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Streamlining of Ocean Wave Farms Impact Assessment

Co-funded by the Intelligent Energy Europe Programme of the European Union

Deliverable 3.5

Work Package 3 Final Report

Daniel Conley, Davide Magagna, Deborah Greaves, Eduardo Aires, Jose Chambel Leitao, Matthew Witt, Clare Embling, Brendan J. Godley, Antony Bicknell, Jean-Baptiste Saulnier, Teresa Simas, Anne Marie O'Hagan, John O'Callaghan, Brian Holmes, Jan Sundberg, Yago Torre-Enciso, Dorleta Marina

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Report on the analysis of the Environmental Impact Assessment Experience for Wave Energy

October 2013[1]

[1]Version 3 – October 2013

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Streamlining of Ocean
Wave Farms Impact
Assessment

SOWFIA project synopsis

The Streamlining of Ocean Wave Farms Impact Assessment (SOWFIA) Project (IEE/09/809/SI2.558291) is an EU Intelligent Energy Europe (IEE) funded project that draws together ten partners, across eight European countries, who are actively involved with planned wave farm test centres. The SOWFIA project aims to achieve the sharing and consolidation of pan-European experience of consenting processes and environmental and socio-economic impact assessment (IA) 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. Through project workshops, meetings, on-going communication and networking amongst project partners, ideas and experiences relating to IA and policy are being shared, and co-ordinated studies addressing key questions for wave energy development are being carried out.

The overall goal of the SOWFIA project is to provide recommendations for approval process streamlining and European-wide streamlining of IA processes, thereby helping to remove legal, environmental and socio-economic barriers to the development of offshore power generation from waves. By utilising the findings from technology-specific monitoring at multiple sites, SOWFIA will accelerate knowledge transfer and promote European-wide expertise on environmental and socio-economic impact assessments of wave energy projects. In this way, the development of the future, commercial phase of offshore wave energy installations will benefit from the lessons learned from existing smaller-scale developments.

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Grant Agreement number: IEE/09/809/SI2.558291
Project acronym: SOWFIA
Project title: Streamlining of Ocean Wave Farms Impact Assessment

Deliverable D3.5

Final WP3 Report

Report on the analysis of the Environmental Impact Assessment Experience for Wave Energy

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October 2013

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Revision History

Rev.	Date	Description	Author	Checked by
01	June 2013	First Draft	D. Magagna	All other partners
02	August 2013	Second Draft	D. Conley	All other partners
03	October 2013	Final Draft	D. Conley	All other partners

List of Acronyms

AA	Appropriate Assessment
AC	Alternating Current
ADCP	Acoustic Doppler Current Profiler
AR	Artificial Reef
BACI	Before-After-Control-Impact
BAG	Before and After Gradient
CEFAS	Centre for Environment Fisheries and Aquaculture Science [UK]
COWRIE	Collaborative Offshore Wind Research into the Environment
DECC	Department of Energy and Climate Change [UK]
DMP	Data Management Platform
DPH	Detection Positive Hours
DPM	Detection Positive Minutes
EIA	Environmental Impact Assessment
EMF	Electromagnetic Fields
EPS	European Protected Species [UK]
FAD	Fish Aggregation Device
GES	Good Environmental Status
GPS	Global Positioning Systems
HF	High Frequency
HRA	Habitats Regulation Appraisal [UK]
IA	Impact Assessment
IPC	Infrastructure Planning Commission [UK]
MMO	Marine Management Organisation [UK]
MPA	Marine Protected Area
MRE	Marine Renewable Energy
MREI	Marine Renewable Energy Installations
MSFD	Marine Strategy Framework Directive
NIS	Natura Impact Statement
ORED	Offshore Renewable Energy Development
OWC	Oscillating Water Column
PAM	Passive Acoustic Monitoring
PTS	Permanent Threshold Shift
RDP	Refined Data Product
RMS	Root Mean Square
ROG	Recommended Operating Guidelines
SAC	Special Area of Conservation (Habitats Directive)
SAM	Static Acoustic Monitoring
SCI	Sites of Community Interest
SEA	Strategic Environmental Assessment
SEL	Sound Exposure Level
SNH	Scottish Natural Heritage
SPA	Special Protection Area (Birds Directive)
SPL	Sound Pressure Level
TTS	Temporary Threshold Shift
VHF	Very High Frequency
WEC	Wave Energy Converter
ZUC	Zero Up Crossing

Executive Summary

The wave energy industry is an emerging sector and, in comparison to more established industries, is a new user of maritime space. In order to realise the potential for wave energy to contribute towards EU renewable energy goals several technological and non-technological barriers need to be overcome. Many of the non-technological barriers are due to wave energy being at a relatively early stage in its development. Much attention has focused on the potential environmental impacts of wave energy and the burden of responding to this attention represents a significant barrier to the wave energy industry. As part of the SOWFIA project, an evaluation of experience related to the detection of environmental impacts at EU wave energy test centres along with information gained from environmental impact assessments produced for other similar renewable energy developments has been undertaken. This experience has been examined to understand key receptors of concern and methods used for detecting impacts, to produce effective methods for communicating the information gathered and to identify where possible, the type and magnitude of impacts which may be expected.

The key environmental receptors of concern for wave energy EIA include the physical environment (morphology, waves and current etc.) and flora and fauna as represented by marine mammals, seabirds, benthos and fish and shellfish.

There is a concern that removal of energy from waves and currents in the marine environment may result in significant environmental impact, whether to the marine ecosystem or to users of the marine space. Standard measurements such as wave buoys and ADCPs along with numerical simulations and more innovative measurement techniques can be used to study this issue Preliminary studies suggest that the magnitude of the non-local effects on the amplitude of waves or currents from projects studied so far are of order 10% reduction or less.

The introduction of additional anthropogenic sound into the marine environment is of concern for its potential to impact marine species which use sound for communication, navigation, finding prey and evading predators. Key aspects of assessing the impacts from introduced noise include identifying the baseline noise signal at the site of interest, the noise signature of the planned devices and the auditory sensitivity of species present. There is very limited experience in measuring noise emissions from wave devices with results which varied from being unable to distinguish the device noise from the ambient anthropogenic signal to having to limit measurements to very low sea states in order to avoid sensor saturation. Limited measurements from a deployed Pelamis device confirm that the signal varies with sea state and that the noise emitted would be detectable by marine species.

That all marine mammals are protected by national, European and/or international legislation is reflected in the fact that the impacts of wave energy on marine mammals was of significant concern at all the test centres in the SOWFIA project. There are a wide range of methods for monitoring marine mammals and the methods utilised will be determined by the questions to be assessed. Whatever methods are employed, it is critical to determine whether the survey design method will be able to detect an impact at an early stage. Limited existing experience within marine renewable energy developments suggests that marine mammals may avoid devices but further studies are needed. Experience with nets and static (but slack) fishing gear indicate that entanglement is a potential issue although the risk associated with wave energy devices is likely to be much lower than other ocean energy technology. This risk is potentially aggravated by the increased food arising from the FAD potential of WECs. Because of the highly mobile nature of marine mammals, cumulative

effects from increasing MREI deployments are of a special concern which must be carefully considered primarily during SEA and secondarily in planning.

Seabird species are subject to various levels of regulatory protection and monitoring of seabird distribution and behaviour is a universal component of wave energy EIA. A special and key feature of this work is understanding the connectivity of development sites with SPAs which can be achieved only through tagging studies. The potential effects of marine renewable energy developments on birds can be summarised in three main categories: direct (collision, entrapment, displacement), indirect (noise, habitat enhancement, de facto MPAs), and cumulative. WECs have a much smaller above-water profile than wind turbines, and so are likely to have much lower risk of collision but the considerable underwater structure of some devices may provide an enhanced collision or entrapment risk. Entrapment of birds can be mitigated by covering openings, where possible, with a protective mesh. Migratory species and species that are restricted to foraging in specific habitats may be particularly vulnerable but sensible development planning to avoid sensitive foraging areas will help mitigate possible population impacts.

Expected impacts from wave energy developments on benthos are largely limited to the construction phase of development and relate to habitat disturbance, increased suspended sediment, sediment deposition, scour and abrasion and release of contaminants from dredged sediments. Potential operational impacts include changes in hydrodynamics and the introduction of new habitat types from foundation structures and/or other submerged equipment. The experience provided from test centres EIA suggests that the effects of the deployment of wave energy converters on coastal processes and geology would be insignificant in comparison to the natural processes occurring at the sites. Similarly, seabed disturbance from construction are generally considered to be local, temporary and similar in magnitude to common natural occurrences in the marine environment. Similarly, the evidence to date is that the potential impacts to fish and shellfish from wave energy developments are limited and of a short duration. The greatest potential for displacement effects is limited to construction phase and can be mitigated by keeping this phase as brief as possible. Entrapment and, to a lesser extent, collision remain as viable threats during the operation phase but can be mitigated by appropriate protective measures. Wave energy developments have credible potential to exhibit positive impacts, for example, by behaving similarly to fish attraction devices, artificial reefs and no take zones. At the Swedish Lysekil test centre, WECs were judged to exhibit clear features of artificial reefs (ARs), with expected positive effects.

A review of the EIAs performed at all of the test centres associated with SOWFIA confirms several lessons regarding the wave energy EIA process which were developed during SOWFIA. While the selection of receptors discussed in this report is confirmed by this experience, there is clear evidence that the receptors of primary interest are dependent on factors such as the local environmental characteristics, the presence/absence of protected species and the regulatory authority under which the EIA is performed. Across all test centres, the impacts which were perceived as lowest significance were air quality and climate and water quality and ground water with physical processes as the next least significant.

Some common themes appear in the study of EIA for wave energy projects. These include: the necessity of two years of monitoring to provide a baseline sufficient to detect changes attributable to the presence of WECs; the lack of any documented evidence of significant behavioural effect on a species level from EMF emissions by any existing undersea power cables; the logistical preference for BAG design on impact studies due to the BACI requirement for an appropriate independent control site and the high number of replicates required to achieve the desired level of impact detection sensitivity.

Finally, concern related to cumulative impacts from an expanding level of wave energy development taking place in a background of growing utilisation of the marine environment which is difficult for individual developers to address adequately suggest that this issue be comprehensively addressed at the national level as part of SEA.

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Foreword

The present report highlights the work carried out by the SOWFIA project within Work Package 3 (WP3): "*Collection and Representation of environmental assessment data for wave energy test sites*".

The objectives of WP3 are to gain experience in activities related to the detection of environmental impacts at wave energy test centres and to use that experience along with information obtained from environmental impact assessment activities in analogue activities in order to refine recently developed EIA recommendations.

These are achieved by including examples of EIA data collected at wave energy test sites from across Europe. This data is to be analysed to examine the effectiveness of different techniques for detecting potential impacts and to assess their effectiveness at communicating to stakeholders their potential for impact detection. As a result, procedures improve data presentation methods and platforms to enhance stakeholder communicability will be implemented.

The experience gained and outputs developed in this work package will be used to inform the recommendations for the streamlining of pan-European consenting procedures.

Purpose of this document within the SOWFIA Project

This report highlights the work undertaken by the consortium to homogenise methodology and data collected for EIA purposes at the different tests centres. This follows the "Catalogue of EIA" produced by the consortium in July 2011 (http://www.sowfia.eu/fileadmin/sowfia_docs/documents/D3.1_April12.pdf) and an interim report updated in January 2013 (http://www.sowfia.eu/fileadmin/sowfia_docs/documents/D3_3_final_v7f.pdf). The current work is complemented by examples of the production of refined data products which are present on the SOWFIA Data Management Platform (http://sowfia.hidromod.com).

1. Introduction

The wave energy industry is an emerging sector and, in comparison to more established industries, is a new user of maritime space. The potential of wave energy to contribute towards EU renewable energy goals and climate change mitigation have been long discussed (Cruz 2008; Falcao 2008; Clément et al., 2002). However, technological and non-technological barriers still need to be overcome in order for wave energy to become an established energy source.

