showing the turbine mounting tripod have been obtained (see Figure 2 below), and it is anticipated that algorithms can be developed to correct for the degradation and restore the desired resolution.

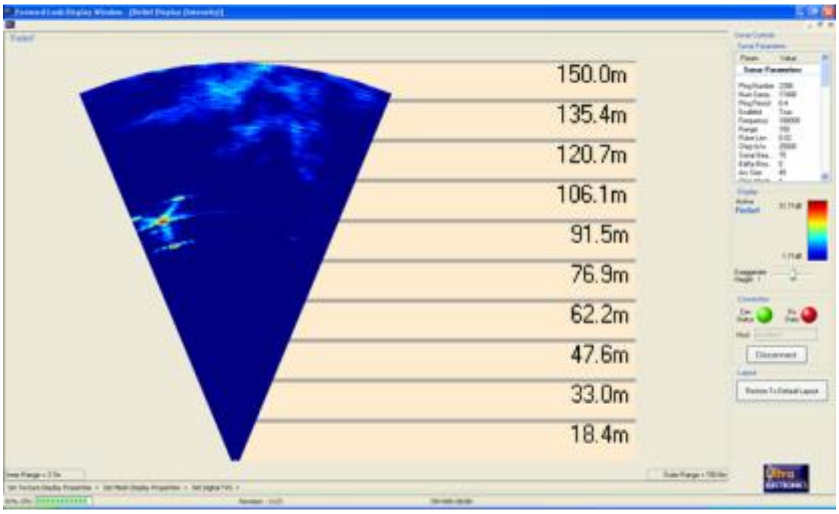

Figure 2: Sonar image showing turbine tripod base at a range of approx. 94 metres

4.1.6 Recommendations

Further work is required to develop active sonar systems for use in high-energy marine environments. Use of active sonar as a marine wildlife monitoring tool should form one element of a monitoring package, which would include other technologies/methods (e.g. underwater video, hydrophones, strain gauges, land-based wildlife observations) to corroborate potential detections.

4.2 Marine Radar

Commercially available radar systems can be used to gather data to provide information on sea state at marine test sites in near real-time. Some of these systems can also potentially be used for tracking marine wildlife. This information can then be used as part of a wider environmental monitoring programme at marine energy test sites. Near field observations may be made with standard X-band marine radar, with a range of a few kilometres. Long range observations may be made using HF radar systems.

4.2.1 Background

Routine wave measurements are typically obtained using a surface following buoy held on a compliant mooring. Such measurements are local to the buoy, so to map the spatial variation of wave climate across a site a number of buoys must be deployed. Furthermore, the nature of the mooring allows a buoy to drift within certain limits, and so the measurements do not truly represent a fixed location. At a tidal test site the fast tidal flows in any case make this method impracticable. The tidal stream itself affects the wave following properties of the buoy, and in fast flows frictional forces on the mooring tend to pull the buoy under water, preventing the principle of measurement of these devices.

Acoustic current profilers may be able to provide auxiliary wave measurements in certain locations. These, however, have physical limitations: the device will normally be located on the sea-bed, and an expensive communications system is generally required to return data to a shore-based station (radio communications are not directly possible because of the intervening seawater). Also, the profiler will only provide a single point measurement - providing good coverage over a spatially changing wave field would again require multiple units and associated marine works.

Radar systems developed for real-time measurement of ocean wave spectra, such as *WaMoS®II* (Wave and Surface Current Monitoring System) used at EMEC can be used to provide continuous availability of wave data in rough seas, under harsh weather conditions with limited visibility, and at night [68]. Such a system analyses the sea surface of a patch of sea as recorded by radar. Marine X-band radar may be installed without expensive marine operations, and the coverage of the radar allows wave parameters to be measured over an area of sea, rather than at a single point. HF installations may also be installed without marine operations, but require significantly more infrastructure ashore.

The FLOWBEC project and the environmental monitoring work-stream of the ReDAPT project utilise such an X-band system for taking site-wide sea state measurements to derive the directional wave spectrum and the surface currents at the EMEC Fall of Warness tidal test site. These measurements can be used to look at energy extraction and wakes caused by MECS, which may potentially have an effect on marine wildlife using the area.

While there are a number of radar systems on the market which may be suitable for this type of application, the following sections describe the radar system installed at EMEC's tidal test site.

4.2.2 Technology

An OceanWaves GbmH *WaMoS®II* system (funded by the ReDAPT project) was installed at the EMEC electricity substation on the island of Eday, providing coverage of the Fall of Warness test site area. The system consists of a dedicated Windows PC+PCI Interface card, and is fed with data from a Kelvin Hughes *MANTA 1700* marine radar system provided by the National Oceanography Centre (see Figure 3 below). This marine X-band radar operates continuously, taking site-wide sea state measurements based on the backscatter of microwaves.

Figure 3: Marine X-band radar system installed at EMEC electricity substation

4.2.3 Methodology

The Kelvin Hughes *MANTA 1700* marine radar system is available 24/7, and is initiated by the *WaMoS®II* system at the start of each sampling period. The raw radar signal is sent to a dedicated PC running the *WaMoS®II* monitoring software, used solely to run the *WaMoS®II* system (a splitter-box is used to send the same raw data signal to both the FLOWBEC and EMEC monitoring projects). The *WaMoS®II* system receives radar data for a set number of antenna rotations, and then stops the radar while the collected sample is analysed. When analysis is complete, the cycle recommences.

The installation must be made at a site with suitable coverage of the target area. The achievable range will depend on the installation height of the antenna(e).

The data files are presented in a format proprietary to *WaMoS®II*, but the general layout is typical of other directional wave recording systems, with the necessary modifications to represent the radar source of the data. A screen-shot showing typical information obtained from the system is shown in Figure 4 below.

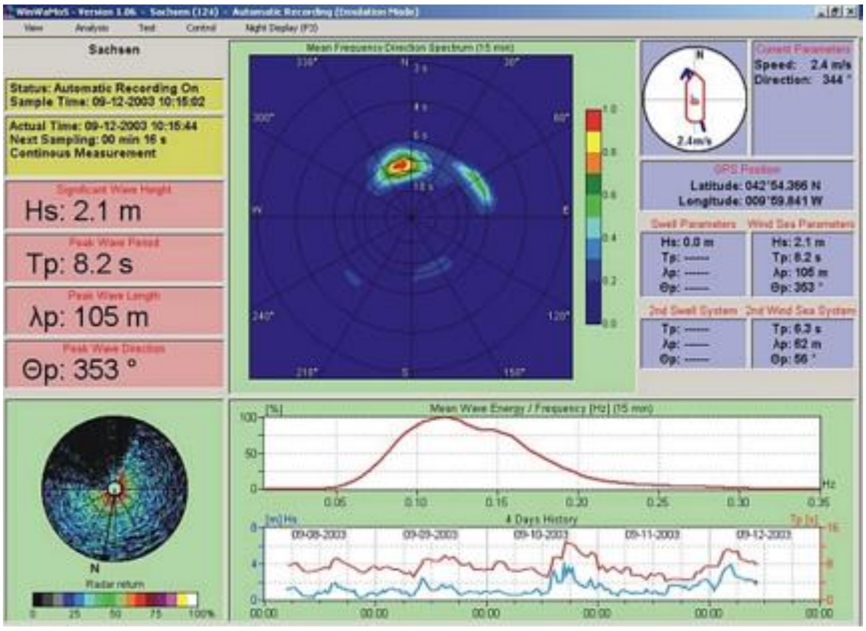

Figure 4: Sample screen-shot of output from the *WaMoS®II* system

4.2.4 Calibration

Full calibration of the *WaMoS®II* system was performed using real-time data from an ADCP device installed within the EMEC sea-bed mounted cabled environmental monitoring pod. The calibration was performed over a one-month period between April and May 2013, and involved comparing the significant wave height values obtained from the *WaMoS®II* system with corresponding values obtained from the ADCP device. This calibration showed a correlation of 79%.

4.2.5 Analysis

The radar signal requires a certain amount of sea surface roughness to provide sufficient signal to analyse. Sea surface roughness is provided by the interaction of wind and sea, and in light winds the wave data may not be analysed. Similarly, the radar requires surface waves of several cm high to be observable. (The use of X-band to track marine wildlife is unaffected by these features). The *WaMoS®II* system has an internal quality control procedure that assesses radar signal quality.

The following data are recorded for analysis:

- "Polar" plots of the radar signal
- Frequency spectra
- Directional spectra

- Wave and current parameters
- Partitions of the sea state into swell waves and wind sea waves

The *WaMoS®II* system performs an analysis of the sea state averaging over a measuring box, with the target box centre placed in this case approximately 2000m from the radar antenna, covering an area of approximately 600m x 1200m. The analysis is carried out over three measuring boxes located in different directions (304°, 275° and 244°) relative to the radar image heading. The measurements represent spatial mean values with regard to a spatial area of approximately 1.8km². The coverage of the radar analysis at the EMEC test site is shown in Figure 5 below.

Figure 5: WaMoS®II radar coverage at the EMEC tidal test site

4.2.6 Recommendations

The use of radar systems in environmental monitoring is still relatively new and requires a lot of work to develop into an environmental monitoring tool suitable for routine use. While such systems can be expensive to install (X-band: ~£100k, and HF systems are £M) they are relatively cheap to use as no marine operations are required. They also offer the potential to gather a wide range of information (e.g. can provide data relating to waves, currents, and bathymetry). The X-band systems also allow observations of marine mammals & birds, etc.

These systems generate a large amount (Terabytes) of data, which must be managed appropriately. Dedication of sufficient computer resources is also required for timely execution of analysis routines.

4.3 Underwater Acoustics

One of the key uncertainties described in section 2.1.1 is the potential negative effects of underwater noise due to installation activities and operation of MECS on sensitive marine species. Of particular concern is the potential for negative effect or impact on species such as marine mammals and fish that utilise underwater sound as part of their survival strategy. Techniques and equipment are being developed for the measurement of underwater noise in the harsh marine conditions typically found at marine energy test sites in order to provide a detailed assessment of the acoustic environment to inform this uncertainty.

4.3.1 Background

The underwater soundscape typically present at marine energy test sites is made up of natural ambient noise (e.g. rain and wind noise, biological noise), anthropogenic ambient noise (e.g. passing boats), noise from activities associated with the installation/maintenance of MECS (e.g. drilling, pilling, vessel noise), and noise from MECS operating at the site. In order to assess the potential effects of underwater noise due to MECS activities on marine wildlife, a detailed analysis of sound levels across the frequency spectrum must be compared to typical levels of ambient noise.

At the time of writing there are no standard methods for measuring and reporting underwater noise [69] resulting in various inconsistent methods being used, some of which are not informative to any useful extent. The problem caused by this inconsistency and lack of robustness has been recognised by the acoustics and wider communities and there are various work-streams in progress to address this [70].

The problem was also raised at the EMEC Monitoring Advisory Group (MAG) during the group's routine review of the adequacy of a range of underwater acoustic monitoring studies that had been performed at the EMEC test sites. The group observed that there was a wide range of reporting approaches and assumptions, with a variety of parameters reported, and that each study was found to be lacking in some respect. This highlighted the need for consistency to be introduced during the initial discussion sessions between project developers and regulators, at which recommendations can be made by the Regulator. It was clear that there was a need for a 'guide' aimed at regulators, to enable them to make the appropriate level of detailed recommendation to developers when discussing the scope of underwater acoustic monitoring to be undertaken.

Having identified this need, EMEC was able to gain funding from the Natural Environment Research Council (NERC) to run a UK-wide training workshop for regulators and their statutory environmental stakeholders, with input from acoustics experts commissioned to deliver the training. This has led to the production of high level guidance on the assessment of underwater acoustic measurement activities, aimed at regulatory bodies to inform their discussions with project developers about requirements for acoustic monitoring of MECS (*Underwater Acoustic Monitoring at Wave and Tidal Energy Sites: Guidance Notes for Regulators – 2013*, in preparation). Although aimed primarily at regulators, this guide will also be accessible to project developers in planning their monitoring proposals.

As these work-streams progress there is likely to be a trend towards a consensus of methods and metrics. In the UK, The Crown Estate commissioned a study to undertake a review of existing data assembled from the public domain, as well as from commercial measurements often solicited by developers [71]. This study summarises the underwater noise measurement activity undertaken around the world to date for which data is available (see Table 13 below).

At a practical level, several projects have been undertaken at EMEC to look at developing novel techniques for measuring underwater noise at high-energy wave and tidal sites, and to use these techniques to measure baseline underwater noise at marine renewable energy test sites.

Organisation	Site	Date	Survey Type
EMEC	EMEC Wave Test Site, Scotland	2011	Ambient noise baseline surveys.
			Operational noise survey of Pelamis Wave Power.
	EMEC Nursery Wave Test Site, Scotland	2011/12	Ambient noise baseline surveys.
	EMEC Tidal Test Site, Scotland	2008/11/12	Ambient noise baseline surveys.
		2011	Noise surveys of cable installation using a Dynamic Positioning vessel.

		2012/13	Operational turbine noise surveys of Tidal Generation Ltd (ReDAPT).
	EMEC Nursery Tidal Test Site, Scotland	2011/12	Ambient noise baseline surveys.
OpenHydro	EMEC Tidal Test Site, Scotland	2010	Operational turbine noise survey.
Voith Hydro	EMEC Tidal Test Site, Scotland	2010	Acoustic characterisation survey of Dynamic Positioning vessel for installation.
Aquamarine Power	EMEC Wave Test Site, Scotland	2011	Installation and operational noise characterisation surveys.
Scottish Association for Marine Science	Sound of Islay, Scotland	2009	Ambient noise baseline survey.
Aquamarine Power	Lewis, Scotland	2012	Noise modelling undertaken together with desktop studies to assess potential impact.
Wave Hub	Cornwall, England	2012	Long term hydrophone deployment for research purposes.
Swansea University	Ramsey Sound	2011/12	Ambient noise measurement.
Marine Current Turbines	Lynmouth, England	2005	Baseline and operational noise measurements.
Marine Current Turbines	Strangford Lough, Northern Ireland	2008	Baseline and operational noise measurements.
Uppsala University	Lysekil, Sweden	2011	Baseline noise monitoring at one location and noise monitoring with a device present at a second location. No data available.
Cobscook Bay Tidal Energy Project	Maine USA	2010	Demonstrator project with turbine deployed from barge. Radiated noise level measured.
RITE TEC project	New York, USA	2011	Three turbines deployed. Radiated noise level measured while operational.
SeaRay WEC	Puget Sound, USA	2011/12	Scale model demonstrator; Operational noise measured.
Admiralty Inlet TEC	Puget Sound, USA	2011/12	Used OpenHydro data from EMEC to estimate noise levels. Study undertaken on fish sensitivity.
Oregon Energy Trust WEC	Oregon, USA	2009	Planning stage – no data available.
Bay of Fundy TEC	Bay of Fundy, Canada	2009, 2012	Demonstrator project. Background noise. OpenHydro data from EMEC used for estimates of operational noise.
Wave Energy Centre	Pico plant, Portugal	2010	Operational noise measurements for EIA.
AW Energy SURGE	Peniche, Protugal	2010	Ambient noise baseline survey.
IBM Research and the Marine Institute Ireland	SmartBay, Galway, Ireland	2012	Ambient noise baseline survey.

Table 13: Summary of underwater noise measurement activity undertaken worldwide (adapted from [71])

4.3.2 Technology

Commercially available hydrophones have varying specifications and it is essential that the hydrophone(s) selected is/are appropriate for the particular monitoring to be undertaken. This is important because hydrophones used to measure pile driving, for example, are required to cope with high peak pressures without overloading, whilst hydrophones intended to measure background noise are required to be more sensitive in order to pick up lower noise levels. In addition, the system used to convert and store the acoustic data must have a high enough bit-rate to cover a wide amplitude range and a high enough sample-rate to cover a wide frequency range. Ideally, the frequency range covered by the hydrophone should be up to ~150kHz in order to cover the upper hearing range of sensitive species, such as the Harbour Porpoise. This would require a digital system sample-rate of ~300kHz due to the Nyquist sampling theorem [72]. However, these higher frequencies are more rapidly attenuated will not propagate far from MECs (a recent study found high frequency MEC noise travelled <2400m [13]) whilst requiring increased storage and battery life from recording systems. Low to mid frequency noise (Hz to low kHz) can travel long distances and can be better characterised with the use of lower frequency hydrophones and/or analogue low pass filters. Therefore, noise in the low to mid frequency range has more potential to be detected over longer distances.

A number of cost-effective systems on the market provide two or more hydrophone channels, allowing simultaneous recording from both higher and lower frequency hydrophones over long periods, although their real-world performance remains to be tested. It is important that the hydrophone and system specifications are clearly detailed when reporting the results of underwater acoustic surveys, in order to make comparisons with past/future surveys.

Due to the different environmental challenges between wave and tidal sites, the technologies used for measuring underwater noise can be split into two broad categories: fixed hydrophone systems and drifting hydrophone systems.

Fixed hydrophone systems
Underwater noise measurement using fixed hydrophones is typically more suited to wave energy convertor sites, where the effect of tidal flow on the hydrophone is less of an issue than at tidal sites. Fixed hydrophone systems can be deployed from a vessel or mounted within a support structure (e.g. a frame or other housing) sitting on the seabed. Although the use of fixed hydrophones to measure underwater noise is not particularly novel, new methods for using such equipment to measure noise in the challenging environment of marine renewable energy sites need to be developed.

Drifting hydrophone systems
Conventional acoustic measurement techniques using hydrophones suspended from boats or mounted on the seabed are not always practical in high-energy tidal environments. The high current can cause strumming on cables, and flow noise on fixed hydrophones that do not move with the tidal flow. Impact noise from debris moved by the current can also be an issue. Drifting hydrophones travel with the flow, therefore reducing this source of sound contamination.

Drifting hydrophone systems include cabled deployment from a suitable small boat or autonomous drifting hydrophones systems. If using a boat-deployed system it is imperative that the engine and all electronics (e.g. echo-sounder) are switched off during the recording run. It is also important to have some method of linking location of the drifting unit and time to the acoustic recording.