The overarching goal of the present report is to summarise experience related to the detection of environmental impacts at wave energy test centres located across the EU along with information gained from environmental impact assessments (EIAs), produced for other similar renewable energy developments, in order to provide European wide recommendations for streamlining of approval and EIA processes.

A particular issue experienced across Europe by different device and site developers is the necessity of this new industry to deal with European and national regulatory frameworks. In particular, wave energy developers often have to comply with the EU Environmental Impact Assessment (EIA) Directive and associated national legislation, which necessitates the collection and collation of significant amounts of environmental data in order to enable regulatory authorities to make an informed decision on the proposed project and its potential environmental impacts at an early stage.

In Europe, the EIA process is regulated by the Directive 85/337/EEC (as amended by Directives 97/11/EEC, 2003/35EC and 2009/31/EC[2]), which defines the framework for the EIA process. The Directive identifies the projects subject to mandatory EIA (Annex I), and those for which EIA can be requested at the discretion of the Member States (Annex II), whereby the national authorities have to decide whether an EIA is needed.

Whilst ocean energy (wave and tidal) developments are not explicitly listed in Annex I, where EIA is mandatory, they have nonetheless been subject to EIA arising from Annex II which lists “industrial installations for the production of electricity” as potentially requiring an EIA. Wave and tidal projects have often been subject to EIA because of the uncertainty surrounding their environmental impact on the receiving environment. The EIA process requires developers to supply comprehensive environmental data relating to both baseline conditions and possible environmental impacts of device installation. Given the novelty of wave and tidal energy device deployments, many effects and impacts are unknown and have not been quantified as yet. This has resulted in a recognised number of information, data and knowledge gaps with which regulatory authorities and developers must contend. Accordingly the procedures and process to be followed is not always clear to either party often leading to increased costs, delay and frustration.

Uncertainties are experienced throughout the EIA phase of the consenting process from the scoping exercise, to the evaluation of the possible impacts, and finally to the design of the monitoring programme. In an early SOWFIA Workshop (Muñoz Arjona et al., 2012) addressing the experience of the wave energy industry, it emerged that one of the main problems constraining the development of the sector is the definition of the scope of the EIA, e.g. what kinds of data is collected, the resolution required for each type of data, timescale of the monitoring programme. These

[2] Now codified in Directive 2011/92/EU.

uncertainties can have a great impact on the cost of a project, delaying the development phase of the project.

This report examines experience in key areas of wave energy EIA, identifies key receptors and reviews monitoring requirements and methodologies while suggesting data presentation techniques and summarising principle findings to date in order to help reduce uncertainties and facilitate the performance of wave energy environmental impact assessment.

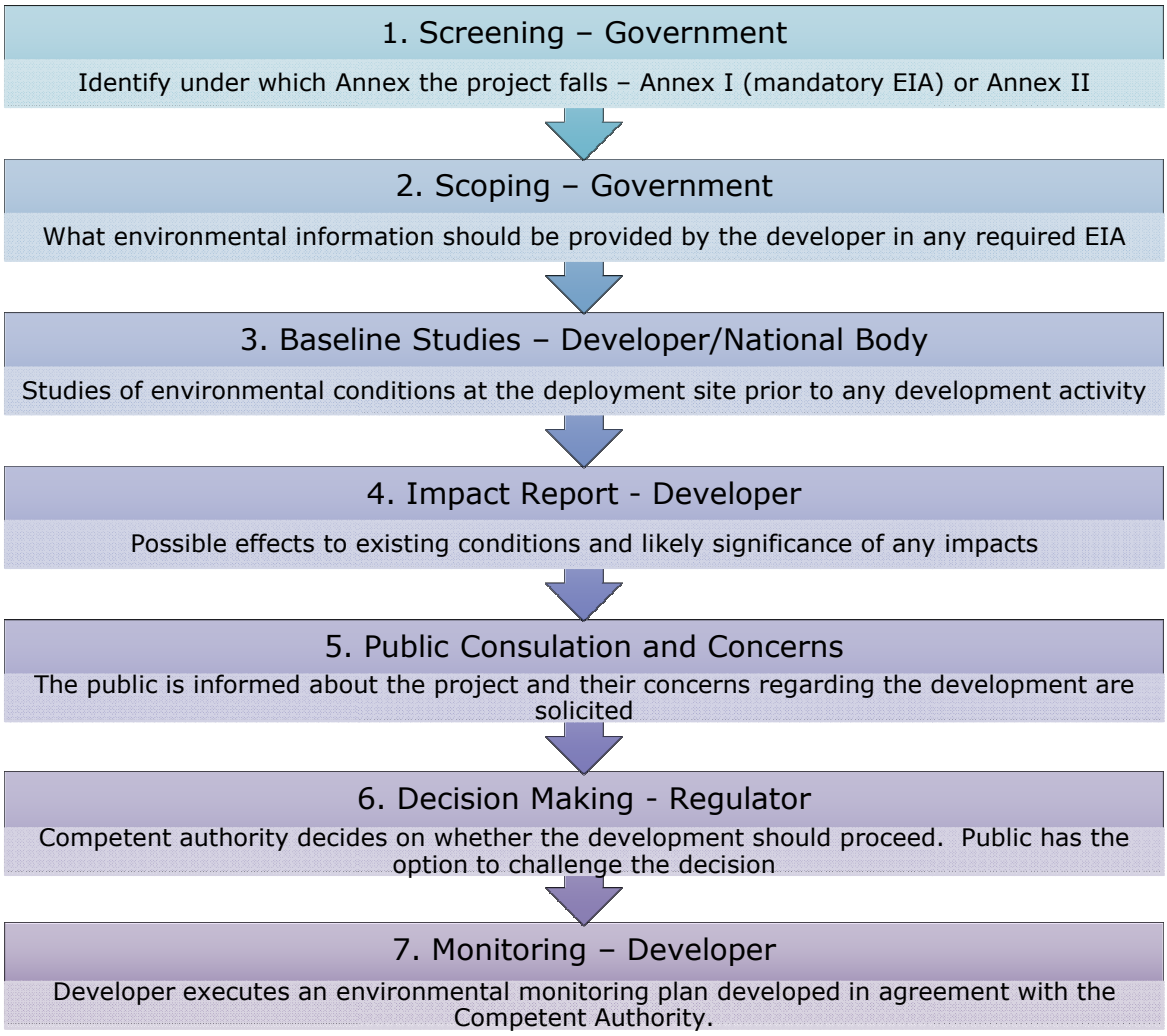


Figure1: EIA Process adapted from EQUIMAR (2010b)

1.1. Key EU Directives

The EIA process is just one element of the broader consenting process applicable to a specific project. The EU has policy and legislation on a number of issues of global concern including climate change, renewable energy and biodiversity. The EU's biodiversity policy, for example, aims at halting the decline in biodiversity and protecting Europe's endangered species and habitats. This in turn requires protection of habitats and species through site designation and also provides safeguards against potentially damaging developments. These associated Directives, namely may affect the location of the proposed wave energy farms, and influence the type of monitoring to be carried out at or near the site by a competent authority or a developer. Of particular relevance to the consenting of wave energy developments are the following Directives:

- ***The Strategic Environmental Assessment Directive (2001/42/EC),*** which ensures that an environmental assessment is carried out of certain plans and programmes, at national, regional or local level, which are likely to have significant effects on the environment. Whilst the EIA Directive operates at the individual project level, the SEA Directive operates on a broader scale where plans and programmes are prepared or adopted by an authority and are required by legislative, regulatory or administrative provisions. An SEA is mandatory for *plans/programmes which are: (i) prepared for agriculture, forestry, fisheries, energy industry, transport, waste/ water management, telecommunications, tourism, town & country planning or land use and which are set the framework for future development consent of projects listed in the EIA Directive; or (ii) have been determined to require an assessment under the Habitats Directive.* (European Commission 2012).

- ***The Birds Directive (2009/147/EC)*** provides far-reaching protection for all of Europe's wild birds, including offshore species. It is a Member State's duty to carry out an Appropriate Assessment (AA) every time significant effects on the environment are likely to take place, particularly for threatened and migratory species. It also provides for a ban on activities that directly threaten birds such as the deliberate killing of birds or destruction of their nests and habitats.

- ***The Habitats Directive (92/43/EEC)***, aims to ensure the conservation of a wide range of rare, threatened and endemic species, including offshore species, and enables protection of 450 animals, 500 plants and some 200 rare and characteristic habitat types. It provides a high level of safeguards against potentially damaging developments. The lists of habitats, animal and plants protected are listed in the Annexes of the Directive. Sites designated under the directive are known as Special Areas of Conservation (SAC).

  Sites designated under the Habitats Directive (SACs) and the Birds Directive (SPAs) are collectively known as Natura 2000 sites. Whilst the above Directives do not preclude installation of wave energy developments in Natura 2000 sites or adjoining areas, they prioritise investigation on the sensitivity of an area and on the type of monitoring and mitigation activities that may be required. Other Directives with the potential to influence the deployment of wave energy devices include:

- **The Renewable Energy Directive (2009/28/EC),** which sets renewable energy targets for all Member States ensuring that the EU will reach a 20% share of energy from renewable sources by 2020. This Directive has stimulated a number of Member States to put in place measures to encourage the development and commercialisation of wave energy in the expectation that this industry will contribute towards renewable electricity generation targets.

- **The Marine Strategy Framework Directive (MSFD,2008/56/EC**) aims to ensure Good Environmental Status (GES) of EU waters by 2020 and to protect the resource base upon which marine-related economic and social activities depend. It aims to protect marine biodiversity by adopting an ecosystem approach to the management of human activities which have an impact on the marine environment. Under this legislation, Member States must develop a strategy for its marine waters (or Marine Strategy) according to a set of environmental descriptors, one of which is the introduction of energy, including underwater noise.

- **Water Framework Directive (2000/60/EC)** aims to ensure achievement of "Good water status" in all bodies of surface water and groundwater by 2015. Surface waters include

coastal waters out to 1 nautical mile. Good surface water status" means the status achieved by a surface water body when both ecological and chemical status is at least "good". According to the European guidance documents on the Implementation of the WFD, good status means low levels of chemical pollution as well as a healthy ecosystem.

1.2. Monitoring, Data and Potential impacts

Under most consenting processes, wave energy developers will have an obligation to examine the potential effects that installation of their device(s) may have on the environment. This usually requires detailed monitoring of the area affected by the installation prior to, during and post construction and throughout the life cycle of the wave energy device deployment.

As previously highlighted, uncertainties are experienced by site and device developers with regards to those receptors[3] that need to be monitored and on the monitoring methodology to be utilised, resulting in difficulties in assessing potential effects and therefore delaying or even halting the development of Marine Renewable Energy Installations (MREI). In order for the competent regulatory authority to make their decision, they must have access to robust scientific information derived from relevant scientific studies as well as monitoring data.

The availability of relevant data provides quantifiable information and aids the development of informed knowledge, which will through time enable scientifically valid decisions to be made in a more effective and efficient manner (Figure 2). It should be noted that many of the uncertainties relating to the potential effects of wave energy device deployment result from the limited amount of data and information available for this technology; with governmental agencies recommending that site specific assessments are determined, as highlighted for example in the Offshore Energy SEA (OESEA2, DECC 2011) prepared by the UK Department of Energy and Climate Change (DECC). As a result, in preparing the SEA, DECC has been required to forecast scenarios of wave and tidal energy installation based on experience obtained from demonstrator sites.

Following the introduction of the EU Renewable Energy Directive (2009/28/EC), many European Member States have started a process to evaluate their marine energy potential, resulting in the creation of test centres around Europe for the testing and validation of Wave Energy Converters (WECs) at pre-commercial state.

The SOWFIA consortium (Osta Mora-Figueria et al., 2011) produced a catalogue of the operational wave energy test centres and demonstration sites of Europe. These centres were created for testing and demonstration of WECs and their components; however, some also monitor the environmental, physical and socio-economic receptors so as to increase knowledge of the various impacts of ocean renewable installations. The results of such monitoring can then be analysed and interpreted by scientists and regulatory authorities tasked with managing the marine environment and ultimately enable them to make more informed and scientifically robust decisions on consents for similar developments in the future.