A more suitable technique to successfully measure underwater noise in these conditions is to deploy a hydrophone from a free-drifting buoy that drifts with the tidal flow. In 2008, EMEC undertook a project working with the Scottish Association for Marine Sciences (SAMS) to develop a drifting hydrophone system, which became known as the 'Drifting Ears', to carry out underwater acoustic monitoring at its tidal test sites [15]. The Drifting Ears system was further developed by EMEC in 2012 through work with Chickerell BioAcoustics and funding from the ReDAPT project, and the improved system is now known as the Drifting Acoustic Recorder and Tracker (DART) system. EMEC's DART system has been used to collect additional baseline underwater acoustic data at the EMEC grid-connected tidal site [16] and to provide a baseline acoustic characterisation for the EMEC Shapinsay Sound scale test site which was established in 2011 [17].

The DART system consists of three key components: a hydrophone suspended within a drogue at a depth of approximately five metres; a floatation system to keep the whole system afloat and aid recovery; and a water-tight electronics canister containing the recorder system, GPS, and required battery power supply (see Figure 6 below).

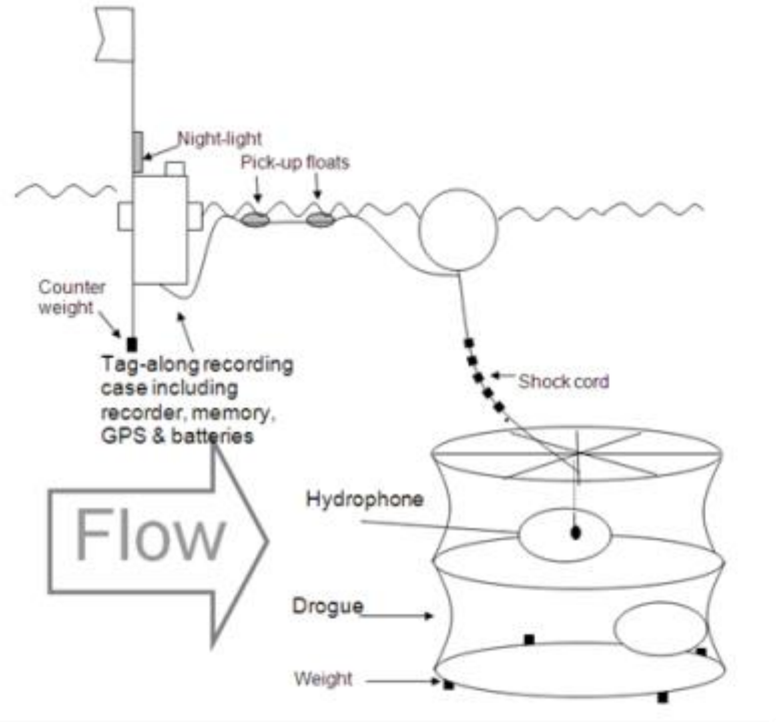

Figure 6: Schematic showing components of the EMEC DART system

The recorder unit used in the DART system is the Songmeter SM2+ from Wildlife Acoustics Inc., an off-the-shelf unit adapted to fit within the water-tight electronics canister. The DART system also incorporates a Garmin GPS16 GPS unit which allows the track of the drifting hydrophone to be recorded. The hydrophone used in the DART system is the Cetacean Research C55, an omnidirectional unit which connects to the recorder via a waterproof SubConn® 3-pin connector fitted to the top cap of the electronics canister. Both audio data and GPS data are recorded to the same SD memory card using Wildlife Acoustics Inc.'s proprietary .wac lossless compression file format.

Figure 7 below shows an assembled DART unit ready for deployment. The GPS unit can be seen on the top of the electronics canister, which is surrounded by a white flotation collar. The drogue is folded inside itself for ease of transportation. The red flag and strobe light help maintain visual contact with the unit when deployed.

Figure 7: Assembled DART unit

4.3.3 Methodology

As mentioned in section 4.3.1, there is a need for standard methodologies to be developed for collecting underwater acoustic data at marine renewable energy sites.

Fixed hydrophone systems

EMEC has undertaken work to develop a methodology for measuring underwater noise at its grid-connected wave energy test site at Billia Croo using a bespoke system utilising both autonomous seabed mounted hydrophones (SRD Ltd HS70 units) and cabled hydrophones (Reson 4014 & 4032 units) deployed from a vessel [13]. This methodology has also been used to gather initial underwater acoustic data relating to an operational wave energy converter device [73]. At the EMEC scale wave energy test site at Scapa Flow, baseline acoustic characterisation of the site has been carried out using the SM2M seabed mounted autonomous hydrophone/recorder system from Wildlife Acoustics Inc. [14] (see Figure 8 below).

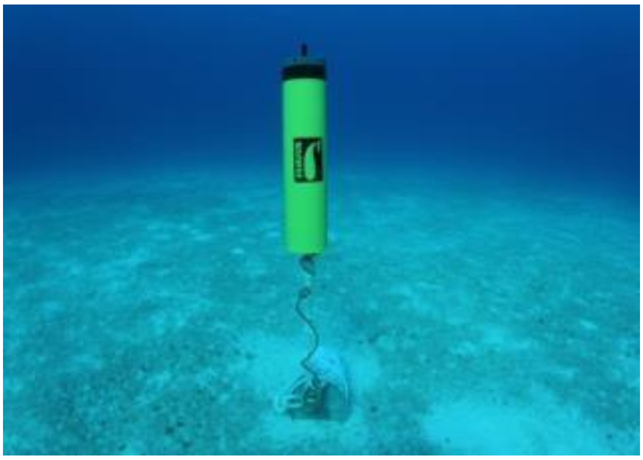

Figure 8: SM2M autonomous marine recorder (photo courtesy of Wildlife Acoustics Inc.)

Drifting hydrophone systems

Fixed hydrophone systems are suitable for collecting a long term data set however, as described above, in a tidal-stream environment they are susceptible to recording noise generated from the flow of the water past the hydrophone thus affecting the noise levels recorded. The Drifting Ears methodology developed by SAMS in 2008 [15] has been adopted for use with the EMEC DART system. This methodology can be used to collect underwater acoustic data from operating MECS as well as for baseline acoustic characterisation of sites.

Construction noise monitoring

Construction noise monitoring aims to characterise the noise of works associated with the installation of MECS. Measurements should be taken at increasing distances from the source to enable the back calculation of the sound source. Ideally this should be repeated at different angles from the works to understand any directivity and thereby enable the source level to be calculated.

Operational noise monitoring

Monitoring the operational device noise output from novel MECS deployed at test sites is key to understanding the potential input of sound into the marine environment. A robust and full characterisation of the sound emitted by operational devices is the first stage of addressing the concern about possible effects of such machine output on marine species. The assessment of the detectability, by sensitive marine species, of the sound emitted by a device within the already noisy environment is a second stage to this process. The work that is being described here relates to the data gathering process that seeks to accurately characterise the acoustic output of MECS within the typically high energy sites in which they are likely to be deployed.

As these MECS operate in the natural environment, a proportion of the recorded noise will be attributable to the background noise-field as well as the device, and so it is important to measure baseline background noise levels prior to undertaking operational noise measurements in order to characterise the receiving environment. This will allow comparison of noise recorded when the device is operating with recordings made when the device is not operating, to assist attribution of the device acoustic characteristics. It is important to consider all other sources of noise in the wider area, which may affect any acoustic measurements being taken.

Noise measurements of operational MECS at tidal sites should sample across the full range of operation, i.e. from slack water to full flow in both ebb and flood tidal regimes, as well in variable meteorological conditions.

Ancillary measurements required
Underwater noise levels are significantly affected by local conditions, therefore it is important that the following non-acoustic data is logged and presented for every survey:

- A log of survey activity
- A log of the weather conditions (including sea state, wind speed and direction, precipitation, tidal-flow speed) linked to the noise recordings
- An accurate position of all acoustic recordings and sound sources
- A log of all other activity on the site during the survey (including shipping/vessel movement in the area, operational status of other devices deployed at the site where known)
- Bathymetry and seafloor sediment type
- For device operational noise surveys, there should be a log of the device activity, including a range of parameters whose operational state may be expected to affect the noise output of the device being studied

4.3.4 Calibration

A robust description of both construction noise and operational noise would normally be considered to require absolute sound levels to be measured. It is therefore important that the entire measurement chain (i.e. hydrophone, pre-amp, and recording system) is calibrated. There are numerous methods and metrics available for the calibration of acoustic data, and at the time of writing there is no accepted standard available for calibration. Ideally, system calibrations should be traceable to standardised hydrophone calibration from an accredited source. All calibration details should be presented within any monitoring reports, with calibration factors applied to noise measurements and their analysis as appropriate.

Ideally, equipment should be calibrated before and after each survey deployment. This may not always be possible, and therefore the minimum requirement should be that the survey is carried out within a year of the system calibration, together with a calibration check using a piston-phone or alternative.

4.3.5 Analysis

There are various methods and metrics available for analysis of acoustic data, and at the time of writing there is no accepted standard available for analysis of underwater acoustic data at marine renewable energy sites. To be of any real value, reporting should include analysis of the variation of the sound recorded by frequency, flow speed, and bearing, and should attempt to attribute the dominant frequencies and levels from the source.

Broadband reporting
Broadband measurements illustrate the recorded sound energy over the full range of frequencies measured. For all metrics presented, the bandwidth (frequency range) and integration period of analysed samples should be clearly stated. As a minimum, the following metrics should be reported [74]:

- Unweighted sound pressure level (SPL) Root Mean Square for continuous sound (dB re 1 µPa)

- Unweighted sound exposure level (SEL) for transient sounds (dB re 1 µPa^2.s)
- Unweighted zero-peak sound pressure level (SPL_{0-p}) for transient sounds (dB re 1 µPa)

It is recommended that a 60 second window is used for analysing continuous sound in 'snapshot' surveys [12][15][17] and that 1 second integration is used for SEL analysis [15][75].

The source level (calculated for both construction and operational noise) is an apparent level, calculated by back-propagating measured received levels to a nominal distance 1 metre from source. There are numerous models that can be used to estimate back-propagation - from simple geometric spreading laws to much more sophisticated numerical models. It should be noted that simple spreading laws do not provide an accurate source level estimation for most marine renewables deployments, since they ignore the effect of the local environment on noise propagation. However, more complicated models require accurate environmental input data as well as greater technical resources [71]. Analysis should include details of the particular model chosen, and recognise any uncertainty involved.

Frequency spectral analysis
This technique decomposes the broadband sound file into its individual frequency components, which details any dominant frequencies found in the recording. This is necessary in order to characterise the noise-field (e.g. local vessel noise and acoustic deterrents at fish farms can be clearly seen in a frequency spectral profile).

Currently there are no standard methods for spectral analysis, although a number of reviews of best practice are soon to be published [71]. Commonly used metrics include spectral levels, third octave bands spectral levels, spectral density and long-term spectral averaging. All integration periods, frequency bandwidths, sample rates, bit rates, window function, overlap parameters, etc. should also be stated. Known sound sources should be identified within the recorded spectra, and dominant frequencies from the device being studied should be compared to baseline data in an attempt to attribute them.

Metrics for assessment of impact to specific species
As mentioned above, determining the extent to which acoustic output that has been characterised is detectable by marine fauna is a separate matter. How marine species respond to sound is poorly understood and is highly context driven. This is an evolving area of research and as such opinion is likely to change over time, but there are a number of metrics that have been used within various reporting mechanisms.

Southall *et al* (2007) published a comprehensive review of the effects of noise on marine mammals [76]. Within this they proposed noise exposure criteria for 'functional hearing groups'. They proposed a frequency weighting filter (M-weighting) that can be used to adjust the received level where the frequency falls outside the most sensitive range of hearing. This filter can be applied to SPL ($_{0-p}$) and SEL metrics for functional groups of marine mammals.

Nedwell *et al* (2007) proposed a metric $dB_{ht(species)}$ whereby a filter is applied to the recorded sound based on the audiogram of the species [77]. The $dB_{ht(species)}$ is a perception metric rather than a noise level, and can be used for marine mammals and fish provided there is an audiogram available.

At the time of writing, these are the two main metrics used in the analysis and reporting of underwater acoustic data. Southall's M-weighting is preferred by the acoustics and scientific community because it is based on a significant review of scientific studies. The $dB_{ht(species)}$ approach has not found extensive support outside the group that proposed it [78] but this metric has been used extensively by developers of marine renewable energy systems when reporting on underwater acoustic monitoring within EMPs.

4.3.6 Recommendations

There are various methods of collecting and presenting underwater acoustic data in relation to monitoring at marine renewable energy test sites. Further work is required in this area in order to deliver more detailed guidelines in the future, but in the interim it is recommended that all metrics presented within an underwater acoustic monitoring report should be clearly defined, and should include detail on the bandwidth, integration time, and species weighting used. A detailed explanation of any methods used should be provided to enable future comparison and repeatability.

At the time of writing, there is an urgent need for acoustic data from MECS operating at test sites to be collected and characterised in a robust, consistent and consequently usable manner. This will provide data to ground-truth the various very good models that combine estimated output from device components, to give estimates of overall acoustic output.

4.4 Use of Modelling Techniques

There are many opportunities for the development and application of mathematical modelling techniques to predict outcomes and inform studies to help address the environmental uncertainties surrounding OREDs. This section describes some examples of work using modelling techniques, although this is by no means an exhaustive list.

4.4.1 Optimising Array Form for Energy Extraction & Environmental Benefit (EBAO)

The EBAO project [42] will establish and evaluate a design feedback process which can protect and perhaps enhance the natural environment, while allowing energy extraction to be maximised. Engineers will work with project and device developers to establish appropriate development scenarios which will then be considered using state of the art modelling techniques to assess the levels of ecological impact across a range of key ecological parameters.

4.4.2 TeraWatt

TeraWatt [79] is a three year long project led by Herriot Watt University looking at developing computer based numerical models to simulate the effects of extracting energy using wave and tidal renewable energy devices. The models produced will offer decision makers specific, targeted predictions of the impact that individual OREDs may have and where they should be allowed to be sited. The project will use the Pentland Firth and the waters around Orkney to develop models which will help to predict the physical and ecological consequences of wave and tidal energy extraction.

4.4.3 Marine Wildlife Collision Modelling

SNH have developed a Collision Risk Model (CRM) which provides a means of estimating collision risks and hence the potential bird mortality which may be caused by wind farms [80]. This model is currently being developed for use in estimating collision risks between marine wildlife and MECS.

An Encounter Rate Model (ERM) was developed by SAMS in 2007 for the Scottish wave and tidal Strategic Environmental Assessment to help develop an understanding of rates of potential collisions between marine mammals and tidal turbines [81]. The concept has since been refined and applied to the consented Meygen Tidal Array project [82], and the Skerries Tidal Stream Array [83] and West Islay Tidal Energy Park [84] projects (under consideration).

The SAMS ERM is based on studies of predator-prey interaction rates, and considers a range of input parameters including, among others, the physical characteristics of the devices, the hydrodynamic properties of the site of interest and biological information on the occurrence and 3D swimming behaviour of the animals. When applied to tidal-turbines, the estimation of potential interaction rates provides an understanding of the scale of the issue and sensitivity to physical (eg device size/RPM) and behavioural parameters. The model continues to be refined as new information arises and its application is being considered alongside that of other related modelling techniques such as those used to predict the risk of bird collisions with wind farms (e.g. the SNH CRM described above).

It is important to remember that this modelling is intended to give an estimate of potential encounter rates should animals choose not to avoid (skirt around), evade (dodge) or even be attracted to turbines. It is thus bases to either entirely exclude the issue or, if deemed important, upon which further studies of actual behavioural responses can be added as positive or negative modifiers to understand real risks. It also provides a number with which to consider the statistical power of monitoring schemes.

4.4.4 Acoustic Modelling

Acoustic modelling for marine renewables is split into two specific types: far-field propagation models and near-field source models. Far-field describes the combined noise travelling away from the device after a set distance, whilst near-field describes the complex vibrations near the device and their interference patterns.

Most studies employ far-field measurements, i.e. set away from the device, which provide data for simpler far-field propagation models. As discussed earlier for source level models, very simple propagation models are not suited to marine renewable environments. More sophisticated models require seabed and other environmental parameters to be included or the ’calibration’ of an environment through the use of a known source, although there are currently no standard recommendations for use of models [71].

More recent studies have involved Finite Element Method (FEM) models to calculate component vibration, feasibly allowing calculation of noise levels in the near-field [85]. Such models still require validation through measurements of component vibration and near-field propagation; this would require further development in both technology and data analysis [71].

4.5 OTHER TECHNIQUES/APPLICATIONS

A variety of other novel monitoring techniques have been tried by developers testing marine renewable energy devices. Some of these techniques may not be effective when used in isolation, but may offer some value when partnered with one or more of the monitoring techniques described above.

4.5.1 Strain Gauges

Strain gauges can be built into the rotor blades of tidal turbines in order to detect stresses on the blades. Whilst these may be aimed primarily at detecting blade stress from the water column, there has been some interest in using strain gauges to detect blade stress that could possibly be due to contact with marine wildlife. These devices vary with body mass and while they may be effective for detecting collision with larger marine mammals, will not be as practicable for small marine mammals and diving birds. Other problems with using these gauges to detect marine wildlife collision result from their responding also to turbulence in the water column, and impact from inanimate objects in the water column, such as marine debris.

The amount of data produced by these monitoring systems makes analysis a highly cumbersome process, and it is likely that more efficient automated data analysis routines will be required before strain gauges can be used as a primary monitoring tool. There is, however, some potential for strain gauges to be used in combination with, for example, active sonar, hydrophones, or underwater video, to examine the stresses on turbine blades at specific points in time.

4.5.2 Visual Observation Techniques

Novel work using adapted wildlife observation and data collection methodologies is underway, notably at Strangford Lough and EMEC, where shore-based monitoring has been used to assess surface presence and distribution of seabird, marine mammal, and basking shark activity. Other researchers are looking at evolving survey methods for specific offshore marine energy developments [86] combining shore-based surveys with modified boat-based line transects and point counts.

It is recognised that assessing marine species' usage of particular areas of ocean is a challenging task. In contrast to offshore wind sites, marine renewables test sites are usually situated relatively close to shore, making land-based surface wildlife observations a cost-effective method for gathering long-term data. Such land-based visual observation programmes can inform the industry-wide concern of wildlife displacement by recording surface-visible birds, marine mammals and other wildlife that are present on site.