[4] The term receptors is used to define those aspects of the environment likely to be affected by the development, including, in particular, population, fauna, flora, soil, water, air, climatic factors, material assets such as the architectural and archaeological heritage, landscape and the inter-relationship between the above factors.

To facilitate the process, the SOWFIA project is working closely with six European wave energy tests centres: AMETS in Ireland, BIMEP in Spain, Lysekil in Sweden, Ocean Plug – Pilot Zone in Portugal, SEM-REV in France, and Wave Hub in England (Figure 3). The European Marine Energy Centre (EMEC) in Scotland has also contributed to the project. Data gathered from monitoring activities have been uploaded to the Data Management Platform (DMP), an interactive tool designed and developed during the SOWFIA project for the inter-comparison, benchmarking and analysis of the data collected. The DMP is complemented with data available from other European test centres, like the Galway Bay test centre in Ireland, and information on environmental monitoring procedures provided from other wave energy sites. The DMP contains scientifically robust data of potential environmental impacts in a format suitable for a non-technical audience and details on the philosophy behind its design, its structure and how to utilise it can be found in SOWFIA deliverable D3.3 (Magagna et al., 2012)

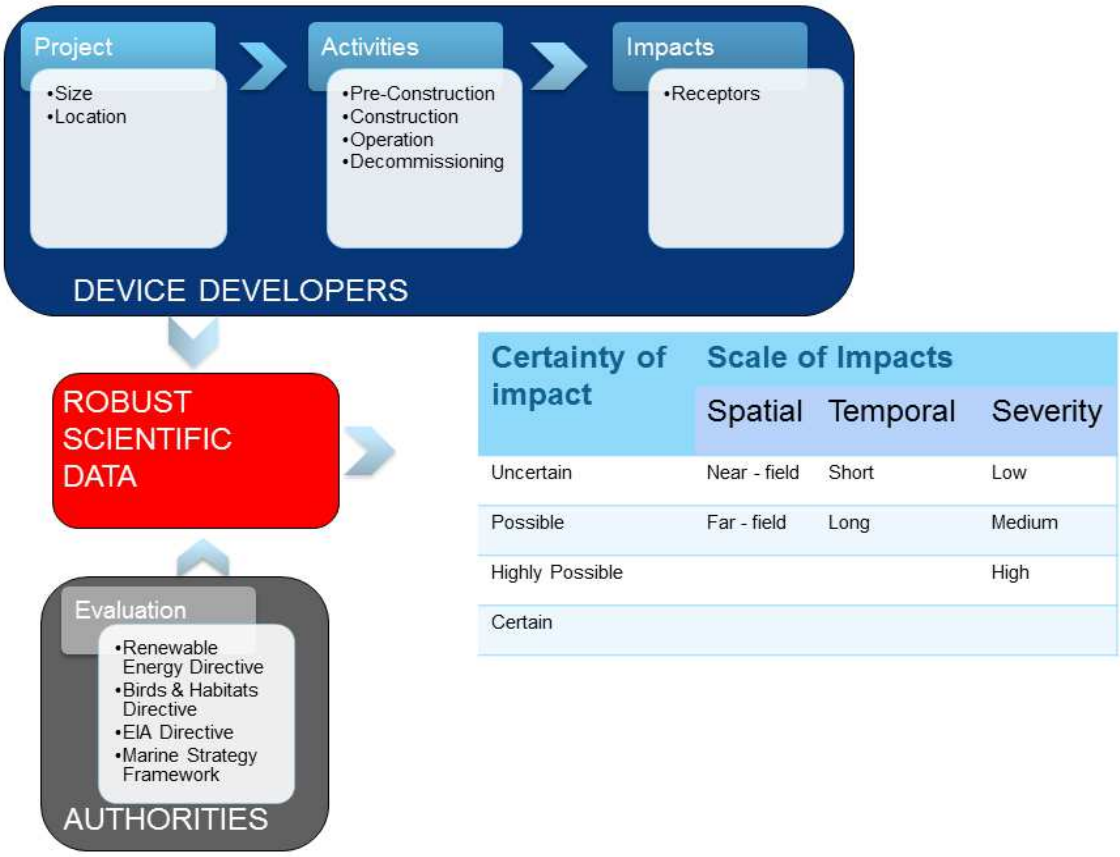


Figure 2: The role of scientific data in the decision making process

Having recognised the need for having readily comparable data, suggestions towards uniformity in procedures have been created and are described in this report.

1.3. Test Centres and Data Availability

Data from the monitoring activities undertaken at six European tests centre are collated in the DMP. A list of the monitoring activities carried out at each of the different test centres is presented in Table 1.

The activities are divided into three main categories:

1. Studies on physical factors such as geomorphology and hydrodynamics;
2. Studies on biological factors such as benthos and marine mammals;
3. Socio-economic studies evaluating the impacts of the proposed installation on local communities.

These categories provide a bigger envelope for the monitoring of the eleven descriptors of GES of water included in the MSFD (JRC 2011).

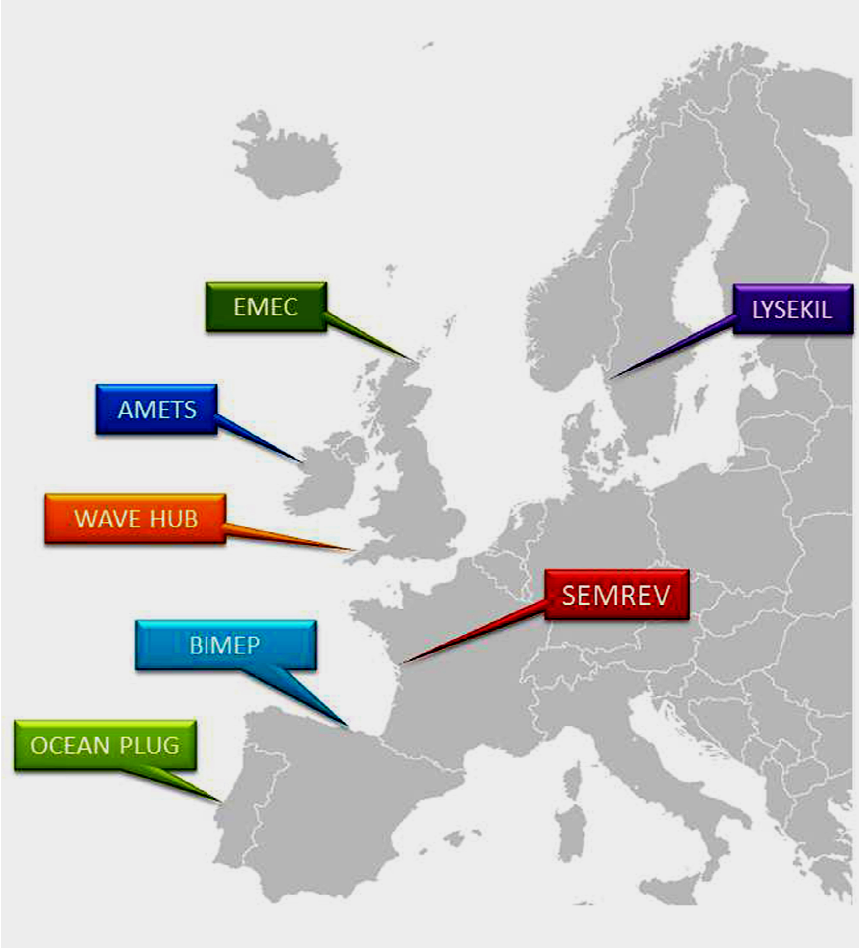


Figure 3: Test centres providing information to the SOWFIA Project

The implementation of the MSFD (2008/56/EC) identifies the development of criteria and indicators to assess the GES, which motivate monitoring requirements at a particular location. The monitoring activities for each test centre vary due to different environmental conditions (habitats and species), legal requirements or as a result of consultation with other authorities, developers and stakeholder groups.

For example, monitoring of wave conditions is carried out to provide device developers with information on the sea-conditions for optimization of their devices; or, as in the case of Wave Hub, requested as part of the consultation with local stakeholders (DECC 2007). Biological monitoring such as visual surveys for marine mammals and migratory birds are carried out to fulfil obligations under the EU EIA Directive (85/337/EEC, as amended) and Birds and Habitats Directives (79/409/EEC as amended and 92/43/EEC as amended, respectively). Socio-economic studies on the impacts of marine renewable installations are carried out to document the potential consequences of a

development on a local community, businesses and infrastructure and to assist in the preparation of mitigation measures or alternatives, where deemed appropriate. The integration of environmental data from the different sites could provide a foundation for understanding the environmental impact of marine renewable energy installations (Wilhelmsson 2010; Inger et al., 2009).

Table 1 : Monitoring activities at six partners test centres AMETS, BIMEP, Lysekil, Ocean Plug, SEM-REV and Wave Hub. Physical receptors are presented in orange, biological factors in blue and socio-economic studies in purple.

Factor	AMETS	BIMEP	Lysekil	Ocean Plug	SEM REV	Wave Hub
Bathymetry	✓				✓	✓
Geomorphology	✓			✓	✓	✓
Hydrodynamics	✓	✓		✓	✓	✓
Acoustic and Noise		✓	✓			✓
Benthos	✓	✓	✓	✓	✓	✓
Fish & Shellfish		✓	✓			✓
Plankton studies						✓
Marine Mammals	✓	✓	✓	✓		✓
Marine Ornithology	✓			✓		✓
Landscape & Visual	✓					✓
Archaeology						✓
Navigation and Shipping						✓
Fisheries	✓			✓		✓
Economics						✓
Tourism						✓

2. Monitoring Design

It is widely recognised that one of the main non-technological barriers affecting the development of offshore renewable energy installations is related to their unknown impacts on the marine environment (Muñoz Arjona et al., 2011). With increasing interest in harnessing the different forms of renewable energies available offshore (wind, waves and tides); it is necessary to provide developers with tools that will allow them to fulfil statutory licensing requirements (The Scottish Government 2012; Norris 2009). Offshore SEAs (The Scottish Government 2012; DECC 2011) completed in Europe have highlighted the lack of understanding on the impacts of MREIs on marine biodiversity; and in particular on marine mammals, seabirds, migratory fish and benthos.

Given the regulatory requirements placed on a development by European and national legislation such as the EIA Directive 85/337/EEC (as amended by Directives 97/11/EEC, 2003/35EC and 2009/31/EC[4]), the Habitats Directive (92/43/EEC), and Birds Directive (2009/147/EC), it is necessary to establish "baseline conditions" for potential MREI sites for the following licensing activities:

- Environmental Impact Assessment of the project (EIA);
- Habitats Regulation Appraisal (HRA) and Appropriate Assessment (AA), in case of Natura 2000 areas;
- Post installation monitoring and measurement of future environmental changes.

In order to help project developers overcome possible hurdles presented by environmental regulation, protocols and guidance documents outlining methodologies for the monitoring and survey of environmental receptors affected are being developed and updated to bridge knowledge gaps. These protocols provide information on how assess the potential impact that could affect a particular environmental parameter of feature during the different phases of a wave and tidal energy arrays or offshore wind farms.

The process of survey design requires that common issues are addressed to define data acquisition strategies, as follows:

- What is the rationale of the survey? Which parameters should be assessed and why?
- What data types need to be collected and how will they be analysed?
- Are existing datasets available, are they sufficient to provide the information required or do they need integration with new datasets?
- Are there seasonal and temporal and spatial considerations to be applied?
- Which survey techniques will provide the data to meet the rationale?
- Are data sufficient for future predictions?

The clear definition of the objectives of the environmental studies will promote the development of a multi-stage framework for the successful implementation of appropriate assessments methods. The stages of assessment and their outputs are presented in (**Table 2**).

[4] Now codified in Directive 2011/92/EU.

Table 2: Stages of environmental monitoring for MREI developments. Stages marked with the * correspond to stages of the EIA process. Adapted from (Trendall et al., 2011; Judd 2012; Margheritini, et al., 2012).

Stage	Objective	Outputs
Scoping*	Process of defining the potential significant direct and indirect impacts of the proposed development, including methodologies for characterisation surveys and significance criteria.	Target parameters for specialist studies
Site characterisation*	Process of understanding the environmental components and to characterise the existing environment; and investigating parameters which may exhibit significant effects	Baseline information, including existing literature.
Impact assessment*	Determining the impacts of the development on the environmental components. Impacts should be characterised as follows: - Magnitude of the impact; - Extent; - Duration, time over which the impact will last; - Temporal scale, i.e. permanent or temporary; - Timing and frequency, i.e. coincidence with critical life stages - Cumulative effects - Confidence in future predictions	Environmental statements and mitigation measures
Targeted monitoring	Phase of evaluating the impacts that could be associated with the presence of marine renewable energy structures	Development and analysis of mitigation measures
Substantive review*	Evaluation of monitoring techniques and development of surveying best practice	Feedback to consenting, potential implementation of adaptive management procedures
Decommissioning	Monitoring phase to ensure that environmental effects associated with the removal infrastructure and environment restoration are appropriate.	

2.1. Design of Monitoring Activities

When designing environmental surveys it is necessary to ensure that the data collected are fit for purpose, robust and scientifically defensible. The objectives of the study need to be clearly stated and the activity should aim to answer clear questions, as highlighted in section 2; with the aims of (Trendall et al., 2011):

- Providing information on the distribution and abundance of key species to inform site location and facilitating decision making process;
- Providing a baseline against which impacts can be measured

Surveying methodologies employed will be dependent on the type of the expected impact and on the monitoring phase, which will affect the resolution of the survey, its size and temporal scale and frequency. It is therefore important to understand how these parameters could affect the monitoring strategy for a given environmental descriptor.

2.1.1. Potential impacts and significance

The installation of an offshore renewable structure, its operation and decommissioning can affect the marine environment and alter the status of a space or habitat. Different types of impacts could take place from physical injuries to displacement/barrier effects to increased turbidity and contaminant displacement, however not all impacts may have negative effects or even be significant enough to cause a permanent alteration to the species or habitat considered.

The guidance document developed by SNH (Trendall et al., 2011) has identified two types of significance of the impacts:

- **Significance under the Habitats Directive**, which links the potential effects to the conservation objective of a particular site. If the potential impacts cannot be excluded and are deemed to affect sites of EU importance then an appropriate assessment may be required.
- **Statistical significance**; in this case the changes measured on the habitat or species are not deemed to pose a wider risk to conservation objectives although they may have statistical relevance. For example small changes to migratory routes may have statistical significance but not pose a risk to the abundance of the species. In this case objective judgement by regulators is needed.

2.1.2. Temporal scale

The length of time and the frequency of sampling that characterises a particular survey are dependent on the receptor being considered and the metrics being measured.

Sampling frequency

The sampling frequency of a survey is dependent on site-specific factors, such as site usage, seasonal variations and natural variability. During the characterisation phase of the site a single visit or few seasonal visits may suffice to provide the required information, however during the monitoring stage more frequent surveys may be required.

Survey and monitoring periods

The guidance documents developed by SNH (Trendall et al., 2011; Macleod et al., 2011) suggest that the minimum length of monitoring for baseline conditions should be of two years especially for surveying of mobile species to allow for an understanding of both seasonal and temporal variations and temporal inter-variations in population. These follow the guidelines developed by COWRIE for baseline data acquisition at offshore wind farms. Whilst two years may not provide a sufficient time frame to evaluate the abundance of the population, this timeframe should permit the detection of changes due to the presence of marine renewable energy (MRE) devices.

2.1.3. Spatial consideration

In a similar way to monitoring frequency and period, it is important to determine the **development footprint** and the **potential impact footprint** for a given project. Whilst the development footprint may be limited, the footprint of potential impacts may be larger and will have to be taken into consideration for monitoring purposes. For example, the potential impact footprint of anthropogenic noise may be significantly larger than the project footprint where the noise is generated. Identifying the correct footprint for each descriptor is required for selecting suitable control areas and the spatial extent of monitoring required to evaluate impacts.

2.1.4. Data

Data play a key role in assessing the potential impacts of MRE structures on the environment. It should be noted that historic data may not always be used to determine impact due to the presence of MRE devices. Therefore supplemental data may often need to be collected to address the requirements of the EIA.

Data collected is normally classified in two categories, distribution/abundance data and behavioural data. The first group provides indication of the abundance of particular species, whilst the second type provides information on the interactions between species and devices.

Abundance and distribution data allow for the detection of broader impacts of devices on receptors, such as changes in distribution or abundance of animals as a result of devices. Behavioural data allows both for the assessment of the relative importance of a site for key receptors, and provides metrics for the assessment of potential impacts. However both types of data need to be contextualised against the background environment to allow for changes to be related to a particular driver.

2.1.5. BACI and BAG designs

In order to measure the magnitude of any effects of a development on environmental descriptors it is essential to establish control areas for the collection of comparative data. The need to provide comparative information affects the design of the survey and has to be considered form the start of the monitoring campaign. Two study designs are normally developed:

- BACI, Before and After Control Impact;
- BAG, Before and After Gradient.

BAG designs may be preferable for birds and marine mammals survey as they require less monitoring effort in terms of spatial coverage. BACI designs are well established for biological impact assessment but found limited use in MREI development, since they can be employed only when the conditions for a control site to be comparable to but independent from the study site are met. BAG designs

assume that the impacts will decrease with distance from the development, which is highly applicable to marine energy developments.

2.2. Key Environmental Receptors

The guidance documents produced by the UK Centre for Environment Fisheries and Aquaculture Science (CEFAS) (Judd, 2012) and SNH (Trendall et al., 2011) indicate that there is a general lack of knowledge in procedures for monitoring impacts of offshore renewable structures on the marine environment. These gaps have lead to the on-going development assessments based on the more stringent legal requirements and impacts from other established marine sectors. As a consequence the SNH guidelines focus predominantly on marine mammals (separated into cetaceans and seals), seabirds (migratory and diving) and on benthic ecology. Marine mammals and seabirds are protected under the Habitats and Birds Directives and specific monitoring to support Appropriate Assessment in addition to EIA may be required. Benthic characterisation is often required by the EIA as it provides important information on the status of the habitats around the development.

CEFAS guidelines also include fish studies, underwater noise, intertidal studies, and physical and sedimentary process studies as suggested components for EIA studies.

The following sections of this review document will provide information on the protocols developed for different environmental descriptors divided in two main categories as follows:

- Physical environment
- Flora and fauna including:
  - Marine Mammals;
  - Seabirds;
  - Benthos;
  - Fish and shellfish.

3. Physical Environment

3.1. Wave and Current Monitoring

Monitoring of wave and current conditions at test centres is generally undertaken in order to assess environmental met-ocean conditions and the energy resource available. Wave and current data are also important to assess changes in the wave field and flow (wake zone), water column (mixing, turbulence, turbidity), sediment transport and possible drivers of long-term changes to beach morphology due to the presence of wave energy farms. Through the analysis of wave and current data it is possible to determine the general climate (mean conditions, seasonal variations) and the amount of power available at a site. Information on the frequency, severity and duration of storms can also be obtained. It is also important to have wave and current measurements for periods when other environmental monitoring is being undertaken, for example, during baseline noise studies it is important to measure variations in noise with different sea states when no wave energy converters are present.

For both wave and current measurements, the aim is to collect high-quality data on a regular basis in a reliable way (high data collection success rate). Real-time availability of such data, although not always technically possible, is a key advantage because it allows for real-time monitoring of environmental parameters as well as the implementation of control strategies for WECs based on environmental conditions.

3.1.1. Wave and current monitoring requirements & methodology

For wave measurements, moored directional wave buoys should be used if possible because they are the most robust and advanced commercial product in the field (e.g. Datawell 2012; Oceanor 2012; Axys Technology 2012). However, alternative devices such as bottom-mounted Acoustic Doppler Current Profilers (ADCPs) in moderate depths (<40m) or high-frequency (HF) radar may be used. The wave measurement campaign should span 1 or 2 years with minimum temporal resolution of 3 hours and as few interruptions due to technical failures (e.g. sensor displacement or loss) as possible. One advantage of using wave buoys is that data can be transmitted in real-time by VHF or other wireless communication straight to onshore receivers without any intervention at sea. Also, for most wave measurement buoys, the three-dimensional sensor system permits the estimation of directional wave spectra. While wave measurements from HF radar have the advantages that they have the convenience of remotely sensed data, they are available in real-time, and they have wide spatial coverage, questions about measurement accuracy and reliability are still being assessed.

For current measurements, bottom-mounted commercial Acoustic Doppler Current Profilers (ADCPs) are preferred (e.g. TeledyneRDI Instruments 2012; Nortek U.S.A. 2012) as long as the water depth is not too great (< 100-150m). It is generally accepted that the last 5-15% of the range below the surface should be disregarded as measurements from this location are contaminated by strong surface reflections (TeledyneRDI Instruments 1996). The current profiles can be averaged over a period of time ranging from 10 to 30 minutes. A measurement campaign generally consists of one to two months of continuous recording (depending on the device settings) and requires collection of the device from the sea once the batteries or memory are exhausted. ADCPs (Hoitink and Schroevers 2004) also allow the estimation of wave parameters and spectra through water orbital velocity measurements (hourly rate at 2Hz by default on Teledyne RDI ADCPs for instance). However, the relative brevity of ADCP deployments makes it less convenient for operational use compared to wave buoys. ADCPs are also commonly equipped with built-in pressure sensors from which water level

variations around mean depth can be determined. This is a convenient measurement in order to monitor tidal cycles and local storm surges.

Wave buoys, once installed (single-point mooring), can be inspected every 6 to 12 months and possibly replaced for maintenance. Raw and processed data are sent through radio transmissions and stored onboard simultaneously, so that all data may also be retrieved by collecting the memory card at sea.

ADCPs generally require replacement or turn-around every 1-2 months depending on battery life and memory capacity. Continuous current measurement campaigns would require setting up direct data transmission through, e.g. VHF, and independent continuous power supply, which is not commercially available from manufacturers yet. Current measurements may be carried out in the vicinity of the wave buoy for ease of maintenance operations and better wave-current data coherence.

Measurement instruments are subject to technical limitations (resolution, range, accuracy), which are generally documented by the manufacturers. A Waverider or Triaxys wave measurement buoy, for instance, is claimed to have a resolution of 1cm with +/-20m range for the vertical estimate and, as said previously, ADCP devices are not able to provide reliable measurements of currents near the surface or close to transducers (parasitic reflections of side acoustic lobes and blanking period for transducer ringing effect respectively). In addition to measurement error, wave and current parameter estimates are also subject to sampling variability due to the finiteness of the data samples collected (for uncertainty on parameters such as significant wave height or mean wave periods estimated from spectra, see e.g. Krogstad et al., 1999).

3.1.2. Monitoring locations

Wave measurements at wave energy test centres are generally taken close to a test berth, ideally upwind of the berth, at a location unaffected the presence of a device or local topography or bathymetry. Other wave measurements can be taken at other areas of interest within a test site. From experience, it has been found that the variability of environmental and resource parameters is quite small over relatively small areas such as those occupied by wave energy test centres (provided the field and bottom characteristics are not too peculiar, e.g. with strong currents or abrupt bathymetric variations like rocky protrusions or sandy hills and vales, etc. causing large refraction effects and dissipation) (Ashton et al., 2013). Nevertheless, it is often relevant to install a measurement device at both the upstream and downstream side of a test site, so as to measure the resource variation across the site due to both natural oceanic processes and energy absorption related to the presence of wave energy structures in the facility (e.g. this is done at SEM-REV and Wave Hub). The same hypotheses may hold for currents: deploying an ADCP close to a wave buoy is relevant for ease of retrieval, maintenance operations and data cross-coherence as already indicated previously. Again, placing two independent devices upstream and downstream of the testing area is also recommended if more than one current profiler is available (monitoring of wake effect).

Information regarding the monitoring activities undertaken at different test centres including availability of data in the SOWFIA DMP is presented in (Table 3).