Observation methodologies include scanning defined areas, e.g. arcs (see Figure 9 below) or recording to defined grid-squares. Where grid-based recording is used, simultaneous boat and land-based validation surveys can be useful for validating positions of grid lines in the field. Watching defined areas such as are described by grid cells, for fixed amounts of time can be beneficial in allowing a well-defined, straightforward quantification of effort during analysis.

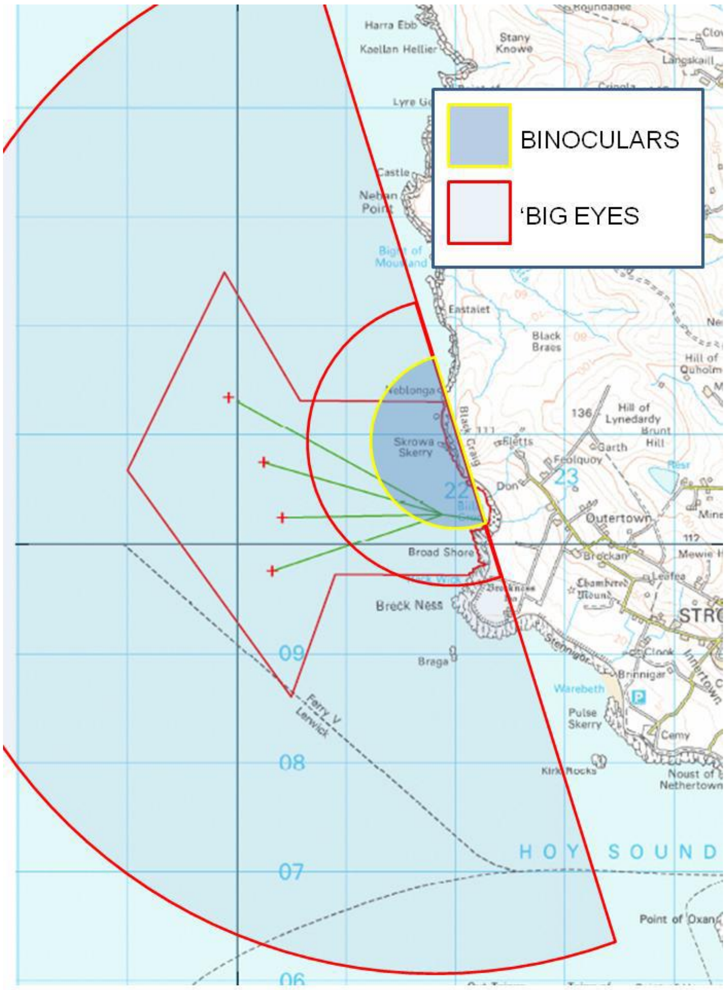

Figure 9: An example of an arc-scanning methodology observation area (EMEC Billia Croo wildlife observations programme)

In some circumstances, multiple vantage points may be used to survey an area where one vantage point does not offer enough spatial coverage to observe the area of interest. Such techniques are advantageous in reducing concerns about detectability, in cases where multiple observers observe overlapping areas at the same time ('detectability' refers to how accurate detection varies across the observations area). Boat-based, strip-transect surveys are commonly employed in offshore situations such as for offshore wind projects, where the underlying distribution of animals with respect to the boat can be assumed to be random. However in near-shore surveys, animal distribution cannot be assumed to be random due to inherent differences in microhabitats, which would be expected to affect species distribution across the survey area. Therefore, issues associated with variable detectability across the survey area must be accounted for in near-shore surveys.

To obtain a detection function for the survey area, a 'true' picture of the animal distribution must be measured, across a range of environmental conditions. This can be done by using aerial photographic surveys, or boat-based strip transect surveys with a restricted transect width (where perfect observation can be assumed) running perpendicular to the vantage point.

Raw or partially processed wildlife observation data can be used by developers to inform EIAs as necessary, and data from such observation programmes can be valuable in supporting other research projects.

4.5.3 Infra-red Cameras

Land-based infra-red cameras could potentially be used to detect marine mammals and diving birds, and their behaviour in the vicinity of OREDs. A key benefit of such a monitoring system would be increased hours of possible detection due to the scope for night-time detection. A study undertaken at Admiralty Inlet showed that observation time increases by 74% for infrared-based systems versus visual detection [87]. Infra-red cameras may also simplify the implementation of automated detection, by detecting temperature gradients instead of motion.

Whilst infra-red cameras may also be of some use as a tool to monitor underwater interactions between marine fauna and MECS, their usefulness in this respect is limited due to the high degree of attenuation of infra-red in water.

4.5.4 Tagging

Tagging techniques can be used to gather data to describe the abundance and distribution of marine mammals and diving birds to inform site specific and cumulative assessments of the likely nature and extent of potential impacts from OREDs. The Sea Mammal Research Unit (SMRU) has used such techniques to present an analysis of existing satellite telemetry and aerial survey data, in order to describe the abundance and distribution of harbour and grey seals in the Firth of Forth and Firth of Tay in Scotland. This work was undertaken in order to inform site specific and cumulative assessments of the likely nature and extent of potential impacts from the development of offshore wind farms in the region [88].

4.5.5 Emerging Integrated Monitoring Platforms

Environments which host OREDs present opportunities for new and novel development in integrated environmental monitoring equipment. Examples of this include the FLOWBEC monitoring pod [66], the EMEC Integrated Environmental Monitoring Pod, and surface monitoring platforms such as the WavEC Monitoring Buoy [89]. Further details of the FLOWBEC monitoring pod and EMEC Integrated Environmental Monitoring pod are provided in Appendix 1 of this document.

The Wave Energy Centre in Portugal (WavEC) Offshore Test Station (KIC-OTS) is a technology market driven project which has been created in the framework of KIC-Innoenergy, a company funded by the European Institute of Technology (EIT). This project has developed a system for environmental monitoring of disturbances and their impact on marine life, designed to meet environmental, operational and navigational needs in one unit (see Figure 10 below). This aims to lower risk and enable live decision-making via real time monitoring using UHF and GSM communication technologies. Instrumentation including ADCP, turbidity sensors, water quality sensors, a weather station and hydrophones will inform environmental and operational needs, whilst the buoy will be fitted with navigational aids.

Figure 10: WavEC monitoring buoy

5 RECOMMENDATIONS

Any new sector is bound to have associated risks that need to be assessed in order for society to formulate an informed opinion on the costs and benefits of its further development to full commercial reality. The clean energy drivers for the development of sustainable low carbon energy give increasingly strong incentives for the development of successful commercial scale energy from OREDs. There is a range of potential risks that apply across this developing sector, from health and safety, navigational safety, environmental, and commercial interests due to conflicting use of the same resource.

Some of these sectorial risks lend themselves to objective assessment, but for many of the uncertain risk areas the extent of the real risk is unknown. Efforts to gather data to inform on the extent of these risks have been hindered by the lack of relevant equipment for gathering the necessary data to increase our understanding. The area that is perhaps most difficult to address objectively is the potential risks to the receiving environment that operational MECS may present.

There is thus a real need for more robust methods and equipment to be developed for gathering data to inform on a range of uncertainties, especially (but not solely) those uncertainties that are key to the regulatory,and hence societal, concerns. There is also a need for collaboration, both between developers testing at a particular test site, and between different test sites. Efforts need to be made to ensure that consistency is encouraged where appropriate, in parallel with continued striving for innovative technology development. At the same time we should be maximising collaboration between different information gatherers concerned about the same issue, in order to share as much of the learning as possible from an early-stage.

The regulatory body in Scotland has worked closely with its primary statutory environmental consultee to introduce a system that enables the deployment of prototype devices, even though there is no objective data available from which to accurately assess the various uncertainties and therefore the risks. The 'survey, deploy and monitor' policy has been of key importance to the testing of these early-stage devices in the open sea environment, most of which have been deployed at the EMEC test sites. This means that it is crucially important for regulators, developers and policy makers to learn from the early stage monitoring that has been undertaken.

Monitoring at test sites is a key enabler to the establishment of OREDs as a clean and benign energy industry. As this report has discussed, there is a range of approaches to gathering the necessary data to inform on the key uncertainty issues for which data is urgently needed. This variability has both positive and negative consequences. On the positive side, the development of a variety of methods for data collection and analysis encourages innovation and therefore increases the likelihood of appropriate robust methodologies being developed. On the negative side, having a range of early-stage developers using a variety of methodologies in pursuit of the same questions reduces the opportunities for regulators to take a large-scale collective view of the learning from all the different deployments, due to the lack of consistency. This reduces the opportunity for making comparisons between different types of devices, should there be a wish to do this.

In order to address the challenges identified above, the following recommendations should be considered.

5.1 Development of Specific Tools and Techniques

Specific tools and techniques need to be developed for the environmental monitoring of MECS. Development of the different sensors, tools and techniques required must be prioritised against the main areas of concern identified in Section 2.1.1 (primarily collision risk, impact of noise, and displacement of marine wildlife).

The equipment must be validated for use in the challenging high energy marine environments that are typical of future deployment sites for OREDs, and appropriate platforms need to be developed to deploy, mount and retrieve equipment for rigorous testing in these resources. Since it is unlikely that any single data source will be sufficient to address the key areas of concerns, integrated data collection programmes should be developed where multiple measurement systems can be used to monitor complex issues.

5.2 Coordinated Approach to and funding for Environmental Monitoring

European test centres should adopt a coordinated approach towards environmental monitoring of MECS, with increased opportunities made available for data gathering at test centres during this crucial early stage of the sector development. For maximum efficiency, there needs to be an initiative aimed at the development of a platform for sharing knowledge and undertaking collaborative projects. This would create the opportunity to share information about innovative procedures and equipment being developed locally, that may lead to improved guidelines, protocols and, eventually, standards. However, if such a platform is developed as a dedicated project, it is important to recognise the need for it to be regularly updated and maintained over the long term, beyond the end of any short-term funded initiative that may see it developed.

This approach was discussed at the Global Test Centre Symposium hosted by EMEC in October 2013, with the majority of delegates showing a high interest in progressing the development of such a platform.

5.3 Shared Access to Findings

The findings from environmental monitoring of MECS at different sites will be of most value if they are viewed from a collective perspective, with the pertinent findings summarised in a common location. This would form a reference repository, available for existing and emerging test centres to utilise, but would also be accessible to developers looking for project-specific guidance.

The findings from these early-stage monitoring programmes would be well suited to being used in endeavours to establish acceptability thresholds for potential environmental interactions, which would directly inform site wide and developer-specific environmental monitoring plans.

Developing such a coordinated approach would require a dedicated body charged with assessing the findings of different monitoring campaigns as they are reported, and making recommendations for further studies or actions to be developed into strategy and policy.

5.4 Common Approach to Licensing

Through coordinated action from test centres across Europe, the appetite amongst national regulators to develop a common approach to the licensing of prototype MECS and sharing of information gleaned from the assessment of the early-stage environmental monitoring of OREDs should be investigated.

6 CONCLUSIONS

Sections 1-4 of this document explain the context of some of the regulatory and wider societal concerns about the potential for wave and tidal steam energy extraction devices to affect, or even impact on, the environment. We must remember that such effects or impacts may be positive, but where there is potential for negative effect, most of these concerns tend to be about the sensitive faunal species that habitually use the sea areas that provide a good resource for energy capture. Such sea areas are likely to be targeted for establishment of OREDs at a commercial scale.

For some of the areas of concern (such as the potential for benthic change) there are good monitoring methods available at the time of writing. However, using environmental monitoring as a means of informing the extent of environmental risk associated with the installation and operation of MECS is a complex and long-term approach – but is the method most likely to provide the information necessary for accurate risk assessment.

One key hindrance to this data gathering is the fact that there are some issues for which monitoring may be required, for which there are no effective available methods for gathering the necessary data. It is for these cases that guidance on the best methods available, or new monitoring techniques or equipment may be needed.

This document has indicated the approaches being taken at the test sites and beyond, to gather data to inform on these main issues of regulatory concern that pertain to the range of test sites in Europe. We have seen that test centres and other deployment sites use a variety of techniques and have provided case studies for a tidal test site and a wave test site, showing the range of monitoring undertaken at these sites.

The different test sites employ a range of techniques for data gathering and analysis. One point that has been noted is the importance of reaching a balance between developing innovative new techniques and using agreed ‘standard’ methodologies. On the one hand, innovation should not be stifled, since new techniques may provide much higher quality data. On the other hand, when regulators and policy makers are trying to make best use of the data gathered, and reach conclusions about the extent of a potential environmental risk, then it can be more beneficial to assess data from different deployments gathered by an agreed range of consistent methodologies.

At the time of writing, the monitoring practices of different device developers vary. This means that general findings can be more difficult to reach. The benefits of collaboration between test centres on the one hand and encouragement – from regulators and others – of the use of robust methodologies, have been specified. The importance of consistency (where appropriate and possible) has also been highlighted.

As the marine renewable energy sector moves forward into commercial scale deployments, it is hoped that the information presented in this document will be useful to a wide range of developers and regulators. The purpose is aimed not only as a record of the existing range of methodologies, protocols and guidelines used at different test sites, but also as a reminder of the benefits of using robust and possibly consistent methods across different sites and projects, wherever these are appropriate. This will provide regulators with a degree of comparability that can ease the assessment of the extent of the potential environmental impacts to a generic degree, and thereby serve as an aid to the development of the marine renewable energy industry in general.

It is also important to remember the importance of continuing to develop innovative methods and data gathering equipment aimed at gathering more informative data. There needs to be more provision for data gathering at test centres, in order to boost the sector as a whole. Improved data analysis techniques also need to develop hand-in-hand with the improved data gathering equipment and increased acquisition of data from the early stage deployments. Until best practice methods are agreed, innovation needs to continue in parallel with the use of existing techniques applied in a consistent manner where appropriate at the early stage deployments. Ensuring that findings from all the early-stage monitoring and learning are disseminated and appropriately reviewed will ensure that findings are taken into account by regulators, thus further enabling and easing the transition to fully commercial reality.

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APPENDIX 1: TIDAL CASE STUDY – EMEC

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Disclaimer
The views expressed, and responsibility for the content of this case study, lie solely with the authors. The European Commission and/or EMEC are not liable for any use that may be made of the information contained herein.

1 OVERVIEW OF THE EMEC TIDAL ENERGY TEST SITE

The EMEC grid-connected tidal energy test site is located at the Fall of Warness, just west of the island of Eday in the Orkney Islands. The site sits in a narrow channel between the Westray Firth and Stronsay Firth where tidal flow quickens as water flows from the North Atlantic Ocean to the North Sea. The site was chosen for its high velocity marine currents which can reach almost 4m/sec (7.8 knots) at spring tides. The location of the test site is indicated by the red box in Figure 1 below.

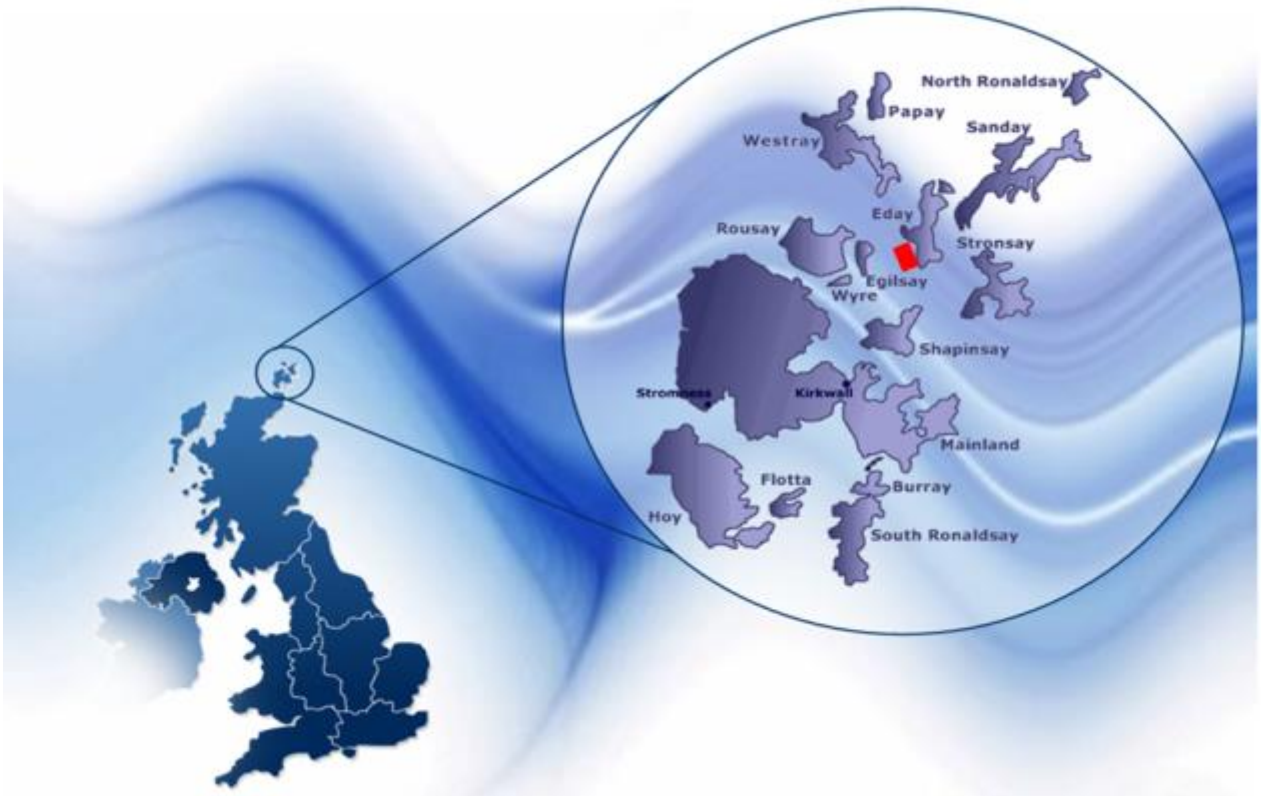

Figure 1: Location of the EMEC tidal energy converter test site (red box)

The site provides eight tidal test berths at depths ranging from 12m to 50m in an area 2km across and approximately 4km in length (see Figure 2 below). The 11kv sub-sea cables extend to the middle of the tidal stream from an electricity substation on the island of Eday which houses the main switchgear, backup generator and communications room. The substation controls the supply from each tidal device and provides connection to the National Grid. An adjacent laydown area provides developers with conditioning equipment required to convert electricity from the level at which it is generated to grid compliant electricity. In addition to transporting electricity, the cables also contain a fibre-optic core which allows developers to communicate with their devices and transmit monitoring data back to the EMEC data centre and office facilities. The Fall of Warness tidal test site can be used by developers to test prototype or full-scale devices.