Table 3 : Summary of the Wave and Current information for each test centre and its availability through the SOWFIA DMP. Information on wave and currents monitoring from other European test sites is presented if available.

Test centre	Monitoring requirements	Sampling stations and time period	Used methodologies	Type of data in the DMP
Wave Hub (Cornwall, UK)	Applied and fundamental research by UNEXE	2009 – 2011	Four Oceanor wave riders buoy installed for directionality analysis and resource assessment. ADCP for wave measurements deployed 2011	N/A
	Resource Assessment by UoP. Monitoring as required by stakeholders	2011 – present	Oceanor Wave rider buoy installed at location HF Radar for continuous monitoring of a larger area.	CSV time series of wave parameters
Ocean Plug – Portuguese Pilot Zone (Portugal)	Resource Assessment	2010 – present	Datawell Wave rider buoys	CSV time series of wave parameters
Pico Pilot Plant (Portugal)	Resource Assessment and control of turbine	2003 – present	Acoustic Doppler Current Meter	N/A
SEM-REV (France)	Resource Assessment	2011 – present	Datawell Wave rider buoys, ADCP	CSV time series of wave and current parameters
AMETS (Ireland)	Resource Assessment	2010 – present	Datawell Waverider buoy used for wave resource assessment and weather window analysis at AMETS	CSV time series of wave parameters
Galway Bay (Ireland)	Resource Assessment	2005 – present	2005-2008: Individual non directional Datawell Waverider buoy 2008-present: Individual directional Datawell Waverider buoy Wave measurements are used for resource assessment and weather window analysis for the Galway Bay Test Site	CSV time series of wave parameters
BIMEP (Spain)	Resource Assessment	2009 – present	Directional Wavescan Buoy	CSV time series of wave parameters
Lysekil (Sweden)	Resource Assessment	2006 – present	Wave rider buoys	N/A
DanWEC (Denmark)	Resource Assessment	2010 – 2012	Wave rider buoys	N/A

3.1.3. Suggestions towards common methodology and data refinement

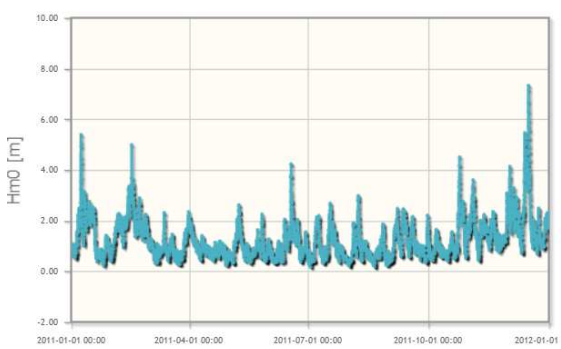
The majority of wave and current instrumentation provide real time series of the heave motion, north and east displacements, current readings as well as directional spectra information. Wave buoys derive time domain and frequency domain parameters from either zero-up-crossing analysis or spectral analysis of the time series.

For the purposes of the DMP, integrated parameters from directional wave spectra like significant wave height, energy period, mean direction, bandwidth and directional spreading have been selected as the most useful parameters. This selection is in conformity with protocols developed as part of the EU funded EquiMar project (Equimar 2010b) and Saulnier et al., (2011; 2012). A list of the wave parameters selected for inclusion in the DMP is presented in Table 4. Appendix A provides further information on wave parameters described in (Lawrence et al., 2012)[1]. Parameters such as velocity magnitude, direction and error are required to describe current profile characteristics. For both wave and current measurement devices, additional information about the device, the processing, the bathymetry etc. is expected. In the DMP, this information is provided in the INSPIRE Metadata form associated with each time series.

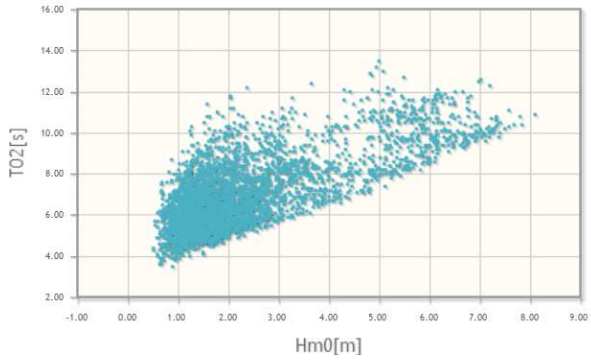
Table 4 : Wave parameters for inclusion in the DMP

Parameter name	Symbol	Unit	ASCII tag
Deterministic significant wave height	$H_{1/3}$	m	H_13
Spectral significant wave height	H_{m0}	m	Hm0
Maximum wave height	H_{max}	m	Hmax
Peak period	T_p	s	Tp
Mean energy wave period	$T_{-10}(T_e)$	s	Te
Mean zero up crossing (ZUC) wave period	T_z	s	Tz
Mean spectral ZUC wave period	T_{02}	s	T02
Maximum wave period	T_{max}	s	Tmax
Peak direction	θ_p	deg	Thetap
Mean direction	θ_m	deg	Thetam
Spectral bandwidth	Λ	Hz	Lambda
Peak's directional spreading	σ_p	deg	Sigmap
Mean directional spreading	σ_m	deg	Sigmam
Wave power/ unit of crest length	P_w	kW/m	Pw
Mean wave steepness	ξ_{02}	-	Ksi02

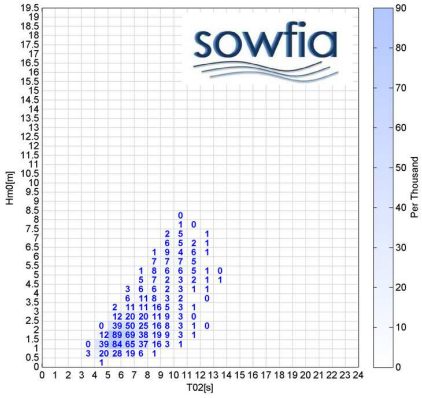
[1]This document was developed as part of the on EU FP7 funded MARINET project and can be found on www.fp7-marinet.eu



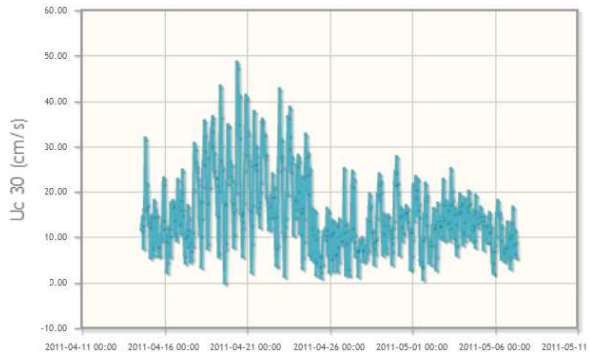
(a)



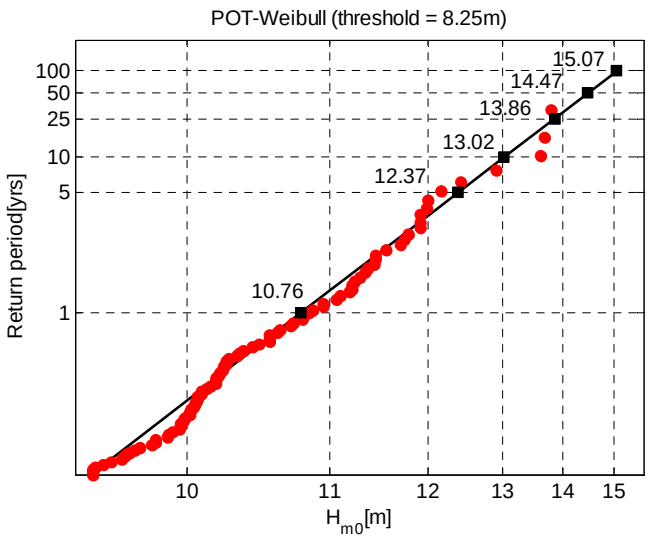
(b)



(c)



(d)



(e)

Figure 4: Examples of Refined Data Products produced using the DMP : wave parameters time-series (a), scatter plots (b) and diagrams (c), current flow speeds (d) and extreme value analysis (e)

3.1.4. Refined data products

The refined data products (RDPs) associated with wave and current data consist of added-value data plots and statistics based on the wave and current data referred to in the previous section. Refined data products for wave and current parameters include user-defined time-series and two-entry occurrences tables (significant wave height/energy period for instance). Extra material is also present, namely long-term modelled time series of global wave data (freely available for download) and extreme-value analyses (Saulnier et al., 2013). Some examples of RDPs are shown in Figure 4. These products are aimed at providing the user with wave analysis outputs – relevant for all kinds of engineering and environmental studies – as well as the raw data used to produce them. Previous protocols for the assessment of wave climate and wave energy resources such as the Equimar (Equimar, 2010b) and EMEC guidelines (EMEC, 2012) have presented information on producing refined data products for wave parameters. These have been submitted as the basis for the international standard International Electro-technical Commission TS 62600-101 "*Wave energy resource characterization and assessment*", due to be published in 2013. SOWFIA has contacted the group working on the above standards, as well as different wave energy stakeholders in order to get guidance for producing refined data products for wave and current data that could find wide use in the sector.

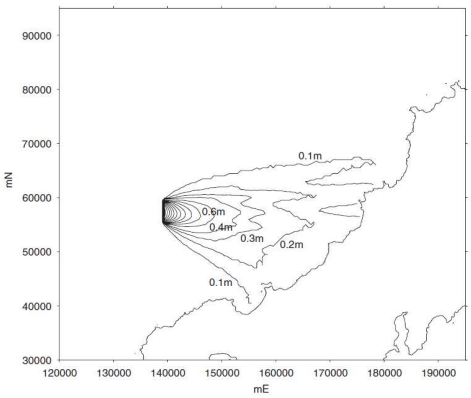


Figure 5: Simulation of significant wave height attenuation downstream Wave Hub test site with no energy transmission (worst case scenario) from Millar *et al*. (2007)

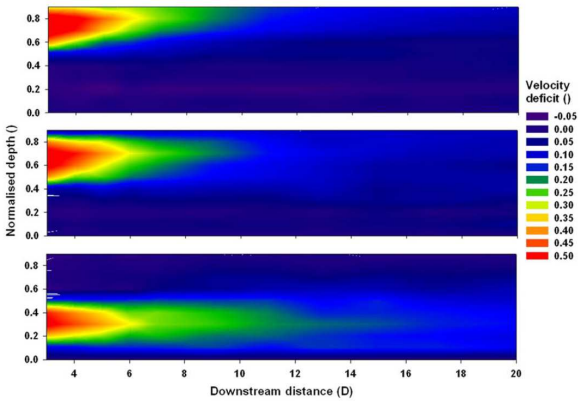


Figure 6: Experimental analysis of flow velocity deficit downstream from current turbines (Myers and Bahaj, 2010)

3.1.5. Lessons on probable impacts

To date, there is no certainty that wave and tidal energy farms will impact the wave and current fields significantly. Various academic studies have been carried out to evaluate the potential change on waves through an array of wave energy converters (WECs) based on wave propagation and simplified hydrodynamic models (e.g. Millar *et al*., 2007; Smith *et al*., 2012; Rusu and Guedes Soares, 2013; Babarit, 2013). A regular comment stemming from the literature review is that the methods used to answer the question still need large improvements, in particular the modelling of the energy absorption of farms. Preliminary studies generally conclude that the change in significant wave height alongshore due to the presence of an array of wave energy devices should not exceed a few percent (see Figure 5). The largest effects of absorption will be experienced immediately

downstream of the array where wave energy, period and spreading are most likely to be modified. The combined effects of wave spreading and diffraction will then lead to reductions in these alterations as distance from the array increases so that the net effect on distant shorelines can be quite small. Smith *et al*. (2012) argue that the changes which will eventually be observed are likely to be overestimated due to the high rates of device energy absorption by the devices which are generally assumed in the modelling.