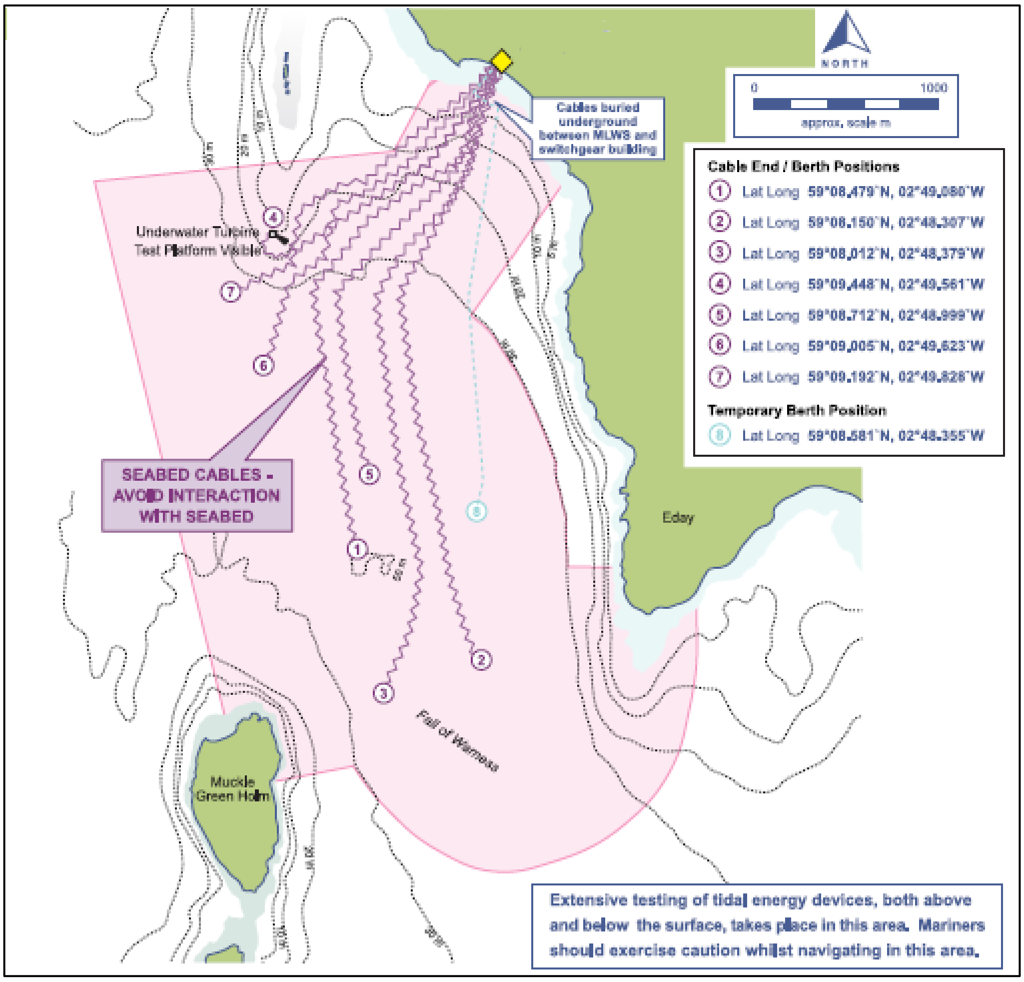

Figure 2: EMEC tidal test site infrastructure

2 REGULATORY CONTEXT

When the EMEC tidal test site was established, there was much discussion concerning the potential for generic site licences and consents, which would then apply to all devices being deployed at the test site. Whilst EMEC is still working closely with the Regulator (Marine Scotland) to progress in this direction, at the time EMEC was set up it was not deemed possible to grant such generic consents. This was due to two main areas of consideration: firstly, some projects would likely require a full Environmental Impact Assessment (EIA) whilst others would not; secondly, EU legislation governing the protection of certain species requires detailed and specific assessments to be carried out by the Regulator and these assessments would be project-specific.

In Scotland, the administration of much of the legislation governing regulation of the electricity and marine renewables sectors has been devolved to the Scottish Government. The following legislation is applicable to new marine energy developments:

- Electricity Act (1989) and related Acts and Orders
- Marine (Scotland) Act (2010)
- Energy Act (2004)

The primary UK legislation governing the Electricity sector is the Electricity Act (1989) and related Acts and Orders. Section 36 of the Electricity Act 1989 requires that consent from the relevant Secretary of State is obtained for the construction, extension or operation of an offshore renewables electricity generating station in the territorial sea of a capacity above 1MW. Projects falling under the remit of this legislation require a full EIA to be carried out in order to assess and report on all potential risks, and reduce high risks to a minimum by planning specific risk-reduction mitigation measures. Developments with a capacity of 1MW or under are exempt, and do not necessarily require formal EIA.

Secondary legislation under the Marine (Scotland) Act (2010) introduced the Marine Licence, which is administered by Marine Scotland and ensures the enactment of all relevant EU legislative requirements, as well as other relevant national legislation. This Act also introduced additional protection for certain 'at risk' species (e.g., seals).

The Energy Act (2004) is the only piece of relevant legislation which applies to marine renewables that has not been devolved by the UK Government to the Scottish Government. The only aspect of marine renewables which falls directly under the Energy Act 2004 is decommissioning, as other aspects of licensing have been devolved. There are close links between Marine Scotland and the UK Department of Energy and Climate Change (DECC) which are leading to closer integration of decommissioning activities within the streamlined consenting process in Scotland.

Projects not requiring EIA

The consequence of the Section 36 exemption described above for developers at EMEC is that for projects seeking to deploy 1MW maximum nominal rated devices, there is no formal requirement for EIA. However, there is still a requirement for all projects to be fully licensed under the Marine (Scotland) Act (2010), regardless of whether or not a full EIA is required. For all projects it is the responsibility of each developer to apply for and obtain a Marine Licence from the Regulator, and to produce appropriate supporting documentation to accompany their application (see below).

EU protected species

When applying for a Marine Licence, developers are made aware that under EC Directive 92/43/EEC (the Habitats directive) and EC Directive 79/409/EEC (the Birds directive) a Habitats Regulations Assessment (HRA) may be required, even when a formal EIA is not. Whilst the HRA is carried out by the Regulator, it is the applicant's responsibility to make available all necessary data to enable this to be done, and this may require additional surveys and data collection.

Supporting documentation

EMEC assists developers with all aspects of applying for and gaining the necessary consents required to deploy at its test sites. As well as working closely with developers in facilitating and guiding them through the consenting process, EMEC also provides much of the background documentation and data required by developers in the production of their device-specific supporting documentation.

An Environmental Appraisal for the Fall of Warness tidal test site has been undertaken by Scottish Natural Heritage (SNH) to assist both EMEC and Marine Scotland in streamlining the assessment process required to inform the Marine Licence application process. This Environmental Appraisal will pre-appraise potential deployments within the context of the wider tidal test site using a “project envelope” description. This project envelope describes the types and characteristics of marine energy convertor systems (MECS) likely to be deployed for testing at the Fall of Warness test site. It also describes the types of marine operations and activities likely to be associated with the installation, operation and maintenance of these devices.

The Environmental Appraisal document does not remove the requirement for each developer to apply for an individual Marine Licence, rather it is provided to help inform the assessment process. Consequently, most potential impacts from the installation, operation and maintenance of tidal turbine devices at the test site have been appraised and conclusions reached, provided the proposal fits within the project envelope description. The Environmental Appraisal document contains comprehensive receptor appraisals that satisfy the requirements of legislation relating to designated sites and protected species. Some potential effect pathways may require project-specific appraisal, depending on their relevance to the proposal, and therefore developers must ensure that they are familiar with this documentation. The appraisal process has also identified mitigation and or monitoring requirements and suggestions, to be used in the formation of a Project Environmental Monitoring Programme (PEMP).

It is the initial responsibility of the developer to ensure that their proposal fits within the project envelope description. If this is confirmed by EMEC and the Regulator, then the potential impacts of the proposal will be considered to be pre-appraised.

The documentation that must accompany all licence applications includes the following device-specific reports:

- Project Description
- Device-specific Project Environmental Monitoring Programme (PEMP)
- Device-specific Navigational Risk Assessment (NRA)
- Third Party Verification report/certificate (TPV)

The PEMP is developed with and agreed by the Regulator and its appropriate statutory consultees. The PEMP and NRA reports must include an assessment of the device-specific risks associated with the proposed project, and must include proposed measures that the developer will put in place to mitigate risks that cannot be reduced by design and/or process factors. The full set of reports is then assessed by the Regulator and their consultees during the licensing application process.

3 SITE CHARACTERISATION & KEY SENSITIVITIES

An Environmental Statement (ES) for the Fall of Warness test site was produced in June 2005. The aim of the ES and its supporting studies was to identify the environmental receptors that might be sensitive to the construction and installation of the proposed test site infrastructure, and to suggest management controls and mitigation measures to reduce any impacts to a tolerable level. Where this was not possible further study areas were identified. Various preliminary studies were carried out to inform the ES, including terrestrial habitat and vegetation survey, coastal habitats survey, coastal and seabed processes review, seabed surveys, assessment of birds, cetaceans, sea mammals & coastal wildlife, and assessment of otter populations. Archaeological, visual & landscape, and navigational risk assessments were also undertaken. From the outset the importance of selecting knowledgeable local experts and reputable specialist organisations to undertake these studies was recognized, as the outputs would provide the foundation for information on which recommendations for subsequent monitoring would be based. The primary recommendation for further study which arose from the Regulator's consideration of the ES was for a land-based visual surface wildlife observations programme to be undertaken. This programme commenced in July 2005.

SNH identified key site sensitivities to aid developers in addressing potential interactions between MECS and species found within the receiving environment. The main sensitivities identified at the test site are harbour seals, which haul out and pup on rocks to the north of the site, European Protected Species such as cetaceans and otters, basking sharks, and diving birds.

As described in Section 0 above, an upgrade to the EMEC environmental documentation was undertaken by SNH in 2012-13 which resulted in developing a suite of species-specific Environmental Appraisals to facilitate the consenting process by informing licence applications for the deployment of tidal devices for testing at the Fall of Warness test site.

4 DRIVERS FOR ENVIRONMENTAL MONITORING

4.1 LEGISLATIVE AND POLICY DRIVERS

The UK Government has binding EU renewable energy targets following the Kyoto Protocol for obtaining 20% of electricity from renewable sources by 2020. By 2020 the Scottish Government aims to supply 100% of Scotland's electricity demand from renewable energy sources. This represents more than a third of the UK's renewables output from Scotland. By 2050 the Scottish Government aims to reduce "greenhouse gas" emissions by 80%. These ambitious targets have led to strong political support for deployment and testing of MECS, resulting in high levels of activity at the EMEC test sites.

The Scottish Government has developed a risk-based approach to deployment of MECS, known as the Survey, deploy and monitor policy[2]. This policy distinguishes between those proposed developments for which there are sufficient grounds to seek determination on a consent application based on a minimum of 1 year of wildlife survey effort and analysis to develop site characterisation pre-application, and those where a greater level of site characterisation is required.

The policy is based on the following three main factors:

- Environmental Sensitivity of the proposed development location
- Scale of development
- Device (or technology) classification

This allows deployment of MECS which are appropriately monitored for the scale of deployment and sensitivities of deployment location. As knowledge is gained about any effects of MECS on the marine environment at the Fall of Warness test site, the Regulator's confidence is increased and any environmental monitoring practices which are no longer deemed necessary can be stopped (e.g. the requirement to undertake benthic ROV surveys was removed in 2012 when sufficient information had been gathered to characterize the benthos at the Fall of Warness site, demonstrating that the impact risk from installation of MECS at the site was sufficiently low).

4.2 REGULATORY DRIVERS

Since 2003, EMEC has been proactively involved in detailed discussions with a number of regulatory bodies in order both to clarify and streamline the consenting process, and to gain wide agreement from the relevant experts on the issues that are of primary concern to regulators. Through this detailed involvement EMEC has in-depth knowledge of the shortcomings of the issues, the approaches being taken to address them, and the technical limitations of much of the data collection techniques and equipment used.

In early communications between EMEC, regulators, and environmental stakeholder groups (particularly SNH), there was an emphasis on the unrepeatable opportunity for early research and monitoring associated with the marine renewable industry. It was recognised early on that if the responsibility for device monitoring were to lie with individual developers and/or their environmental consultants, then there would be a high risk that a suite of inconsistent approaches would be adopted, which would not necessarily employ the best available methods, and that a piecemeal approach to environmental monitoring would become the norm.

The EMEC Monitoring Advisory Group (MAG) was established as a vehicle to formally extend and coordinate the on-going monitoring discussions with regulators and their consultees. Advisors are asked to contribute on specific methods in relation to the devices deployed at EMEC, including both device-specific and generic issues, and taking

[2] http://www.scotland.gov.uk/Topics/marine/Licensing/marine/Applications/SDM

full account of the scale of deployment at the test sites. The MAG also provides an on-going feedback mechanism for monitoring processes being put in place.

Membership of the MAG includes representatives from EMEC, Marine Scotland (Science), Marine Scotland (Licensing Operations Team), SNH, Sea Mammal Research Unit, Scottish Government, and DECC.

The key objectives of the MAG are to:

- Translate policy requirements into practical monitoring effort to ensure that the EMEC facility is optimised to meet existing and future monitoring and assessment needs for wave and tidal energy converters.
- Oversee the production of relevant monitoring tools and best practice techniques at the EMEC test sites whilst ensuring monitoring effort and methods of data stewardship are compatible with relevant methodologies.
- Exchange knowledge and information relating to similar initiatives so as to avoid duplication and establish links with other relevant research programmes at national and international level.
- Maintain an overview of emerging research and technology and identify new requirements.
- Identify sources of funding available for research and supporting studies.
- Undertake an annual assessment of the strategy and goals for monitoring undertaken at the EMEC test sites.
- Undertake systematic review and QA of project specific Impact Monitoring reports submitted by developers at EMEC to the Regulator, and assess the wider implications and relevance of the methods pursued and results obtained to the Marine Renewables sector in Scotland.

Although outputs from monitoring projects will initially serve developers who deploy at EMEC, in the longer term they are expected to serve as an essential resource for both developers and regulators in the licensing of future installations as these industries develop into commercial stages.

4.3 Industry Drivers

EMEC has close links with developers of marine renewable energy devices, academic institutions, and regulatory bodies, whilst maintaining independence from any one party. This places EMEC in a unique and crucial position to drive the development of environmental monitoring within regulatory and industry R&D frameworks by fostering partnerships to establish and encourage best practice monitoring methods as devices are deployed at its test sites. EMEC is also able to present information that may be commercially sensitive in an anonymous context, thus increasing the likelihood of developers being willing to share their device-specific monitoring data in a collective yet anonymised fashion, if necessary.

To this end, EMEC has established a successful Developers Research Forum (DRF), which is a platform for developers at EMEC to share experiences, combine voices and provide opportunities for collaboration. This forum aims to make best use of the EMEC test facilities by coordinating a joint approach to industry-related research and monitoring needs, and encourages knowledge transfer with the MAG (see Section 4.2 above).

The DRF provides a unique vehicle in which the majority of the UK developers who have full scale devices deployed at EMEC can share opportunities and challenges in relation to research involving their devices. The key objectives of the DRF are to:

- Understand and map regulatory requirements and identify those which can be addressed through collaborative working/research
- De-risk development activities through research and monitoring targeted towards addressing both regulatory and technical issues
- Guide research and encourage developers to work collaboratively, sharing research findings to support monitoring requirements and reduce post-construction monitoring for future projects
- Simplify the consenting process

Membership of the DRF is open to developers contractually signed to test at EMEC. The group is covered under a multi-party confidentiality agreement and as such commercially sensitive information can only be made available as agreed by the members. EMEC coordinates and chairs the group, runs four workshops per year and undertakes a variety of dissemination activities.

This partnership approach recognises the importance of developing industry standard methodologies to enable robust and comparable datasets to be gathered. It also recognises the benefits of using consistent monitoring methodologies and equipment to monitor devices under test.

5 STRATEGY FOR ENVIRONMENTAL MONITORING

The principal objective of site-wide environmental monitoring at EMEC is to provide a targeted benefit to developers through provision of supporting data, thus reducing the monitoring obligations placed on them individually. The results of site-wide environmental monitoring enables the Regulator and its statutory advisors to gain a more comprehensive understanding of the environmental sensitivities of the sites, which can then be used to inform recommendations for monitoring as part of developers' device-specific PEMP. Site-wide environmental monitoring also provides valuable outputs at a site level, which can aid the Regulator in informing any decisions regarding other commercial scale projects. EMEC has been guided in its strategy for site-wide environmental monitoring by its MAG (see Section 4.2 above).

A key aspect of the environmental monitoring strategy at EMEC is the developers' PEMP. This document is produced by each developer wishing to install at the test sites, and highlights the device-specific environmental concerns associated with the proposed project, together with the developers' commitment to monitor for any effects of these concerns. The PEMP is agreed in consultation with the Regulator and its statutory consultees, and must be signed-off by the Regulator prior to installation of any MECS at EMEC.