3.2. Noise Monitoring

The ocean is not a 'silent world', particularly near coastlines. Wave breaking, seismic events and marine inhabitants all contribute to background noise. In recent years, sounds from human activities such as shipping, seismic surveys and seabed drilling have increased the ambient level in certain areas (Hildebrand 2004). The deployment of marine renewable energy devices will introduce new sources of noise into the underwater environment. Many marine species use sound for communication, navigation, finding prey and evading predators (see e.g. Richardson et al. 1995). Different species detect and emit sound over a broad range of different frequencies and amplitudes. Because of their dependence on sound, it is possible that the noise added to the underwater environment from the construction and operation of marine renewable energy devices and farms could have an effect on these underwater species.

Species that could be most at risk from underwater noise include whales and dolphins, seals, fish and diving seabirds, many of which are afforded protection under the EU Habitats Directive (92/43/EEC, as amended). Effects may include temporary and permanent damage to hearing, irregular formation of gas bubbles in fish and marine mammal tissues and changes in behaviour (Götz et al. 2009). These changes in behaviour could be avoidance of, or attraction to, the sound source (See Section 4.1 for more details).

In the EU, anthropogenic underwater noise comes under the Marine Strategy Framework Directive (2008/56/EC) which lists the introduction of energy, including underwater noise, as one of the eleven descriptors to be used by Member States for determining Good Environmental Status,. The over-arching aim of this Directive is to achieve or maintain Good Environmental Status (GES) in the marine environment by 2020 and to protect the resource base upon which marine-related economic and social activities depend. Under this legislation, Member States are required to determine a set of characteristics of GES for their waters and then establish and implement a programme of measures designed to achieve or maintain good environmental status in the waters concerned. The set of characteristics for GES are based on eleven qualitative descriptors. A Task Group (TG) was established for each of the qualitative Descriptors, and the report on the criteria and indicators in relation to Descriptor 11 (Noise) considers the descriptor to mean 'anthropogenic sound that has the potential to cause negative impacts on the marine environment, which in this case includes component biota but not necessarily the whole environment'. It suggests that 'a systematic inventory of acoustic conditions in regional seas would help in documenting the extent of current noise exposure, and estimating the pristine historical or desired future conditions for the resources. This would help in understanding the impacts of different noise sources in different areas and show differences between regional seas. This comparison will help making objective decisions of a good or bad environmental status' (Tasker et al. 2010). Accordingly the measurement of noise is expected to become a much more pressing issue at national level which in turn may have consequences for wave energy developers and the potential noise output of their devices.

Noise from wave energy developments may also come under EIA Directive (85/337/EEC, as amended). In projects where noise is required to be included as part of the EIA, Annex IV of the

Directive states that the EIA should include an estimate by type and quantity of expected noise emissions resulting from the operation of the proposed project.

3.2.1. Monitoring requirements & methodology

Noise measurements have been required as part of the EIA for some, but not all, of the European wave energy test centres (see Chapter 1). Noise measurements have also been required for tidal energy projects, an important example of which is the Marine Current Turbines (MCT) project in Strangford Lough where MCT were required to make baseline, construction and operational noise measurements to ensure that sub-surface noise did not cause a level of disturbance to marine animals sufficient to displace them from areas for foraging and social activities. Given that noise monitoring has been required for the above EIAs and that anthropogenic underwater noise is covered under the MSFD (2008/56/EC), it is likely that underwater noise monitoring may become a term and/or condition of the consent issued or indeed a more frequent requirement in EIA as it applies to wave energy developments. Austin *et al.* (2009) states that comprehensive environmental assessments examining potential impacts associated with wave energy converters (WECs) should include an assessment of any potential underwater noise impacts.

Measuring underwater noise is a well-developed science, however, measuring noise in high-energy locations where marine renewables are to be deployed presents difficulties. There is no established instrumentation or methodology for measuring noise from WECs and their effects on marine animals (Copping *et al.* 2013). Recently there are examples of underwater noise monitoring at tidal energy sites (see e.g. Norris 2009; Keenan *et al.* 2011 and Broudic *et al.* 2012) from which some guidance can be drawn for wave energy deployments. There are many requirements that need to be considered when designing a noise monitoring programme for a wave energy deployment, some of which may not have to be considered for tidal energy developments:

Before assessing the noise contribution of WECs, the baseline noise conditions at the site need to be understood. This includes natural noise contributions (waves, wind, sediment movement, etc.) and anthropogenic noise contributions (shipping, piling etc.). These can vary with, amongst other things, wave conditions, weather conditions, season, current speed and direction. A baseline monitoring programme needs to take the variation of these parameters into account.

Noise monitoring programmes during construction and operation will be dependent on the environmental sensitivity of the site, its classification, construction methods being used (i.e. piling, no. of boats etc.) and the device being deployed. The noise emitted by the device will vary under different wave and operating conditions. At present, there is little data of any sort available for the noise output from any type of wave energy converter. Like other types of environmental monitoring, the level of monitoring required is likely to be dependent on the location of the site, the national implementation of EU Directives, the marine species present at the site and the sensitivity of the site (e.g. whether it is a designated Special Area of Conservation (SAC) or Special Protected Area (SPA) or whether strict protection measures are required for the species at the site under the Habitats Directive (92/43/EEC)). The instrumentation and methodology used needs to be capable of distinguishing between noise from the WEC installation and operation and other noise, such as that mentioned above and from turbulence.

Sound waves have two components: pressure and particle velocity (see e.g. Southall *et al.* 2009). It seems that marine mammals have greater sensitivity to sound pressure while fish can detect particle motion or sound pressure or both depending on the species, hence, sound pressure measurements are of interest when studying the impacts on marine mammals while particle motion measurements may be required for certain fish species. Single hydrophones can be used to measure sound pressure

while hydrophone arrays or particle velocity detectors can be used to obtain particle velocity measurements. Directional hydrophones such as those used in Directional Frequency Analysis and Recording (DIFAR)[1] sonobuoy, can be used to give bearings as to where an acoustic signal originated. Hydrophones and hydrophone arrays have been used mostly for impact assessment of wave energy deployments and so measurements using this instrument are focussed on in this document.

3.2.1.1. Noise monitoring equipment

Recommendations are given in Austin *et al.* (2009) for the type of recording equipment which should be used in a noise monitoring programme. The monitoring devices used should have sufficient autonomy and be suitably rugged to withstand long term ocean deployments. Short term measurements can be made by deploying hydrophones from boats but, due to the likely weather conditions at wave energy development sites, these are unlikely to provide measurements over a wide range of conditions. Suitable systems include autonomous recording systems which record acoustic data internally, cabled systems which can send data to shore in real time via a subsea cable or radio telemetry systems which again provide real time monitoring. Autonomous recording systems are commonly used due to their ease of deployment, their precise sensor calibration and the high quality of data recorded. These systems are deployed on various kinds of moorings or directly on the seafloor and retrieved once the internal memory is full or their power supply is exhausted.

Current autonomous recording systems technology may be potentially limited by power requirements, bandwidth and internal memory. Systems are available working with bandwidths from a few 10's Hz to greater than 100 kHz. Higher bandwidth measurements require greater storage capacity. It has been speculated that the noise emitted by WECs will be in the region of a few kHz and so a sample rate of 16kHz would be adequate to measure this (Austin *et al.* 2009). By setting measuring devices to record in duty cycle mode, whereby only a certain number of minutes are recorded per hour, the deployment period could be extended and deployment periods of up to a number of months could be achieved at this frequency. Sounds up to 180 kHz are, however, audible to marine mammals and so it may be necessary to measure noise at higher bandwidth until the noise output from WECs is better understood. At present, this would allow only up to a small number of days of data to be recorded in duty cycle mode. There is currently a rapid development of autonomous recording systems allowing longer and wider band recording, and it is likely that as newer recorder systems come on to the market, the capability of longer term deployments at wider bandwidths will increase (Lepper *et al.* (2012)). Before this technology is available, a cabled system or radio telemetry system, both of which are more expensive would be more suitable for long term measurements. These systems would also be used if real-time data, which may be necessary for time critical construction or operational monitoring, is a requirement.

3.2.2. Monitoring locations

Some, but not all of the wave energy test centres, have been required to undertake baseline, construction and operational noise monitoring as part of an EIA. At BIMEP in Spain, a baseline noise monitoring programme was conducted using a sonobuoy moored at 40m depth for six months. The sonobuoy was designed to detect and classify automatically all acoustic events (presence of cetaceans and noise) above the ambient noise (see Bald *et al.* 2012). At Lysekil in Sweden a baseline

[1]http://www.dosits.org/technology/locatingobjectsbylisteningtotheirsounds/directionalfrequencyandrangingdifarsonobuoy/

noise monitoring programme was conducted at one part of the site along with as a noise monitoring programme with a device in place at another part of the site. The recording device consisted of a hydrophone and a Song Meter 2 deployed on the seabed at a depth of 25m, a distance of 20m from the nearest WEC. The monitoring programme was conducted over a 39 day period. Further details can be found in Haikonen *et al.* (2013). For Wave Hub, in England, the EIA recommended a noise monitoring programme to be undertaken for installation works of piled and drilled foundations to continue once a WEC is in operation at the site, as well as a baseline monitoring programme. The University of Exeter has been collecting this baseline noise data since February 2012 in order to facilitate the ability to detect any impacts from subsequent device installations. For other wave energy test centres (e.g. AMETS in Ireland), no noise monitoring programme has been included as part of the EIA.

Two other examples of noise monitoring programmes which were undertaken during a WEC deployment were found during a literature review, neither of which took place in wave energy test centres associated with SOWFIA partners. The first involved underwater noise measurements during the deployment of the 1/7th scale Columbia Power Technologies SeaRay device off the coast of Washington State (Bassett *et al.* 2011). Autonomous acoustic measurements were obtained from a free drifting buoy with a hydrophone 1m below the surface. A series of one-minute hydrophone recordings were obtained for approximately four hours during a single day's deployment.

The other example is the deployment of a number of hydrophones during the deployment of the Pelamis WEC, an attenuator WEC, at EMEC following a baseline monitoring programme at the same test site (see Lepper *et al.* 2012). The baseline noise monitoring programme involved the deployment of bottom mounted hydrophones at three locations, one each to the north, east and west of the test berth for a one day period. In addition, four autonomous subsurface buoys, each containing two hydrophones were deployed for short duration noise monitoring (up to 3 hours) during this time along with the deployment of a pair of hydrophones over the side of a boat, again for short durations (up to 3 hours) during this time. Noise monitoring was then undertaken during the deployment of an operational Pelamis. This used four bottom mounted hydrophones again deployed for just over a day at locations around the device. Shorter duration measurements were again taken using hydrophones attached to sub surface buoys and broadband measurements were taken using hydrophones deployed from a boat.

The noise monitoring at EMEC aims to contribute towards the standardisation of the methodology for noise monitoring for wave energy developments. Another example of such a project is at the Galway Bay Test Centre where a noise monitoring project has been underway since September 2012 (see Kolar 2012). Initially this is a baseline monitoring programme. The ultimate aim of the programme is to capture and analyse the noise and vibrations from operational wave energy converters and to determine the impact, if any, the sound waves from these devices could have on marine life. Details of noise monitoring projects at wave energy test centres associated with the SOWFIA project and at other locations are given in Table 5.

Table 5: Summary of noise monitoring data for each wave energy test centre and its availability through the SOWFIA DMP. This table will be completed when further information regarding noise monitoring at test centres becomes available. Information on noise monitoring from other European test sites is presented if available.

Noise Monitoring at Test Centres Associated with SOWFIA Project				
Test centre	**Monitoring requirements**	**Sampling stations and time period**	**Used methodologies**	**Type of data in the DMP**
Galway Bay (Ireland)	Research purposes	1 no. particle velocity detector and 1 no. hydrophone September 2012 for approximately 2 years	1 year baseline noise monitoring programme which it is planned to follow with a 1 year noise monitoring programme with a wave energy device in place for which additional sensors will be used. Frequencies covered: up to 160kHz.	Data not available at present
BIMEP (Basque Country, Spain)	Part of EIA	1 no. station to cover the extent of BIMEP area June 6 to November 29, 2012	1 no. hydrophone anchored at 40m depth, frequencies 1Hz-80kHz to measure ambient noise and the presence of marine mammals.	Data not available at present
Wave Hub (Cornwall, UK)	Academic research purposes by the University of Exeter	1 no.station a few hundred metres south of Wave Hub. Deployed February 2012 for foreseeable future.	Hydrophone with archival recording technology deployed 10m from seabed. Frequencies covered: several Hz to 48kHz.	Data not available at present

Lysekil (Sweden)	Part of ongoing EIA	Baseline noise monitoring at one location and noise monitoring with a device present at a second location. Both April 4, 2011 to May 28, 2011.	Both sensors SM2 recorder with a HTI 96 minute hydrophone. Baseline monitoring from seabed at 25m depth. Monitoring for noise from device, 20m from device. SM2 had a sampling rate of 44.1kHz Hydrophone had a flat frequency response range between 2Hz and 30kHz	Data not available at present
Noise Monitoring at Other Locations				
Test centre	**Monitoring requirements**	**Sampling stations and time period**	**Used methodologies**	**Type of data in the DMP**
EMEC (Orkney, UK)	Research purposes	Wave Sites: Billia Croo (Full Scale): 2010-2012: Baseline monitoring and monitoring with a device in place	Bottom mounted hydrophones around deployment area for long term monitoring, hydrophones deployed from sub surface buoy and from boat for broadband measurements	N/A. Reports available from EMEC website (http://www.emec.org.uk/research/emec-site-specific-projects/)
Pico Plant (Açores, Portugal)	Only airborne noise required in the EIA	Two day campaign in May 2010, for the characterisation of the noise source. Two day campaign in September 2010 for noise propagation characterisation.	Noise source characterisation: Hydrophone was moored at 10 m from the plant; Noise propagation campaign: Noise measured in 3 transects as far as a distance of 3 km distance from the plant in different directions	Data under processing;

Peniche (Portugal)	Only airborne noise required in the EIA	One campaign for ambient noise characterisation (for baseline characterisation); A subsequent campaign for device noise characterisation and propagation is expected to be carried out.	Both moored and moving hydrophones (operated from the boat); data acquisition was made at mid water column (maximum depth was 20m) using several transects starting from the predicted site location for the Wave Roller machine	Data under processing; reports will be made available at the end of the SURGE project (http://fp7-surge.com/?page=main&lang=en)

3.2.3. Suggestions towards a common methodology and data refinement

It is hoped that noise monitoring programmes such as those described above will contribute towards the standardisation of methods for measuring underwater noise from wave energy developments. As with other environmental monitoring activities described in this report, it may be difficult in practice for a common methodology to be put in place. As stated previously it is likely that noise monitoring methodologies will be dependent on the site location, legislative requirements, funding available as well as the type of device which is to be deployed and the device installation methods. The methodology used is also dependent on the species present at the site. Different marine animals have widely differing hearing capabilities. Fish detect infrasonic and low frequency sounds ranging from 15 Hz to 1 kHz, marine mammals hear high frequency sounds ranging from below 100 Hz to 180 kHz.

There are a number of different phases required for a noise monitoring programme of a wave energy development. The first stage is a characterisation of the acoustic environment into which devices will be deployed. This stage should be of long enough duration so as to fully understand the baseline noise conditions at a site. This includes the variation of natural and anthropogenic noise contributions with amongst other things, wave conditions, weather conditions, season, current speed and direction. Some guidance on baseline monitoring programmes for wave energy developments is given in Austin *et al.* (2009). This states that a baseline ambient noise monitoring programme should be at least 24 hours in duration but strongly recommends that it should last up to a year to capture both daily and seasonal variability. This duration of monitoring programme is likely to be expensive with the requirement for the data to be transmitted to shore to avoid storage capacity issues.

Austin *et al.* (2009) recommends that at a minimum, a single recorder should be deployed near a proposed WEC installation site with at least one additional recorder placed in a control location, at such a distance where the acoustic emission from the installed WEC is negligible. To enable a more complete baseline characterisation, it is recommended to place additional recorders (2-4) at several locations positioned at increasing distances from the installation site. The recorders should be equipped with GPS so that their locations during the deployment period can be determined during analysis.

There is little experience monitoring noise for operational wave energy devices and the noise profile of specific devices and the cumulative effect of several devices is not yet known. For initial developments, it is likely that a long duration noise monitoring programme will be required in order to gain understanding of the amplitude (dB) and frequency spectrum (Hz to kHz) of the WECs being deployed. Until more is known about the noise emissions from WECs, it is likely that initially noise monitoring will need to measure noise at a wide range of frequencies to cover the hearing capabilities of all species at the site. Measurements from initial deployments of single deployments can be used to help assess the cumulative effect of multiple WECs being deployed as part of wave energy arrays.

Guidance is given in Austin et al. (2009) for noise monitoring during operation of a WEC, much of which is also applicable to construction and installation noise measurements. The chosen sample rate needs to take into account the sources of noise that are being measured at the site. The sound levels should be recorded in the same locations as previously, while making sure that the measuring

device closest to the noise source is not too close to avoid near field effects[7]. If feasible, measurements should be obtained at several orientations around the device to investigate the directionality of the sound emission. During WEC operation, the measurements should be made under all representative WEC operating conditions and sea states. This may require a monitoring programme of greater than a year in duration. Again, this would probably require the measured data to be transmitted to shore in real time. GPS co-ordinates should be recorded for the measuring devices and the operational wave energy device. During construction a log of construction activities and vessel movements should be maintained while during operation a log of operating conditions should be maintained. Environmental conditions such as wave height, current speed, wind speed and water temperature should also be measured.

A methodology for noise monitoring at wave energy test sites has also been produced by EMEC (Lepper et al., 2012). Slightly different monitoring set-ups are proposed depending on whether the WEC is a floating or fixed type device but again it is recommended that if possible more than one measurement device should be used and measurements should be made in different directions around the WEC. In order for the storage capacity of the device to last longer, it is proposed that hydrophones measuring at bandwidths up to the mid 10s of kHz be used mostly while samples at higher bandwidths which cover the hearing range of all animals at the site are taken at regular intervals.

Monitoring of marine animals present at the site should be undertaken during the noise measurement programme. This is described in the Marine Mammal monitoring (4.1) and Seabirds monitoring (4.2) sections of this report. A comparison of the acoustic signatures of the new sound sources should be made with auditory ranges of the species present at the site in order to assess the potential for impacts and to calculate the zones of influence of noise from the wave energy development for different species.

3.2.4. Refined data products for sound measurements

There is currently no noise monitoring data available on the SOWFIA project Data Management Platform (DMP) from the wave energy test centres. The format that refined data products (RDPs) are likely to be presented in can be been informed by reviewing available literature related to the potential impacts of noise in the marine environment. It is likely that data products would be based around the potential exposure of animals to underwater sound based on the following two parameters:

1. Sound pressure level (SPL): A logarithmic measure of the effective sound pressure of a sound, measured in decibels (dB) relative to a reference pressure (generally 1 micro-Pascal (µPa) in water). SPL can be presented as:
    a. Peak SPL: the maximum amplitude of a sound wave;
    b. Peak to peak SPL: the range from the maximum positive peak to the maximum negative peak. These are usually used to describe short, high intensity sounds (Götz et al., 2009);

[8]In the case of a sound source that extends over a larger area, the measured Sound Pressure Level (SPL) what is SPL? in the immediate vicinity of the source would be highly variable. This area is known as the nearfield. Due to this effect it is good practice to make source level measurements in the acoustic 'farfield'. Source levels can then be calculated back by a measured or modelled transmission loss (Götz et al. 2009).

c. RMS (root mean square) SPL: the square root of the average of the square of sound pressure over a given period. This measure is directly related to the energy carried by the sound wave (intensity) & should only be used for measuring non-impulse sounds.

2. Sound exposure level (SEL): This is a measure of the energy of a sound, taking both amplitude and duration into account. It is again measured in dB, this time relative to a squared reference pressure over a one second period (generally 1µPa2s for water). SELs can be considered useful when making predictions about the physiological impact of noise (Götz et al., 2009). SELs can be presented as:
   a. Cumulative SEL: the total sum of energy over a number of individual impulsive events;
   b. Single strike SEL: the energy in a single impulsive event (Copping et al., 2013).

It is important to present the frequency content of measured noise as well as the decibel level of the sound. This is because species differ greatly in their hearing sensitivity at different frequencies. The term bandwidth describes the frequency range of sound. Spectral displays are used to show the SPL or SEL on the y-axis as a function of frequency which is plotted on the x-axis. Spectra display the measured sound in decibels within different frequency intervals. 1/3 octave bandwidths are the most common frequency interval used in physical analysis (Götz *et al.,* 2009).

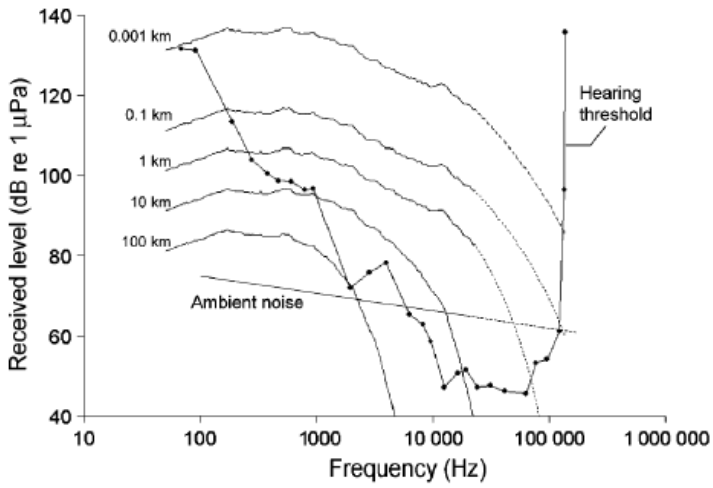


Figure 7: Audiogram of bottlenose dolphin with predicted 1/3 octave pile driver noise spectra at different distances from the source (David 2006).

3.2.4.1. Data presentation

An important tool which can be used to show the potential impact of noise on different species is the audiogram. A species' hearing threshold is the average sound pressure level that is just audible to it under quiet conditions. The threshold varies with frequency. An audiogram is a plot of the hearing threshold with frequency. The noise measured during a monitoring programme can be plotted on an audiogram for different species. This will help to show whether the noise measured will be perceptible to different species. If noise is measured at multiple locations away from the source, it is possible to plot these multiple measurements on the same graph to show the area in which the measured noise will be perceived. An example of this is given in Figure 7, which shows the audiogram of a bottlenose dolphin with predicted pile driving noise at different distances overlaid on it. Different audiograms can be produced for different operating conditions and noise events.

Another means of presenting the impacts of a wave energy development is to show the theoretical zones of influence around the new noise source for each affected species. This method is based on that first proposed in Richardson *et al.* (1995) and is shown in Figure 8 as presented in Götz *et al.* (2009). This model has been used very often in impact assessments where the zones of noise influence are determined by noise propagation modelling or sound pressure levels on the one hand and information on the hearing capabilities of the species in the other. This model gives a very rough estimate of the zones of influence as sound in the sea is always three dimensional.

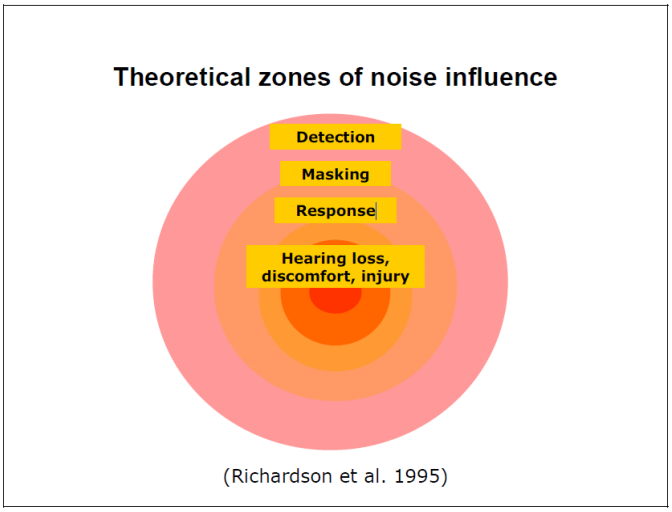


Figure 8: Theoretical zones of noise influence (Götz *et al.,* 2009).