The range of environmental issues which require to be considered in the PEMP are similar to those described in Marine Scotland's Marine Renewable Licensing Manual[3] and include:

- Physical Environment:
    - Water quality and seabed contamination
    - Coastal/marine processes and geology

- Biological Environment:
    - Benthic ecology (including non-native species)
    - Fish, migratory fish and shellfish (including non-native species)
    - Birds
    - Marine mammals
    - Underwater noise, vibration and electro-magnetic fields

- Human Environment:
    - Archaeology and cultural heritage
    - Navigation
    - Commercial fisheries, shellfisheries and aquaculture
    - Other sea users (eg oil and gas, subsea pipelines, tourism & and recreation, military activity)
    - Landscape/seascape and visual impact
    - Socio-economics
    - Aviation

While the wide range of receptors listed above would normally require to be considered as part of a full EIA, there is a reduced requirement on developers planning to deploy MECS at EMEC, for the following reasons:

- Some issues of potential concern have been addressed from a generic perspective at the time EMEC was established, and again as part of the recent environmental appraisal, and therefore do not require to be addressed more specifically by individual developers

- Most developers deploying at EMEC install devices with a maximum generation capacity of 1MW.This means that they are not required to undertake full EIAs for their device-specific Marine Licence applications

[3] http://www.scotland.gov.uk/Topics/marine/Licensing/marine/LicensingManual

- The Scottish Government's 'Survey, Deploy and Monitor' approach to licensing of test devices puts in place a formal adaptive management process for all deployments, based on interactive on-going management of developers' PEMPs and close on-going interaction with the Regulator and/or its advisors.

6 PROJECTS UNDERWAY

As mentioned in Section 4.2, EMEC works closely with its MAG to identify knowledge gaps that are important to the Regulator and its advisors when assessing licence applications. This has led to the funding of a number of environmental monitoring projects at EMEC, the purpose being to develop appropriate methodologies, and use these methodologies to collect data on a site-wide basis. The advantage of this approach is that data collection is carried out in a consistent manner, which enhances comparability and facilitates a consistent methodology to the assessment of data in on-going adaptive management of environmental monitoring. It also offers a cost-time advantage to developers deploying at the site, as any need for baseline surveys has already been met through site-wide monitoring. The monitoring projects underway at EMEC are described in the following sections.

6.1 INTEGRATED ENVIRONMENTAL MONITORING PROJECT

The Integrated Environmental Monitoring project aims to address the key environmental issues that are potential blockers to the development of the marine renewable energy industry. The initial phase of this project was funded by the Energy Technologies Institute (ETI) as part of the ReDAPT project[4]. This project is led by EMEC and consists of the following data collection work-streams:

- Active Acoustic - utilising a custom-made sonar system
- Passive Acoustic - using both drifting hydrophones and fixed hydrophones
- Benthic Survey - assessment of benthos in and around an operating tidal generator based on comparison of pre-and post-device installation ROV data surveys; sampling of test and control areas.
- Physical Environment - real-time long-term measurement of wave and tidal resource and conductivity, temperature, depth, and turbidity (CTD/Tu) of sea water; surface wave and current data gathered using marine X-band radar to build a spatial map of variation in wave and tidal resource at the test site.

Figure 3 below illustrates the various data collection methods available to the project.

[4] http://www.eti.co.uk/technology_programmes/marine

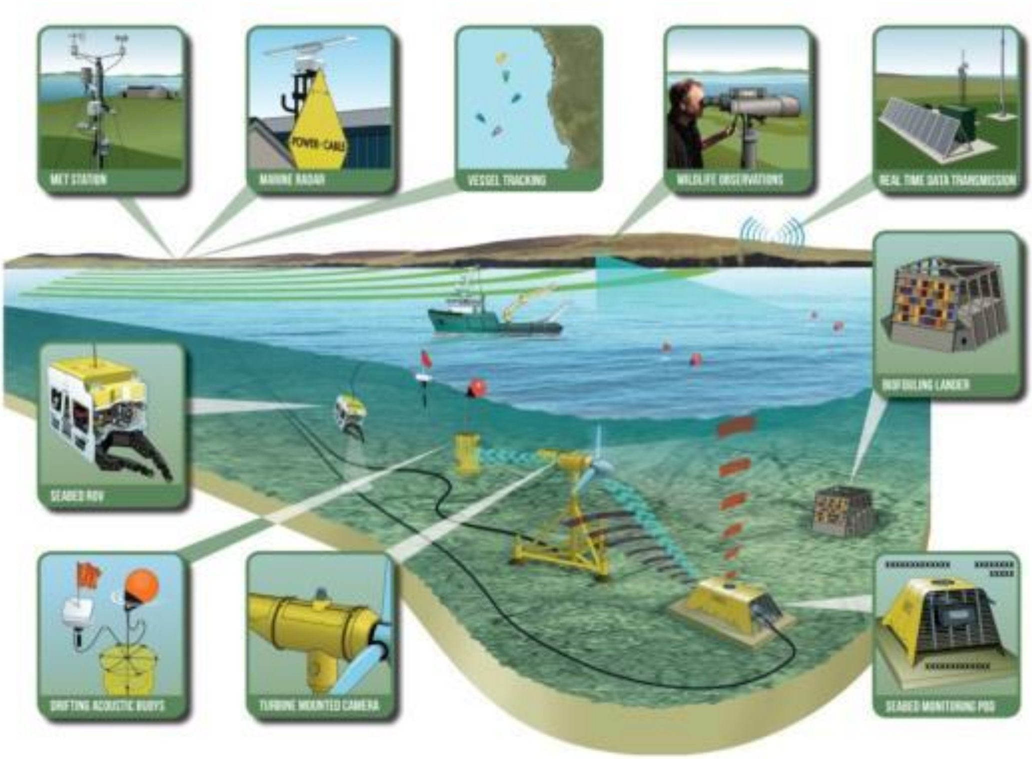

Figure 3: Data collection methods used in the Integrated Environmental Monitoring project

A key part of the project involved the installation of a seabed mounted environmental monitoring pod (see Figure 4 below) close to an operating tidal turbine. The monitoring pod is cabled to shore and includes equipment for the real-time measurement of currents, underwater noise, temperature, salinity, and turbidity. The pod also houses a bespoke active sonar system, capable of transmitting images in real-time, and is linked to output from a video camera mounted on the tidal turbine.

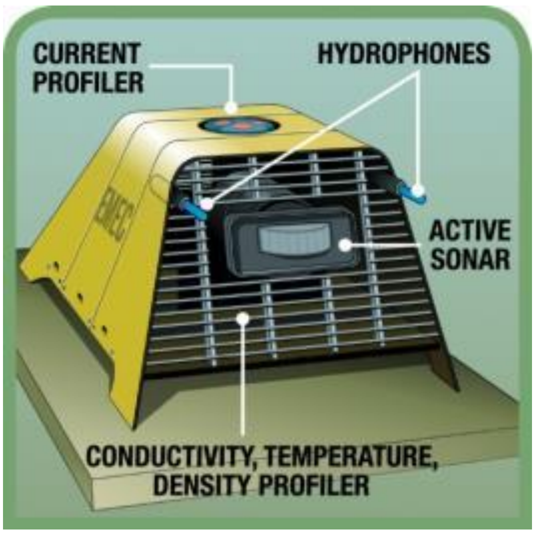

Figure 4: Graphic depicting the EMEC environmental monitoring pod

The integrated monitoring pod will be used to undertake monitoring of marine mammals and diving birds in the close vicinity of the operating tidal turbine in order to assess the close-range behaviour and the risk of harm to marine species due to potential collision (this is still the highest priority issue of concern to the Regulator in Scotland during the licensing of marine devices).

After six months of operation, the pod was removed from the test site for maintenance. This activity took the system beyond the already constrained period of the ReDAPT project. EMEC is now the owner of the pod and related monitoring equipment and is actively seeking alternative funding to take this innovative project forward.

6.2 Land-based Surface Wildlife Observation Programme

The potential displacement of key wildlife species such as marine mammals and marine birds from their normal range of habitats is a key factor which needs to be addressed by developers and regulators alike in order for the marine renewable energy industry to progress. It is recognised that assessing marine species' usage of particular areas of ocean is an extremely challenging task.

The land-based surface wildlife observation project is part of a Scottish Government funded wildlife monitoring programme which has formed the keystone of EMEC's site-wide environmental monitoring strategy since the Fall of Warness test site was commissioned in 2005. The objective of the programme is to inform the industry-wide concern of wildlife displacement by recording surface-visible birds, marine mammals and other wildlife that are present on site.

The methodology involves fully trained observers stationed on Eday carrying out observations through regular scanning of the test site using an Opticron GS815 20-60x magnification spotting scope for four-hour long periods from an elevated vantage point at the south of the island. Wildlife sighted is identified to species level, along with its location on an imposed grid. Figure 5 below shows the Fall of Warness observation area with respect to the EMEC test berths and observation grid.

A schedule has been constructed by dividing each day into four watch periods in order to sample across various states of tide and times of day. Due to Orkney's large variation in daylight hours there are more watches in the summer months than in the winter months. Usually observations are carried out over one four-hour watch per day, however flexibility in the observations schedule is crucial to the high attainment rate of watches which this observations programme enjoys.

The raw data collected is made available to EMEC developers for use in their device-specific PEMPs and to inform their Environmental Statements. The data from this project has also been used to support other research projects such as FLOWBEC, RESPONSE (see below) and the EMEC Integrated Environmental Monitoring project.

Figure 5: Fall of Warness wildlife observation area

EMEC have been awarded funding to undertake a detailed review and comprehensive and statistically robust analyses of the datasets gathered during this programme (see Section 6.7.2).

6.3 Acoustic Characterisation of Ambient Noise

Details of underwater ambient noise at the Fall of Warness test site are essential for providing baseline data which developers can use when undertaking work to characterise the acoustic output of their devices. This project has developed a methodology and procured equipment which can be used both for characterising the underwater ambient noise as well as measuring the acoustic output of operational devices. EMEC manages the project and undertakes all aspects of the data collection, with analytical activities undertaken jointly with our external partners.

A major problem associated with recording underwater ambient noise in a tidal-stream environment using conventional fixed hydrophone techniques is that the hydrophones are susceptible to recording sounds generated from the flow of the water, imparting unwanted noise into the recording. In 2008, EMEC worked with the Scottish Association for Marine Science (SAMS) to develop a solution to this problem, utilising drifting hydrophones which travel with the tidal flow, reducing this source of sound contamination. This solution became known as the 'Drifting Ears' system[5] and was further developed by EMEC in 2011 to produce the Drifting Acoustic Recorder & Tracker (DART) system[6].

To date this methodology has been used to measure the underwater ambient noise in the absence of operational MECS in order to gain a baseline acoustic characterisation of the test site. Analysis of the data collected has shown that the underwater ambient noise levels measured at the test site are higher than that suggested by Urick, 1975[7] for shallow water sites. Rain noise can raise the underwater ambient noise by up to 30 dB and this extends to lower frequencies than flow noise. Based on the data gathered during this project, it seems unlikely that the noise generated by tidal energy converters operating within the site would have a significant impact on marine mammals. However, further detailed studies involving noise measurements in the presence of operational MECS will be required in order to gain a better understanding of this.

The DART methodology and equipment is available to EMEC developers for use in collecting underwater acoustic data to inform the acoustic characterisation of their operating MECS.

6.4 Flow, Water Column & Benthic Ecology 4D (FLOWBEC)

In addition to commissioning environmental monitoring projects itself, EMEC has also hosted several research projects at its test sites. The FLOWBEC project[8] seeks to measure flow, water column and benthic ecology in four dimensions in order to assess the potential effects of marine renewable energy developments on the environment. The project is jointly funded by NERC and DEFRA, and is led by Dr Paul Bell of the National Oceanography Centre, working with researchers from the Universities of Aberdeen, Bath, Edinburgh, Exeter, Plymouth and Queens University Belfast. Project partners are EMEC, Marine Scotland Science and Open Hydro Ltd.

The aims of the FLOWBEC project are:

1. To improve understanding of the fine scale details of the flow regime in areas of high tidal and wave energy and the effects of Marine Renewable Energy Devices (MREDs) on flow conditions.
2. To assess the hydrodynamic habitat preferences of various relevant functional ecological groups (benthos, plankton, fish, birds & mammals), and how individual species may use preferred flow conditions for successful feeding, reproduction and other major biological activities.
3. To parameterize the flow field with and without the effects of both single and multiple MRED deployments and include the mechanistic links to ecological interactions that would enable their inclusion in wider area models and to be developed to allow predictions of large arrays of devices on the environment.

Work is being conducted at three marine renewable energy test sites: EMEC (Fall of Warness and Billia Croo), WaveHub, and Strangford Lough. EMEC has provided a variety of project support, focused mainly on the data collection activities at the Fall of Warness and Billia Croo. At the time of writing the project was focused on the data collection activities, with analysis and reporting due in 2014.

[5] For information on the Drifting Ears system, please see Wilson, B. & Carter, C. (2008). *EMEC Report "Acoustic monitoring of the European Marine Energy Centre Fall of Warness tidal-stream test site; Phase 2: Development, testing and application*".

[6] For information on the DART system, please see Harland, E.J. (2013). *"Fall of Warness Tidal Test Site: Additional Acoustic Characterisation*". Scottish Natural Heritage Commissioned Report No. 563.

[7] Urick,R.J. 1975. *Principles of underwater sound*. McGraw-Hill Inc. ISBN 0-07-066086-7.

[8] For further information on the FLOWBEC project please see http://noc.ac.uk/project/flowbec

The underwater active sonar system uses two state-of-the-art sonar systems[9] mounted in a battery powered seabed frame placed close to a tidal energy generation structure to monitor fish, diving seabirds and marine mammals as they pass through the water and interact with the device. These sonars are normally operated from the surface looking down at the seabed. For the first time they were adapted to operate autonomously for several weeks at a time to capture an entire tidal cycle, imaging a full 'acoustic curtain' along the tidal flow and around the structure in a highly challenging environment. Figure 6 below shows the FLOWBEC monitoring frame containing the active sonar systems being prepared for deployment at the EMEC Fall of Warness test site.

Figure 6: The FLOWBEC monitoring frame being deployed at the EMEC Fall of Warness test site (photo courtesy of Dr Beth Scott)

The frame was tested in 2012 over a 2 week deployment adjacent to a tidal turbine at the EMEC Fall of Warness site by researchers from the Universities of Bath and Aberdeen together with Marine Scotland Science. Following this successful test, four 2-week deployments were conducted within the EMEC test sites both with a MECS present and at control sites with no MECS present.

The FLOWBEC project also uses Marine X-Band radar[10] coupled to a *WaMoS®II*[11] Wave and Surface Current Monitoring System to produce images of the sea surface and anything on the water surface or in the air close to the surface over a range of a few kilometers and with a range resolution of 5-10m. Sample images from this system are available from the FLOWBEC website.

The researchers on the FLOWBEC project are working together to identify the wildlife detected by the monitoring systems, how the various species preferentially use areas of water with different characteristics, and how the surrounding environment is affected by the presence of the MECS structure.

[9] For further details of the sonar platform please see http://dx.doi.org/10.1121/1.4772810
[10] http://dx.doi.org/10.1109/IGARSS.2012.6351856
[11] For further information on the *WaMoS®II* system please see http://www.oceanwaves.de/start.html

6.5 RESPONSE

The NERC-funded Understanding How Marine Renewable Device Operations Influence Fine Scale Habitat Use & Behaviour of Marine Vertebrates (RESPONSE) project[12] is a multi-disciplinary study focussing on causal links between MECS and changes in the fine-scale distribution and behaviour of marine vertebrates. This project is led by Dr David Thompson of the University of St Andrews. Project partners comprise the Scottish Association of Marine Science, University of Edinburgh, Centre for Environment Risk Futures Cranfield University, EMEC, Sea Mammal Research Unit, Loughborough University, University of Aberdeen, SNH, NERC, Defra, Marine Scotland Science.

The overall aim of the project is to identify and quantify actual risk of negative consequences and therefore remove one key layer of uncertainty in the scale of risk to the marine renewable energy industry and natural environment. The main objectives of the project are to:

1. understand how stakeholders see the risks to the industry and to the environment.
2. measure the fine scale distribution of marine wildlife in high tidal and wave energy sites to understand how seals, cetaceans, birds and large fish use such areas.
3. characterise acoustic, visual and electromagnetic signals that MRDs produce and assess the reactions of marine wildlife to those cues.
4. use the results and habitat preference models to infer zones of influence and/or avoidance associated with marine renewable energy developments at both small and large scales.
5. develop effective mitigation methods. (from RESPONSE project summary, DRF).

Although not directly involved with the project, EMEC plays a key role in supporting the field work elements of the project at the test sites.

Surveys have been conducted during May & October 2012, and in May 2013. Early results suggest preference for strong currents among auk species in the centre of the site with cormorant species split between weak and slow currents. There appear to be seasonal or inter-annual trends in the data. In particular black guillemots' use of fast water habitats appears to increase in winter months. Figure 7 below shows an example of the species distribution as recorded during a RESPONSE vessel survey of the Fall of Warness test site in October 2012. The next aims of the project are to quantify habitat preferences in greater detail than just current speeds to allow very precise predictions of the extent of spatial overlap between species foraging distributions and the locations of marine energy converter devices.

[12] For further information on the RESPONSE project please see http://www.nerc.ac.uk/research/programmes/mre/facts.asp

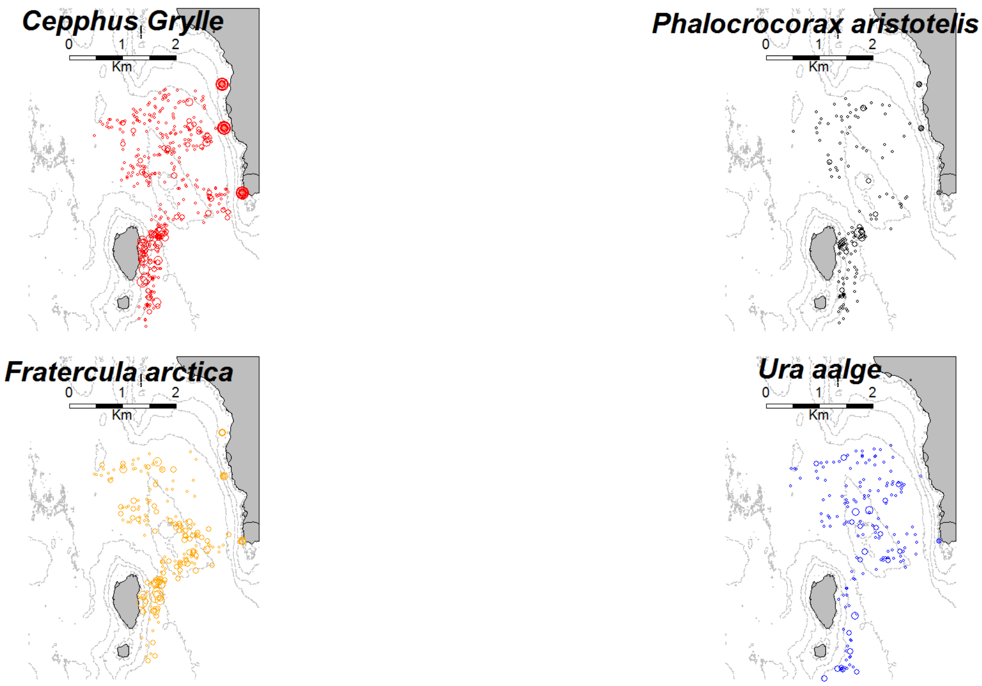

Figure 7. Simple maps showing species distribution as recorded during RESPONSE vessel survey of Fall of Warness, October 2012. All maps show land mass of Eday shaded grey on the right and Green Holms to the left. Panels are (clockwise from top left): black guillemot, European shag, common guillemot and Atlantic puffin.

At the time of writing this work is being prepared for publication (Waggitt, J. and Scott, B.E. (in press). "*Using a spatial overlap approach to estimate the risk of collisions between deep diving seabirds and tidal stream turbines: A review of potential methods and approaches, Marine Policy*").

6.6 Modelling Projects

There is a wealth of both environmental and hydrodynamic data being collected at the Fall of Warness test site. These data streams are supplied to a variety of environmentally focused modeling projects, such as Optimising Array Form for Energy Extraction and Environmental Benefit (EBAO)[13], ReDAPT work-streams (to inform Computational Fluid Dynamics), and marine vertebrate collision modeling.

6.7 Future Projects

In addition to the current research and monitoring projects described above, EMEC has identified several other key areas where environmental monitoring research work could be undertaken at its test sites. Some of these projects are described in the following sections.

[13] For further information on the EBAO project please see http://www.nerc.ac.uk/research/programmes/mre/facts.asp

6.7.1 Fisheries Study

In 2010 a Scottish Government funded project was set up to investigate the possible effects of marine energy converter deployments on resident crustacean species within the area of the EMEC Billia Croo test site. The project encompassed two broad objectives: firstly, to determine the likely influence of a small-scale refuge area on local lobster population; and secondly to explore the potential for using such areas to augment local lobster stocks by using them as nursery grounds for the release of hatchery-reared juveniles.

Following the success of this study there is interest in performing a similar study at the Fall of Warness test site. The potential focus of the study would be on crustacea (brown crab and lobster), and scallops.

6.7.2 Analysis of EMEC Wildlife Observation Programme Data

The EMEC wildlife observations programme (see Section 6.2) is aimed at establishing whether the installation, presence and operation of wave and tidal devices causes displacement of surface visible wildlife (seals, cetaceans, basking sharks, diving birds) from habitual waters, and to identify any discernible changes in behaviour. EMEC have been awarded funding to undertake a detailed review of the wildlife observation datasets gathered during this programme, and to undertake comprehensive and statistically robust analyses of the data.

It is expected that this project will describe and quantify the inter-annual and seasonal variations in the abundance and distribution of seabird and marine mammal species at the test site. Crucially, a power analysis will be carried out and a range detection function for the site will be determined. This will allow site abundance analysis to be done for species whose data display adequate power, as well as analysis of any effect or impact of presence of MECS and associated vessel activity on key species presence and distribution at the test site. EMEC is uniquely placed to carry out this analysis as it can anonymise developers' device operation data, thus preserving confidentiality of commercially sensitive data whilst providing useful study output.

The three principal relationships that will be investigated are:

1) **Effects of turbine presence on species abundance and distribution**. Relationships between species abundance and variations in number of turbines on site (i.e. not simply the presence or absence of development) will be considered.

2) **Effects of turbine operation on species abundance and distribution**. If feasible (i.e. if more than one device was operational simultaneously) analysis will consider relationships between abundance and variations in number of turbines operating at the same time.

3) **Effects of deployment, construction and maintenance activity, including boat use, on species abundance and distribution.** Ideally, the effects of specific activities, such as drilling, vessel presence/movement etc, should be considered separately. Realistically it may be necessary, given the limited time duration of these activities, to aggregate data for all these events under a general category of 'disturbance'.

In addition to the above, this project will also carry out an on-going review of established protocols used to record wildlife at the site, with the aim of improving its accuracy, efficiency and cost-effectiveness.

6.7.3 Testing/Validation of Monitoring Sensors in High Energy Environments

EMEC operates four marine test sites that experience a range of physical and biological parameters and they need to be measured and routinely monitored. Some of the sensors in use for environmental monitoring have not necessarily been designed to gather data in such high-energy environments, and their performance needs to be confirmed, validated or improved. This creates an opportunity for the testing and development of sensors that can perform effectively in these environments and deliver the specific requirements of the marine renewable energy sector. There is a range of technologies that require to be developed, but due to the immediate regulatory demand EMEC will initially focus on technologies proposed in developers' PEMPs.

6.8 DEVELOPER MONITORING

As mentioned in Section 2, developers wishing to install a device at EMEC are required to identify the likely receptors which may be impacted by their project and propose mitigation and monitoring measures in a PEMP, to be agreed with the Regulator prior to consent being granted. The PEMP must include details of what monitoring techniques the developer plans to use for this device-specific environmental monitoring. In addition to environmental monitoring in fulfilment of licence conditions, developers may also include monitoring for their own research purposes.

For monitoring in fulfilment of licence conditions, the Regulator has required developers to employ multiple techniques for detecting collision events. This is because no one proven technique currently exists to detect and identify a collision strike event. Examples of multi-sensor systems which have been used include strain gauges mounted on turbine blades coupled with video monitoring from a video camera fixed to the device or device structure.

Several developers have been required or have chosen to attach underwater cameras to their device. Various lighting technologies have been trialled including blue lights and white LED lights. One hazard of using underwater cameras to monitor potential for wildlife collision with the turbine is that the light could act as an attractant for prey fish species for diving birds and marine mammals. Underwater lighting has been used with caution in close liaison with SNH.

Strain gauges have been fitted to blades by some developers in the hope that they could detect the impact of a seal or cetacean, however some uncertainty remains as to whether these strain gauges are sensitive and reliable enough to detect such an event. The water column at the Fall of Warness can at times exhibit high and unpredictable turbulence which can give rise to readings which could be expected for a collision event. The inherent turbulence in the flow can render video camera footage difficult to monitor, although some success has been had with near-surface mounted video cameras.

In addition to making use of data from the EMEC land-based visual wildlife observation programme, some developers have carried out their own targeted wildlife studies focussed on the area around their device.

All developers at the Fall of Warness site have been required to carry out marine mammal observations during installation works due to the sensitivity of European Protected Species at the site. Any Marine Mammal Observations carried out at the Fall of Warness test site must comply with the methodology and reporting requirements stipulated in the EMEC Standard Operating Procedure, which was developed and agreed with SNH and the Joint Nature Conservation Committee (JNCC).

APPENDIX 2: WAVE CASE STUDY – WAVEHUB

Authors: Davide Magagna, Plymouth University

Acknowledgements

Thanks to Plymouth University, the University of Exeter, and Wave Hub for their input to this case study.

Disclaimer

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1 OVERVIEW OF THE WAVEHUB TEST SITE

The Wave Hub (WH) was designed for the installation and testing of wave energy converter arrays, however the site is soon to be employed also for the testing of grid-connected floating wind platforms. WH is located 16 km off the coast of Cornwall north east of St Ives, covering an area of $8km^2$ of seabed. The site has a total generation capacity of 30MW with an upgrade potential of 48MW.

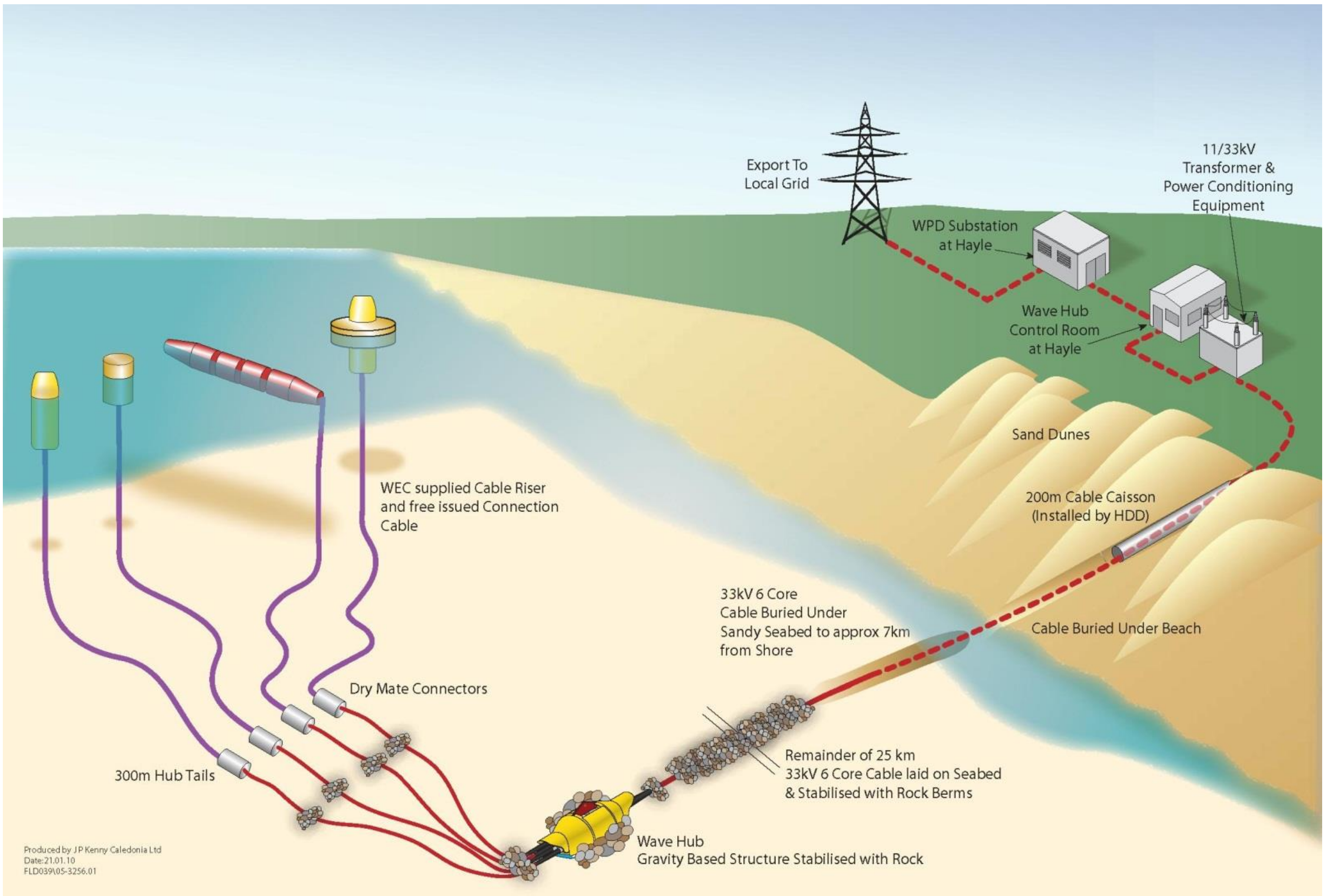

Figure 1: Schematic diagram of Wave Hub test site

The WH aims to attract project developers whose devices are at the last stage of development before the commercialization stage.

An exclusion zone exists around the hub and developers may apply for one for their individual device deployment areas if needed. WH has worked closely to look at the issues of marine navigation and how these may affect the site as a whole, individual developers and users of the sea. Some shipping routes have been modified, but no negative impacts were noticed.

2 REGULATORY CONTEXT

The WH project started in 2003 – Initial concept (South West Regional Development Agency –SWRDA)
2004 → details of the project - SWRDA
2005 → Business Case and feasibility study
2006 → Consent Application started
2008 → Consent granted → 2 years learning curve and baseline information gathering

3 main consent applications were submitted FEPA, CPA and Section 36.

3 SITE CHARACTERISATION & KEY SENSITIVITIES

In 2006 WH commissioned Halcrow to develop an Environmental Statement (ES) for the site[1]. This document provided the necessary information on the key environmental descriptors and survey requirements for site characterization to inform the EIA process. Surveys on birds, intertidal ecology and mammals with an average duration of 1 year were commissioned.

Baseline monitoring activities were also undertaken in collaboration with the PRIMaRE[2] Consortium and South West Regional Development Agency (SWRDA). Some activities, including monitoring of benthic habitats, marine mammals, coastal processes, avian fauna and fish studies are still being undertaken by research at Exeter and Plymouth Universities.

The summary of critical environmental impacts at the WH is based on the ES, detailing the Environmental Impact Assessment (EIA) needs. Focused research upon biodiversity at the WH site is also being conducted by the Universities of Exeter and Plymouth. Site sensitivities identified include:

- Coastal processes
- Water quality
- Terrestrial ecology
- Ornithology
- Marine ecology
- Marine Mammals

In terms of regulatory concerns, the following issues were brought up and discussed in depth by the WH, DECC and Statutory advisors:

- **Maritime Safety** – This issue was raised by Trinity House/British Chambers of Shipping and included consultation with Maritime Coastguard Agency (MCA). They thought that the presence of the WH in the proximity of the traffic separation zone near Scilly Island and Land's End would cause an increasing risk of naval accidents in the area.
- **Fishing** – Reduced fishing areas. A liaison officer has been appointed in order to take into consideration the displacement issues that can affect local fisheries.
- **Surfing** – Reduction to surfing waves height and coastal impacts.
- **Safety Zone** – The creation of a safety area on the proximity of the WH was discussed. At the moment a safety zone is granted within a 500m radius of the actual hub, however developers can apply for an exclusion zone around their devices. A total of 6 navigation buoys are deployed around the site as well as a North and South Cardinal Mark to aid navigation and shipping routes.
- **Benthos** – Monitoring of the benthos is critical. CEFAS requested ground surveys to be undertaken. However, due to the presence of a rocky seabed these are not easy to be carried out, so flyover surveys were employed at site.

4 DRIVERS FOR ENVIRONMENTAL MONITORING

WH held discussion primarily with regulators DECC and MFA, and The Crown Estate. Statutory advisors such as Natural England, Cornwall County Council, Environmental Agency, Perranporth and Hayle Councils were included in the process as required by existing legislation.

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[1] http://www.wavehub.co.uk/information-for-developers/environmental-impacts/

[2] Peninsula Research Institute on Marine Renewable Energy, formed by Plymouth and Exeter Universities.

5 STRATEGY FOR ENVIRONMENTAL MONITORING

Monitoring activities to inform the EIA report were developed by Halcrow whilst drafting the ES report. Monitoring activities undertaken as part of research studies carried out by local universities have been designed to answer specific questions. A description of these has been complied by the SOWFIA project and PRIMaRE project, and details are presented in the following section[3].

5.1 MONITORING AND MITIGATION TECHNIQUES

Coastal processes
Surfers Against Sewage raised a concern that extraction of energy from waves could impact surfing at beaches close to the WH. As a result, the EIA included wave monitoring at the WH site continuously for over a year and to develop wave/sediments models. These found that waves could be impacted up to 13% but more typically by up to 5%, and minimal (this is a value judgement by Halcrow) impact due to changed sediment transport on beaches along the northern Cornish coast. Current research at the site uses a combination of short term and continuous *in situ* measurements of both physical oceanography and plankton to examine the potential effect of any perturbations to the natural system due to localised energy extraction by comparing these to numerical models[4].

Water, sediment & soil quality
The main concern was that pollution or disturbance of the sediment during construction and decommissioning could impact water and sediment quality. Also re-suspension of contaminated sediment could impact water quality by releasing contaminants into the water column. Therefore as part of the EIA, a survey of water and sediment quality was carried out to determine the baseline. Based on the baseline studies, there was not considered to be a likely impact on water, soil or sediment quality during construction, operation, or decommissioning.

Terrestrial ecology
Since the WH included construction of a sub-station, an EIA was required to ensure minimal impact on the local terrestrial ecology. The new substation site and dunes through which the cable passes lie within an area designated as an Area of Great Scientific value and Cornwall Nature Conservation Site. However, since there were no features of national, regional, county or district value, construction at the site was not considered likely to have a significant impact on these habitats. Some features of local value (such as figwort and reptiles) were considered highly likely to suffer habitat loss so mitigation measures were put in place to protect or translocate these species.

Ornithology
The main impacts considered by the EIA included: (i) disturbance of both offshore and intertidal birds during construction; (ii) effects on the nearby Hayle Estuary which is a Site of Special Scientific Interest (SSSI) for wintering bird populations and; (iii) impacts on offshore birds due to the presence of the WEC.

(a) Intertidal birds
There were low numbers of intertidal birds that were concentrated in the estuary during winter months. Since construction (cable-laying) was only likely to take place during summer months, no significant impact on intertidal birds during construction or decommissioning was expected. However, any maintenance work carried out during winter months could have an impact on birds. This impact could be reduced to low risk if any maintenance work avoided the first 2 hours after sunrise.

[3] Simas, T., Magagna, D., Bailey, I., Conley, D., Greaves, D., O'Callagahn, J., ... & Embling, C. (2013). SOWFIA Deliverable D. 4.4.

[4] Witt, M. J., Sheehan, E. V., Bearhop, S., Broderick, A. C., Conley, D. C., Cotterell, S. P., ... & Godley, B. J. (2012). *Assessing wave energy effects on biodiversity: the Wave Hub experience*. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 370(1959), 502-529.

(b) Offshore birds

The offshore surveys identified 13 species of bird of which the key species were fulmar, gannet, auks (guillemots & razorbills), manx shearwaters and storm petrels. Since there was little feeding activity in the area, the construction/decommissioning phase was considered to cause little disruption to feeding birds, similarly the risk of collision was considered low. The highest risk was considered to be from pollution incidents, causing local mortality of surface resting birds such as guillemots and razorbills from surface pollutants such as lubricants and cooling oils, however, the likelihood of such an event was considered low. The ES considered that there would be no significant residual impacts of the construction, maintenance, operation or decommissioning on either intertidal or offshore birds (given the mitigation against pollution incidents & cable laying timing).

Since the EIA took place, the University of Exeter has continued to carry out near monthly surveys of offshore seabirds in and around the WH. Similar to the EIA study that took place, the main seabirds were gannets, gulls (herring, lesser and greater black-backed), and fulmars, in addition to auks, storm petrels and shearwaters. Based on a vulnerability index, all birds observed at the WH are considered as low to very low vulnerability for negative impacts from wave energy devices[5].

Marine Ecology

There are no statutory protected areas within the vicinity of the WH, however, St Ives Bay is designated as a Sensitive Marine Area (SMA) by Natural England with national importance for its marine animal and plant communities.

Benthic ecology

As part of the EIA, intertidal and subtidal surveys were carried out in 2005 along the cable route and within the proposed WH site. Subsequent to the EIA, the University of Plymouth has carried out High Definition (HD) video transects within the WH development zone and at sites to the east and west of the WH to increase the baseline data set[6]. The University of Exeter also conduct a detailed baited underwater camera survey of the WH area and its cable route at least once per year.

The EIA surveys identified a more diverse range of seabed communities within the WH site itself, and a variety of biotopes of conservation interest. Although some of the species found within the WH site are considered to be more sensitive to disturbance, the ES considered the impact to be of minor adverse significance due to the small footprint of the WH site.

Marine mammals

The EIA considered data on marine mammal sightings collated by the Cornwall Wildlife Trust to examine potential impacts of WECs on marine mammals, as well as a 5 month TPOD (dolphin and porpoise click detector, Chelonia Ltd) deployment at the WH site in 2005. Since the EIA there has been an extensive program of research carried out by the University of Exeter to expand baseline data for marine mammals in and around the WH. This has included: (i) near continuous passive acoustic monitoring using CPODs (newer version of the TPOD) for porpoises and dolphins at the WH and at coastal locations around the SW UK peninsula; (ii) boat-based annual counts of grey seals around the coast; and (iii) aerial surveys of marine mammals around the SW UK peninsula. The main species identified from the CWT database in the vicinity of the WH included bottlenose dolphins, grey seals, common dolphins and harbour porpoises.

The EIA considered construction and operation noise to be the most significant concern for marine mammals in the vicinity of the WH. Installation of WEC anchors or moorings is likely to involve either pile driving or seabed drilling for some types of WECs. Pile driving is a significant concern for marine mammals due to the high levels of noise

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5 Furness, R. and Wade, H. (2012*). Vulnerability of Scottish Seabirds to Offshore Wind Turbines.* Report to Marine Scotland.

6 Witt, M. J., Sheehan, E. V., Bearhop, S., Broderick, A. C., Conley, D. C., Cotterell, S. P., ... & Godley, B. J. (2012). *Assessing wave energy effects on biodiversity: the Wave Hub experience*. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 370(1959), 502-529.

introduced into the marine environment (up to 250-260 dB re 1 µPa based on wind turbine pile driving[7]). Potential impacts vary from avoidance to physical harm, particularly hearing damage[8]. The ES suggested that smaller piles would be required for WECs than for wind turbines, resulting in lower noise levels. Based on this, it was predicted that marine mammal avoidance behaviour could occur up to 1 km from the pile driving, and the worst-case scenario (given all berths taken by WECs requiring multiple pile driven anchors) was that this would take place over a maximum of 27 days. As a result of these considerations impact of construction noise on marine mammals was considered to be of minor adverse significance.

There is little available data on operational noise of WECs to determine possible impacts on marine mammals. However, WECs do not contain mechanical components that require power to function and so were not considered to produce significant noise levels during operation. It was therefore considered unlikely that operational noise would have any significant adverse effects on marine mammals and the impact was classed as negligible. However, given the novel nature of WECs the ES did recommend monitoring despite the low risk.

Elasmobranchs

The EIA considered elasmobranch (sharks and rays) sightings data collated both by the Marine Conservation Society and CWT, in addition to sightings recorded during the bird surveys in 2005 to assess likely impacts of the WH. The most frequently recorded species was the basking shark, with some sightings of blue and thresher sharks. There is also a limited fishery for skates and rays off the north coast of Cornwall. Basking sharks have a protected listing under CITES (Convention on International Trade in Endangered Species) also Wildlife & Countryside Act 1981.

The main potential impact considered to be of concern to elasmobranchs in the ES were electromagnetic fields (EMF) generated by the cable. The EMF generated by the cable was predicted to be within the range of detectability by elasmobranchs but is only likely to affect benthic species since the EMF decays rapidly with distance. There was therefore considered to be potential for cabling to impact elasmobranchs but that this was unlikely to be significant enough to cause damage. Given the limited zone of influence and the localised nature of the cable EMF the ES considered the impact on elasmobranchs to be of minor adverse significance.

Fisheries

As part of the EIA, a number of sources were used to assess the potential impacts on fisheries including: baseline surveys; analysis of commercial fisheries data from DEFRA; and local consultation with fishermen. Subsequent to the EIA, the baseline fisheries data has been continued by the University of Exeter, University of Plymouth and Marine Biological Association (MBA). This has used two different methods: (i) acoustic tagging of fish species to monitor fish movements; and (ii) baited HD video cameras[9]. Tagging studies allow for an assessment of potential 'spill-over' effects from closed areas, by monitoring fish movements and gaining an understanding of fish residency. The baited video camera system allows for a wider investigation of the potential effects of WECs on mobile species diversity and abundance.

Based on the EIA, the main fishery in the WH area included spider crabs, brown crab, lobster, mackerel and sole. The fishery is seasonal, with beam trawlers targeting the sole fishery in February-April, brown crab potting between May-November, and a summer fishery for spider crab and lobster. There were two main concerns raised by local fishermen: (i) the effect of any exclusion zones; (ii) the worry of snagging gear on the cable. Although there is no exclusion zone around the cable, safety zones established around the WECs (when deployed) will act as fishery exclusion zones. The EIA assessed the effect of exclusion on fisheries assuming the maximum extent of theWH was populated with WECs. It is unlikely that this will have a significant impact on fisheries landings at the level of the ICES rectangle; however it could impact on the local fishermen that use the WH area for a large proportion of their

[7] Nedwell J R , Parvin S J, Edwards B, Workman R , Brooker A G and Kynoch J E *Measurement and interpretation of underwater noise during construction and operation of offshore windfarms in UK waters.* Subacoustech Report No. 544R0738 to COWRIE Ltd. ISBN: 978-0-9554279-5-4.

[8] Brandt, M., Diederichs, A., Betke, K., Nehls, G. (2011) *Responses of harbour porpoises to pile-driving at the Horns Rev II offshore wind farm in the Danish North Sea*. Marine Ecology Progress Series 421: 205-216; Kastelein, R. A., Gransier, R., Hoek, L., and de Jong, C. A. F. (2012). *The hearing threshold of a harbour porpoise (Phocoena phocoena) for impulsive sounds (L).* J. Acoust. Soc. Am. 132, 607–610.

[9] Witt, M. J., Sheehan, E. V., Bearhop, S., Broderick, A. C., Conley, D. C., Cotterell, S. P., ... & Godley, B. J. (2012). *Assessing wave energy effects on biodiversity: the Wave Hub experience*. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 370(1959), 502-529.

fishing livelihood. Also some parts of the WH area are used as refuges away from trawling areas where static gear fishermen have a lower likelihood of gear damage by trawlers. Thus, any fishery based within the WH area would be displaced to other areas, potentially conflicting with other vessels, and competing for limited resources & limited refuges away from trawling activity. On this basis, the impact of exclusion zones on fishermen was considered to be of moderate adverse impact (the highest environmental impact within the WH EIA). There is no mitigation against this prospect, however, reduced fishing pressure within the WH area could have a benefit on local fish with knock-on benefits to local fishermen by acting as a *de facto* No Take Zone.

6 PROJECTS UNDERWAY

Research activities are on-going at the WH. Research groups at the University of Exeter and University of Plymouth are engaged on different subjects. The PRIMaRE consortium is looking to engage again with WH to provide support on research activities in the proximity of the test site. It is hoped that the collaboration will allow gaps to be filled and provide further information on mitigation techniques to be implemented once the test centre becomes operational.

APPENDIX 3: OFFSHORE WIND CASE STUDY – FRAUNHOFER

Authors: Jochen Giebhardt, Fraunhofer
Jean Baptiste Richard, Fraunhofer

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1 OFFSHORE WIND: ALPHA VENTUS

1.1 ALPHA VENTUS DESCRIPTION

Alpha Ventus is an offshore wind farm in the North Sea and a common project of the three companies EWE, E.ON Climate & Renewables and Vattenfall Europe wind power. It was constructed in 2009, and is located 45km north of the island of Borkum, in a water depth up to 30m. Altogether, there are twelve 5MW-wind turbines of different types in use: six AREVA Wind M5000-turbines on tripods and six REpower 5M-turbines on jackets. Alpha Ventus occupies an area of 4km^2, with a distance of 800m between each turbine. With a total power of 60 MW it was expected to reach an annual energy yield of 220 GWh. This aim was exceeded in the first year of operation. In addition to the production of energy, the first German (none-commercial) offshore wind farm Alpha Ventus is part of an important research program looking at the use of wind energy in the sea. This research program is called “Research at Alpha Ventus (RAVE)” and involves amongst others, studies on how to monitor environmental impacts of offshore wind farms.

2 REGULATORY CONTEXT

2.1 FEDERAL MARITIME HYDROGRAPHIC AGENCY AS A 'ONE-STOP-SHOP'

Specific environmental aspects have to be estimated and assessed before constructing and operating offshore wind farms. This happens in accordance with the administration, which allocates licenses for offshore wind farms. In Germany the Federal Maritime Hydrographic Agency (BSH) is responsible for widespread concerns inside the Exclusive Economic Eone (EEZ). This deals with, amongst others, licensing procedure, Maritime Spatial Plan (MSP), and Environmental Impact Assessment (EIA), which take part in ORECCA's offshore renewable energy roadmap).

The individual German Federal States are responsible for concerns inside the coastal waters, but due to nature conservation and tourism, there is only marginal room for offshore wind power in these near-shore areas.

2.1.1 Maritime Spatial Plan (MSP) as Precautionary Principle

Inside the EEZ an increasing number of interests of use are accumulated (e.g. fisheries, shipping, offshore activities - including offshore wind farms, exploration of the sea and navy activities). These different stakeholders impose diverse demands and produce a conflict in use of the marine environment. For a sustainable use of the sea and fair conflict resolving, an intelligent land management is essential. The basis for an integration of offshore energy and its associated environmental impacts into the EEZ is the Maritime Spatial Plan, which became effective in 2009. This plan achieves as a precautionary principle instrument, a sustainable spatial development by bringing social, economic and ecological interests of spatial demands in line. Detailed information and documents are provided by the German Bundesamt für Schifffahrt und Hydrographie (BSH)[1], meaning the German Federal Office for Shipping and Hydrography.

2.1.2 Environmental Impact Assessment (EIA) and Standard Investigative Concept (StUK) as Precautionary Principle

The Offshore Installations Ordinance is the basic key for each license for buildings inside the EEZ and gives an applicant demand of license if the following conditions are in compliance with Section 6 of the German national regulations for offshore constructions, the so called *See-Anlagen-Verordnung (SeeAnlV)*:

a) No adverse effects on safety and traffic
b) No compromise for marine environment including bird migration
c) Other appointments of ordinance or regulations under public law

This applies to construction inside the EEZ which produce energy from water, current or wind. To be sure that those constructions have no negative effects with respect to the conditions mentioned above, a license procedure is necessary. This must be applied for under the rules of Section 2 of SeeAnlV. The application requires an intensified checking of all potential impacts. If, for example, an offshore wind farm consists of more than 20 turbines, then an Environmental Impact Assessment (EIA) is required, of which the purpose is to foresee all impacts to the marine environment as a cumulative effect. To specify the marine environment, the following subjects of protections are considered (compare with Off-shore Renewable Energy Conversion platforms – Coordination Action (ORECCA)'s definition of an EIA):

- seabed (different types and as habitat)

[1] http://www.bsh.de/en/index.jsp

- water (current, turbidity and oxygen content)
- air/climate
- benthic wildlife
- fishes (which prefer to stay local)
- marine mammals
- birds (resting and migrating birds)
- cultural- and material goods (marine archaeological objects)
- landscape and human

For an easier analyses and a standardized scope of these subjects of protection, BSH developed a guideline called Standard Investigative Concept (StUK)[2]. StUK is designed in multi stages and considers an exact characterisation of the project together with a reference area. Both areas come under an analysis of the marine environment before construction, during construction and during operation (see Table 1 below).

Stage of StUK analysis	Environmental analysis
Application	Literary characterization of the project area, proposal for a research program
Research program a)	Pre-examination, field mapping, ground conditions, choice of reference area
Research program b)	Inventory of present natural environment, counting of birds, fishes and mammals
Monitoring of construction	Registration of the impacts of construction, counting of mammals, measurement of underwater noise
Monitoring of operation	Registration of the impacts of operating, takes a loss of habitat place?

Table 1: Stages of StUK analysis

Research is required to optimize, update and evaluate the StUK guideline and therefore the protection of the marine environment. One project of RAVE, called RAVE-ecology, takes part in such research.

[2] http://www.bsh.de/en/Products/Books/Standard/7003eng.pdf

3 RESEARCH AT ALPHA VENTUS (RAVE)

RAVE[3] is supported by the German Federal Ministry for the Environment. This research initiative attends construction and operation of Alpha Ventus to get detailed information about many aspects, which are important to improve technical, financial and ecological issues of future offshore wind farms. The most important cross-sectional tasks are described in Table 2 below.

general RAVE projects
• operation, coordination & measuring • foundation and supporting structure • installation engineering & monitoring • grid integration • ecology, acceptance and safety

Table 2: General RAVE projects (IWES, et al., 2010)

Over 50 institutes all over Germany are doing researches at Alpha Ventus, which are coordinated by the Fraunhofer IWES Kassel. In the following chapters are described how to monitor environmental aspects of offshore wind farms in each single phase of life-cycle. Newest solutions and results about specific problems are given in context to environmental relevant RAVE-projects.

3.1 RAVE-Ecology

The goal of RAVE-Ecology is to get additional knowledge about the environmental impacts of the construction and operation of offshore wind farms. All results of this project are used to evaluate the StUK guideline. In this context, RAVE-Ecology looks after environmental impacts throughout all phases of the life-cycle and carries out the preliminary work for the improvement of the BSH-StUK guideline. This results in continuous and iterative guideline upgrades and revisions of other regulations by researching and adapting future instruction for offshore wind farms. The following questions are the main objects of RAVE-Ecology:

- How do marine mammals and passage migrants react to the wind farm and will there be habitat losses?
- What impact will have noise during the construction and operational phases on marine mammals and fish?
- Will there be changes in benthic communities and fish fauna that are attributable to the artificial hard substrate used?
- Will there be evasive movements of birds or bird collisions with turbines?

Table 3 below shows an overview of the main tasks in each research field and the involved institutes of the RAVE-project to answer the questions above.

[3] IWES, F., Durstewitz, M., Krengel, U., & Lange, B. (2010). *AVE Research at Alpha Ventus Broschüre.* Kassel: Fraunhofer IWES.

Research field	Task (involved institute)
Benthos and fish	• Completion of time series during the operational phase and investigation of benthic changes on the basis of extended site-specific effects monitoring (AWI) • Examination of the impacts of wind turbines on fish and vagile fauna in the Alpha Ventus test field (AWI)
Migratory birds	• Test field research on bird migration near the offshore test field Alpha Ventus (Avitec Research) • Observation of bird collisions using the VARS system (IfaÖ) • Observation of evasive movements of migratory birds using pencil beam radar (IfaÖ)
Passage migrants	• Studies on possible habitat losses and behavioural changes of seabirds in the offshore test field (TESTBIRD)(FTZ)
Marine mammals	• Supplemental research into the impact of Alpha Ventus construction and operational activities on marine mammals (FTZ)
Noise	• Noise measurements during pile driving and operation at a large distance from the Alpha Ventus test field and data processing using a model (itap)
General research	• Joint evaluation of data on seabirds and marine mammals in the context of environmental effects monitoring at Alpha Ventus (FTZ/BSH) • Joint evaluation of data from research, monitoring programs, and environmental compatibility assessments as a basis for a holistic evaluation of environmental effects monitoring at Alpha Ventus (AWI/BSH) • Evaluation of FINO1-research data on migratory birds (FINOAVIDATA)

Table 3: Overview of the main tasks of the RAVE-Ecology project (IWES, et al., 2010)

4 ENVIRONMENTAL MONITORING FOR OFFSHORE WIND FARMS

4.1 BEFORE COMMENCING CONSTRUCTION

At the beginning of each offshore wind farm project, an application for the construction of wind farms has to be filled in. To ensure that responsible monitoring of the potential impacts has been considered at the outset, the applicant must inform the agency about basic conditions of the project area. This involves characterisation of the project area by undertaking a literature study. Beyond this the applicant must propose a general research program for the project, involving all stages of the project life-cycle (see Table 1):

Pre-examination

This step should characterise the project area and the research program as well as define compatible reference areas. Therefor a sonar field mapping of the project area needs to be developed in order to identify similar ground specific reference areas and sample stations for benthos analysis. To analyse the future environmental impacts sufficiently, the project and reference areas must be adapted to the behaviour of all environmental sensitivities. For example different sizes have to be distinguished. Table 4 below shows the definitions in accordance to the StUK.

	Size of project-analyse area	Size of reference area
benthos; fishes	similar to project area	similar to project area or several little areas corresponding to the project area
avifauna	aerial counts: 2000km² vessel based counts: 200km²	
marine mammals	aerial counts: 2000km² vessel based counts: 200km²	

Table 4: Sizes of project-analyse and reference areas in dependence of subject of protection

To ensure that reference areas give an accurate comparison without any influences of other offshore wind farms, further requirements are needed. The reference areas should not be located in another offshore wind farm planning area. They should be useful in future as well and as possible similar in position, flow conditions, sediment, distance to the coast, differ in species and density of individuals.

Inventory of present natural environment

To generate a significant data base, which describes and characterises the features of the natural environment before starting to construct an offshore wind farm, an inventory is necessary. This applies to the project analysis area as well as to the reference area and their seasonable dynamic biotic communities. Before commencing construction, the analyses should have been carried on continuously over two years. This involves, for example, periodic fishery studies, aerial-supported counts of birds and marine mammals in order to obtain knowledge about the use of the planning area as rest and feeding region of different species[4],[5].

[4] BSH. (2007). *StUk 3.* Hamburg, Rostock: BSH.

[5] Zeiler, D. N. (2005). *Offshore-Windparks in der ausschließlichen Wirtschaftzone von Nord- und Ostsee.* Hamburg: Deutscher Wetterdienst.

4.2 DURING CONSTRUCTION

The main environmental impacts during construction of an offshore wind farm, which have to be monitored, are:

- Visual and audio (pile driving) pressures
- Pressures of vehicles and engines, which are involved in construction
- Loss of habitats in result of construction activities
- Pollution emissions
- Turbidity in results of foundation constructing, cable hauling and anchoring

The control of the construction phase is for determining all impacts into the marine environment by monitoring the project analyse area and reference area. The StUK guideline gives detailed information about how to analyse each subject of protection in that case.

One of the heaviest impacts of constructing an offshore wind farm is the sound of pile driving. Each pile needs up to 3000 hammer blows with a top level audibility of 200 dB. In the case of tripod foundations and wind power plants containing several hundred turbines, pile driving emits a heavy noise impact into the marine environment. For porpoises and seals this noise can effect temporarily displacement and irreversible damage, and potentially result in death. Since a modification in behaviour of porpoises during construction was noticed, scare arrangements with non-hazardous noises before pile-driving are often applied (in the 2012, during erection of the offshore wind farm "Borkum West", a mass mortality in the German North Sea of up to 130 porpoises was detected. A correlation between this and the wind farm construction was not inspected)[6],[7] .

4.2.1 RAVE-HydroSound

Due to the risk of noise, action to decrease the noise impact of pile driving must be developed. To achieve this, the research program RAVE-HydroSound analysed the effect of a "Layered Bubble Curtain" when erecting Alpha Ventus. This method blows air bubbles in several layers from bottom up, closely around the pile. The high difference in density of air and water affects an impedance discontinuity, which decreases the noise. The results of this project are that a mitigation of sound of around 10 – 14dB is possible. However, the benefit of this method depends heavily on the direction of flow, and the critical value of 160dB re 1µPa at a distance of 750m was only maintained in the direction of flow. Further methods should consider the flow direction, so that the bubble drift can be controlled[8] (Rolfes, 2010). Another method, called "Big Bubble Curtain" was tested during constructionn of "Borkum West II" by the Institute for Technical and Applied Physics, where the greater distance from the bubbles to the pile attained higher successes in mitigation[9].

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[6] Schulz, M., Betke, K., & Nehls, G. (2006). *Minderung des Unterwasserschalls bei Rammarbeiten für Offshore-WEA – Praktische Erprobung verschiedener Verfahren unter Offshore-Bedingungen* . Oldenburg: ITAP.

[7] Nehls, G. (2013, Juli 03). *Hydroschall*. Retrieved September 04, 2013, from http://www.hydroschall.de

[8] Rolfes, R. (2010). *Erforschung der Schallminderungsmaßnahme „Gestufter Blasenschleier (Little Bubble Curtain)" im Testfeld Alpha Ventus („Schall Alpha Ventus")* . Hannover: Gottfried Wilhelm Leibniz Universität.

[9] Pehlke, H., Nehls, G., Bellmann, M., & Gerke, P. (2013). *Entwicklung und Erprobung des Großen Blasenschleiers zur Minderung derHydroschallemissionen bei Offshore-Rammarbeiten.* Husum: itap.

4.2.2 Analyzes-Examples of Subject of Protection During Construction of Alpha Ventus

Migratory Birds

In connection with the RAVE-ecology research initiative, Avitec Research GbR monitored the behaviour of migratory birds during construction of Alpha Ventus. The analysis took place in spring and fall (times of bird migration) in the 2009. Using vessel remote sensing methods (vertical radar, migrations call registration) and bird counts from ships, the bird migrations above the area of Alpha Ventus were registered. Different species of birds were detected using the methods provided by StUK. The results of this study show that no adverse effects were caused to the bird migration due to the construction of Alpha Ventus. Also, no large scale modifications in behaviour or reverse migrating of birds were detected. In comparison to the pre-examinations of the preceding years the noticed bird migrations were similar. Still unknown is the effect of the illumination of the wind farm, which should be investigated in future[10].

Fish

The Institute for Applied Biology of Fishery controlled the sources of fishes around Alpha Ventus in the construction phase with the requirements of StUK. Two fisheries with beam trawls in summer and fall were arranged. The results show a typical compound of fish species of the North Sea in the project area. The overall frequency and weight of fishes was smaller inside the project area than inside the reference area. It cannot be said clearly if this is an indication of an effect caused by the construction activities, because of possible differences in territories. Also injured or dead fish as a result of pile driving could not have been found[11].

Marine Mammals

BioConsult and Biola were instructed to monitor the behaviour of marine mammals during construction of Alpha Ventus. With aerial counts at two different heights using vessel based transect counts, and T-POD's at 12 different places, the behaviour of marine mammals was monitored from April to August in 2009. The results show that the provided monitoring guideline from StUK is very suitable to monitor porpoises. In the period of measurement 42 piles were driven into the ground, which produced a noise about 170dB re 1µPa at a distance of 750m. The critical value of 160dB re 1µPa for this distance was achieved between 2000m and 3000m. The T-POD measurement could establish a significant decrease of habitat-use of porpoises around the project area while pile driving. However it could not be shown that this was due to noise caused by the piling, because of seasonal fluctuations of porpoise appearances. The density of other marine mammals like seals was too thin to make a statement[12].

4.3 During Operation

The main environmental impacts due to operation of an offshore wind farm which require monitoring are:

- Visual and audio pressures caused by operating
- Shades of the turbines
- Vibrations
- Electric and magnetic fields
- Usage of space due to infrastructure (cable, foundation, etc.)
- Potential emissions of toxic substances

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[10] Hill, K., & Hill, R. (2010). *Baubegleitendes Monitoring im Frühjar und Herbst 2009 am Offshore Testfeld 'Alpha Ventus' - Zugvögel.* Osterholz-Scharmbeck.

[11] Kafemann, R., Ehrich, S., & Fetsch, S. (2010). *Fischbiologische Erhebungen während der Bauphase des OWP Alpha Ventus* . Hamburg: Institut für Angewandte Fischbiologie GmbH .

[12] Diederichs, A., Brandt, M. J., & Nehls, G. (2010). *Auswirkungen des Baus des Offshore-Testfelds „Alpha Ventus" auf marine Säugetiere.* Husum: biola; BioConsult SH.

- Change of sediment circulation, existing flow conditions and water conditions
- Bird strike, barrier effects and scare impacts
- Pressures due to maintenances and repair actions

Monitoring during operation of an offshore wind farm covers the assessment of environmental impacts in both the project analysis area and reference area. In particular the loss and change of the living marine environment due to noise, flight barricade and untypical hard structure habitats are of importance. The StUK guideline gives detailed information on monitoring the environmental sensitivities during wind farm operation.

4.3.1 RAVE Operational Sound

Next to the risk of bird strike, the sound of operating wind turbines plays a role in research about the environmental impacts of offshore wind energy. To obtain more knowledge about noise produced and how boundary conditions (wind velocity, wind direction, sea state, water height, water flow profiles, water temperature, water temperature profiles, salinity, etc.) affect this, the research program RAVE-Operational Sound undertook measurements around Alpha Ventus. Using 5 hydrophones, noise levels close to the turbines and at a distance of 400m to the offshore wind farm were recorded in the following situations:

- all turbines off (measurement of background noise)
- some turbines on (to compare the different types of tubines)
- all turbines on

All measurements mentioned above were carried out under varying environmental conditions. Analysis of data obtained show that at a distance of 100m the noise is in the order of magnitude of the background noise, and that the local underwater noise level in the region of Alpha Ventus wind farm decreases with increasing wave heights. The reasons for this are that there are fewer ships around the wind farm, and there is a higher transmission loss of noise because of higher air entrainment[13].

4.3.2 Analyzes-Examples of Subject of Protection During Operation of Alpha Ventus

Marine Mammals
Biola and BioConsult monitored marine mammal usage of the region around Alpha Ventus between December 2009 and December 2010. The monitoring guidance provided from StUK was used and tested. Figure 1 below illustrates porpoise behaviour during operation of Alpha Ventus. In context of seasonal variability, porpoises are located consistently and with a homogeny scatter around the wind farm and in-consistently in the reference area. Despite the differences of habitat usage in project and reference area no negative effect of the operation to porpoises could be detected. As in the previous analyses, other marine mammals were too rarely seen to draw any conclusions[14].

[13] van Radecke, H., & Benesch, M. (2012). *Operational underwater noise at Alpha Ventus.* Flensburg; Bremerhaven: RAVE International Conference 2012.

[14] Höschle, C., Diederichs, A., & Nehls, G. (2011). *Statusbericht Meeressäugetiere im Bereich des Offshore-Testfeldes Alpha Ventus.* Husum: biola; BioConsult SH.

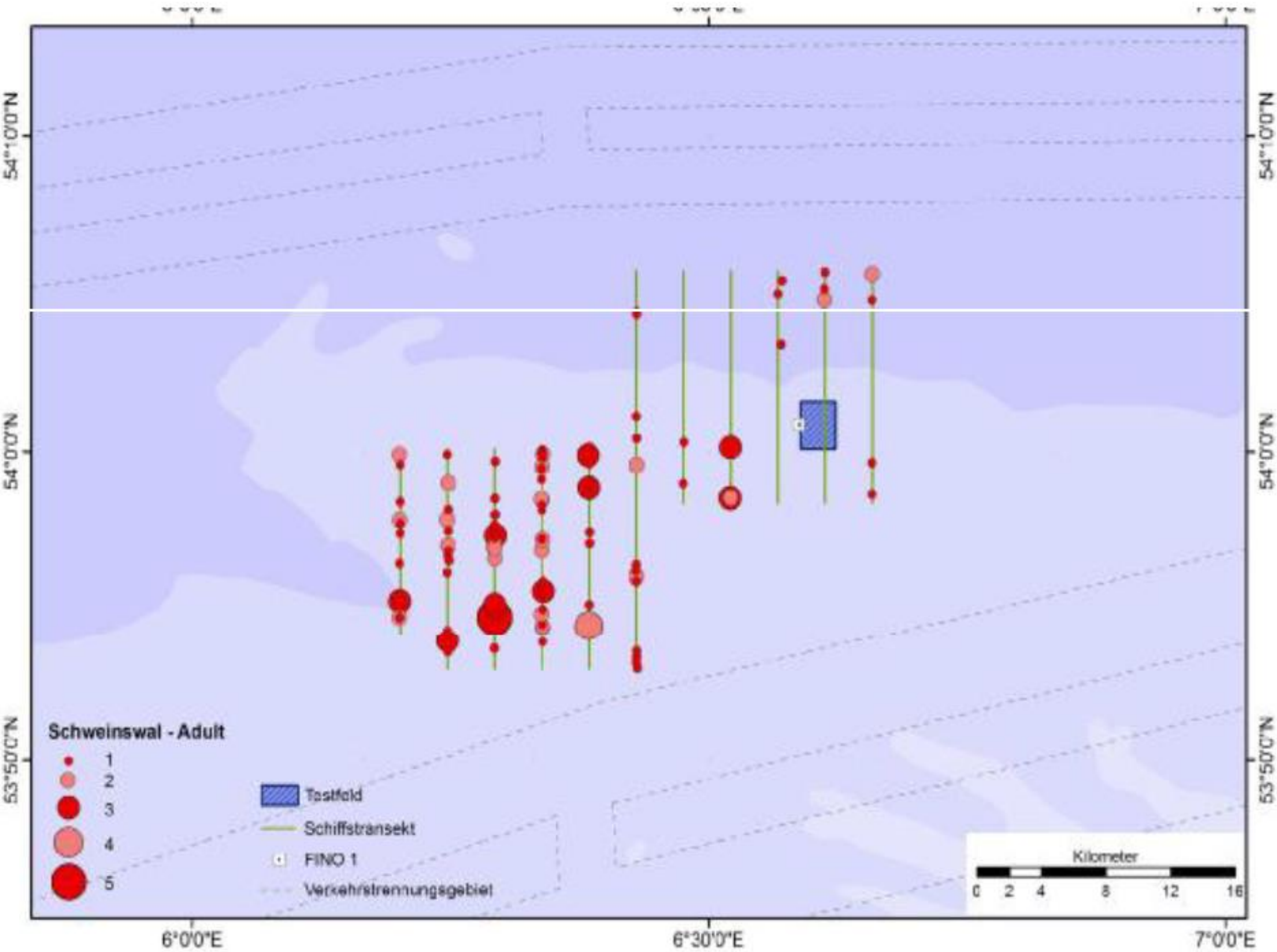

Figure 1: Porpoises behaviour during Alpha Ventus operation (Höschle, et al., 2011)

Birds

The effects of operating wind farms on migratory birds have been investigated by the Institute of Applied Ecology and by Aviteck Research. Two ways to collect data about birds offshore were tested: ship bases surveys (character: lots of space, little time) as it is recommended by StUK, and station based observation from the research platform next to Alpha Ventus "FINO" (character: lots of time, little space). Results show that there is a need to conduct the monitoring using a more station based long term observation. Controls on the research platform FINO1 indicated a number of more than 1000 bird deaths since 2003 due to collision with the platform. Due to the fact that more than 200 birds died in four mass collisions, it would be helpful to think about an "early warning system" (e.g. with a better understanding of the weather conditions and migration events, turbines could be turned off if many birds cross the wind farm area). Furthermore, it would be important to understand the effect of illumination and phototaxis (allure effects) of the offshore wind farm, since two-thirds of the birds migrate during night time. It is possible to track behaviour with radar (circling flights around the illuminated platform were detected), but monitoring of colliding birds especially in times of bad weather is very difficult. In future phototaxis should be mitigated by a compromise between avian and human safety – e.g. fewer lights and lower light intensity, or new light qualities to minimize the attraction to birds in order to prevent phototaxis and collision of birds[15].

[15] Coppack, T., & Hill, R. (2012). *Detecting effects on migratory bird: new results and perspectives.* Broderstorf; Osterholz-Scharmbeck: Institute for applied Ecology; Aviteck Research.

Other analysis from the University of Kiel looked for a correlation between collision of birds and their flight heights. It was identified that the flights of most seabird species are lower than Alpha Ventus rotors, but some species overlap quite substantially. Some seagull species were even affected by the offshore wind farm. To reduce the risk of collision, wind turbines should be constructed as high as possible[16].

Fish and Benthos

The Alfred Wegener Institute for Polar and Marine Research (AWI) looked after the effects of operation on the biodiversity of fish and benthos around Alpha Ventus. To collect data video, diving, fishing and hydro acoustic measurements were carried out. To differentiate local effects around the wind turbines, open areas next to the hard structure were also monitored. The following observation was made due to the artificial reef effect: a high abundance of fish and crabs was observed close around the turbine foundations relative to open areas. Therefore, no differences in tripod or jacket foundations were observed. In reference to the natural species composition, differences of endobenthos between reference and impact area occurred since the wind farm was constructed. Indeed special species decreased but all in one the diversity of species increased in comparison to the reference areas.

To aid identification of possible changes in future, the cornerstone of a large-scaled database of benthos and fish species around the German EEZ was build up by AWI. With this new and unique tool it is possible to catch ecologic data around the EEZ and their marine ecosystems concerning sediment consistency and spatial variability of in-, epi- and fish fauna. Due to the import of hard structure into the marine environment and changes in pressures of fisheries through the wind farm areas, a change in the marine ecosystem is to be expected. Future studies should reveal if spatial temporal dynamics of fish and benthos at small scales will also occur at large scales[17],[18].

4.4 DURING DECOMMISSIONING

Agreement on the future decommissioning of the complete offshore wind farm (turbines, foundations, and cables) forms part of the license. The main environmental impacts due to decommissioning an offshore wind farm which have to be monitored are:

- Visual and audio pressures due to decommissioning
- Pressures of vehicles and engines, which are involved in decommissioning
- Loss of habitats as a result of decommissioning activities
- Pollution emissions
- Increased turbidity caused by foundation decommissioning, cable lifting and anchoring

The impacts of decommissioning offshore wind farms are similar to the construction. Decommissioning of several oil- and gas platform experiences will be used to develop a StUK monitoring program for the future decommissioning of wind farms.

[16] Garthe, S., Mendel, B., & Kotzerka, J. (2012). *Possible Impacts of wind farms on seabirds: the case study Alpha Ventus.* Kiel: Research and Technology Centre; University of Kiel.

[17] Reichert, K., Dannheim, J., & Gusky, M. (2012). *Fish and Benthos at Alpha Ventus.* AWI.

[18] Dannheim, J., Gusky, M., Schröder, & Alexander. (2013). *Fish and Benthos at Alpha Ventus Fischen für das ökologische Effektmonitoring am Offshore-Testfeld „Alpha Ventus“* . Bremerhaven: AWI.

5 SUMMARY

To sum up the environmental monitoring of offshore wind farms in Germany, one can say that the “one-stop-shop” BSH organises a systematic procedure to control the offshore wind energy impacts, addressing all phases of the project lifecycle to prevent and mitigate impacts. The RAVE project is part of “researching and developing” the monitoring guideline, StUK. The role of that research institution is to update the formal requirements to the latest research results, to develop new protection and mitigation tools or systems like the “bubble curtain”, and to uncover unknown effects and future developments in offshore wind energy and the marine environment. Research results show that in some areas the StUK monitoring methods give good results. Other methods will be improved and superseded by the latest StUK (Version 4), which will be published at the end of 2013. The accompanying research on environmental sensitivities protection could show first effects in behaviour and species composition. But to obtain more significant results considerable data are required, especially to achieve important targets like the reduction of bird strikes and mitigate underwater noise during construction. Looking at the future of offshore wind energy development, one can say that a change in the German North Sea environment is very likely, as wind farms are proposed for 25% of the German EEZ. In this area hard structure will be placed, fishery’s pressure will change, and underwater noise will increase.