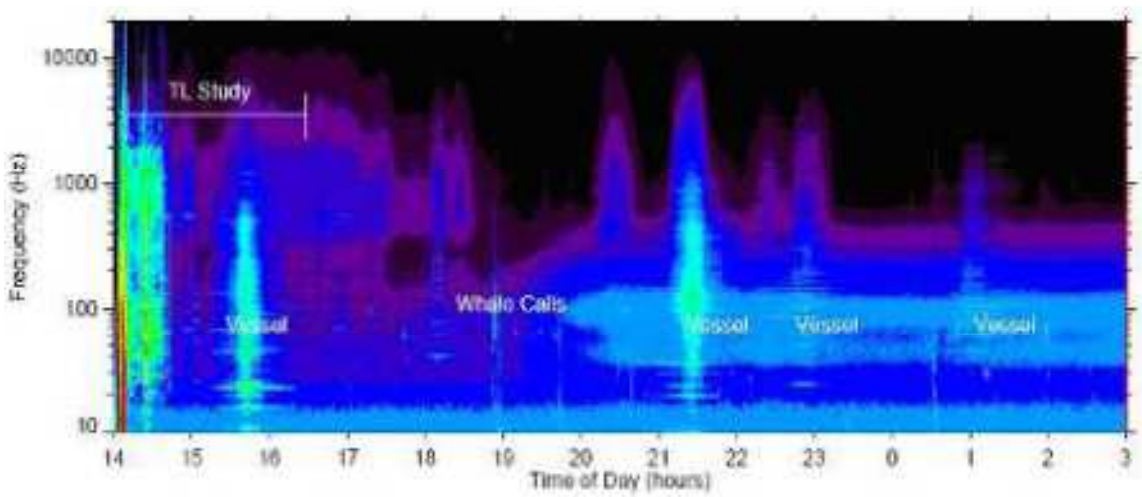


Figure 9: Example of spectrogram (Austin et al., 2009).

For data sets longer than 24 hours duration, Lepper *et al.* (2012) proposes long term spectral analysis. This analysis can be useful for determining long term noise level trends and identification of specific noise events. It is useful to identify the sources of measured noise on the spectrogram as shown in the example of the spectrogram shown in Figure 9. Different WEC operating conditions and modes could be identified in a similar way.

3.2.5. Lessons on probable impacts

3.2.5.1. Potential impacts

To date, no universal conclusion can be made on the effect of sound on marine life. It is, however, generally accepted that exposure to anthropogenic sound can induce a range of adverse impacts to different marine species. Götz *et al.* (2009) has broadly divided the potential effects of sound on marine animals as follows:

- Sounds in the marine environment which are above the hearing threshold for a certain species can mask sounds used by that species, resulting in important information being lost by that species. It should however be noted that most animals use a range of frequencies to communicate so it is unlikely that the full range of frequencies would be masked over long time periods.
- Behavioural disturbance: Changes in animal behaviour can result in response to sound. These changes in behaviour may be attraction or avoidance to the sound source. They can result in adverse effects such as animals avoiding a food source or becoming attracted to the noise source which may place them in danger.
- Hearing loss: Temporary threshold shift (TTS) and permanent threshold shift (PTS) represent changes in the ability of an animal to hear at a particular frequency. Similar to masking, this can result in animals missing important acoustic information. TTS and PTS are very difficult to measure in marine animals in their natural environment (Copping et al., 2013) and are usually measured in laboratory conditions (see e.g. Lucke et al., 2007).
- Non-auditory effects (discomfort/injury): Non-auditory effects caused by sound include damage to non-auditory tissues (swim bladder, muscle tissue in fish), enhanced gas bubble growth in fish and marine mammals, traumatic brain injury/neurotrauma in fish and marine mammals etc. Research on non-auditory effects is in its infancy and again, measurements of non-auditory effects in the marine environment are very difficult.
- Death: In extreme cases, and at very high received sound pressure levels that are usually close to the source, very intense sounds might lead to the death of the receiver.

3.2.5.2. Probable impacts

Impacts from noise from wave energy developments can occur during either the construction/ decommissioning phase or during the operational phase of the development. The impacts during each of these phases will be device dependent. A list of the impacts likely to be caused by generic device types is given in Austin et al. (2009).

The impacts associated with the construction and installation of floating devices will vary with device type. For the installation of floating devices, impacts will be largely dependent on the mooring system required for the device. Some devices will use large anchors to moor floating components. The noise emissions from the installation of these anchors will be the noise associated with the installation vessel(s) used. Underwater noise emissions will also be associated with the vessels required for the installation of the floating device itself. Some floating devices have a fixed seabed component associated with them while other devices are designed to be completely fixed to the seabed. Piling or drilling may be required to install these fixed components to the seafloor. Subsea cables or high pressure pipelines may also be required to be fixed to the seabed. Lessons learned from the impacts associated with some of these activities can be taken from other offshore industries (e.g. offshore wind) and are discussed further in the sub-sections below. The installation of fixed devices will probably create general construction type noise at the shoreline or relatively close

to the shoreline. Construction vessels are likely to be involved in this activity and their impact will depend on the type of vessel, how they are operated and for what duration.

Noise associated with the operational phase of a device will be largely dependent on the energy conversion mechanism used by the device. Many different types of energy conversion mechanisms are being developed for wave energy devices including components such as electrical generators, air and water turbines, pumps, hydraulic and electromechanical components etc. External mechanical noise associated with the devices could arise from vibration of mooring lines and the sound of waves coming into contact with the device. Service visits, both scheduled and unscheduled, will also be required for devices during which vessel noise will also occur. Additional noise that may result from wave energy developments include the noise associated with the construction and operation of collecting hubs that link arrays of devices.

As well as varying with device type, the noise impacts will vary with the physical characteristics of the development site (i.e. depth, topography, sediment structure, hydrography, currents, wave conditions etc) and with the species present at the site.

3.2.5.3. Impacts associated with noise from pile driving

The noise levels associated with pile driving vary depending on the diameter of the pile and the method of pile driving (Götz *et al.,* 2009). The frequency spectrum of pile driving noise varies from less than 20Hz to greater than 20kHz with most energy around 100-200Hz. Source levels of up to greater than 250dB at 1µPa have been reported for offshore wind farm pile driving. The impacts and potential impacts associated with noise from pile driving have been investigated for a number of offshore wind farm developments and a number of species, examples of which are given below.

During the construction of the Horns Rev II offshore wind farm in the Danish North Sea, Brandt *et al.* (2011) reported that porpoise acoustic activity was reduced by 100% from baseline activity in the period up to 1 hour after pile driving and stayed below normal levels for 24 to 72 hours at a distance of 2.6km from the construction site. This period decreased with increasing distance. Reduced activity was observed out to a distance of 17.8km. Sound measurements conducted during the pile driving indicated that hearing impairment could potentially have occurred close to the construction site. During the construction of the Nysted wind farm, during pile driving, Edrén *et al.* (2004) reported a 10 – 60% decrease in the number of hauled out harbour seals on a sandbank 10km away from the construction during days of ramming activity compared to days when no pile driving took place. This effect was of short duration. David (2006) states that it is unlikely that dolphins would experience permanent hearing impairment from sound pressures associated with pile driving activity but that effects on behaviour are more likely. There is limited information on the effect of pile driving noise on fish, but there are reports in grey literature that severe physical damage to fish is possible due to pile driving (Götz *et al.,* 2009).

As stated above, pile driving is only required for certain types of wave energy device developments so noise from this source is unlikely to require consideration for many developments. Where it is required, evidence from other industries indicates that negative impacts may occur and mitigation may be required. Mitigation measures are reviewed in Götz *et al. (*2009). These include reducing the sound levels produced by piling by extending the duration of the impact, by enclosing the ramming pile with acoustically-isolated material (mantling) or installing an air bubble curtain around the pile. Alternatively a soft-start procedure may be applied or piling operations can be timed to avoid particular seasons or ceased if animals are detected within a certain proximity.

3.2.5.4. Impacts associated with noise from operational WECs

There is little available information on the impacts associated with noise from operational WECs. To date noise studies have focussed on attempts to measure the acoustic signature of different WECs. The conclusions from these studies are limited. At Lysekil in Sweden analysis of the noise measurements from a WEC was only possible for significant wave heights of less than 0.5m because above this, the recordings were corrupted due to overload distortion. The main sound emitted from the WEC in these sea conditions was due to a fault in the assembly of the WEC, which resulted in the end stops being reached too early. Most of the analysed noise was less than 1000Hz in frequency. It was concluded that noise levels would be unlikely to induce behavioural reactions in the least sensitive fish and that the intensity of noise is most probably below the threshold of causing physical injury to fish. The low frequencies measured mean that the most of the WEC noise is below the hearing threshold of all marine mammals at the site apart from harbour seals. A preliminary estimation is that the risk of injury to marine mammals at the site due to short time exposure to the analysed WEC noise is unlikely. This study was limited because it was not possible to use data recorded in sea states with a significant wave height above 0.5m, which is what WECs typically require to generate power.

Noise measurements of the 1/7th scale SeaRay WEC were made off the coast of Washington State (Bassett et al. 2011). It was found that an acoustic source level could not be estimated during operation due to significant levels of anthropogenic noise coming from shipping and limited variation in received levels with distance from the WEC. Noise measurements were also made during a Pelamis deployment at EMEC (Lepper et al. 2012). The measured noise spectrum ranged from a few tens of Hz to tens of kHz, within the hearing response of many marine mammals and fish species. Source level estimates to device midpoint showed a 10 minute averaged third octave band (CPB) level at around 120 dB re 1 $\mu Pa^2 Hz^{-1} m^2$ for components in band 10 Hz - 2 kHz for less energetic sea-states rising to 181 dB re $1 \mu Pa^2 Hz^{-1} m^2$ in the 1 kHz band. It was found that both frequency of occurrence and the level of some of the potential noise sources from the Pelamis system are likely to be higher at increased sea states as the system becomes more energetic. It was found that the variation between baseline and operational levels is likely to be highly dependent on sea state, local propagation conditions, other noise sources, and devices status.

The acoustic output of the Pelamis device was modelled in Portugal to investigate potential effects on harbour porpoise (Copping et al. 2013). It was found that a harbour porpoise might hear the WEC at a distance of 5km, might be disturbed at 3km and might suffer temporary auditory injury at 1km. If three WECs were deployed, these distances would increase to 6km, 4km and 2km respectively. Validation of these results by field data has not been found.

Some indication of the impacts of operational WECs can be taken from offshore wind turbines. Lucke et al. (2007) found that simulated offshore wind turbine noise was only able to mask the detection of low frequencies of up to 2 kHz by a harbour porpoise and the zone of masking around a turbine was 20m, indicating a very low impact. Caution should be taken in applying these results to operational WECs because offshore wind turbines are mostly above the water surface whereas many WECs will mostly be below the water surface. In addition, the sound profile of WECs is likely to differ substantially from that of wind turbines.

It is likely that the noise energy emitted by WECs will be frequencies up to a few kHz and the nature and intensity may be comparable to that emitted by machinery onboard typical similar sized vessels. It is unlikely that single WECs will cause significant noise impact at longer ranges, however, further studies are required to determine the output of WECs with more certainty. The impacts of larger

numbers of devices, during both construction and operational phase, also need to be considered further.

3.2.5.5. Impacts associated with boat noise

Noise emissions associated with boats and vessels are dependent on the type of vessel being used and its size, mode of propulsion, its operational characteristics, its speed and other factors (Götz *et al.,* 2009). Boats required for wave energy development installation and maintenance include small craft such as crew boats and workboats, medium sized craft such as tug boats and large vessels such as cable laying vessels.

Götz *et al.* (2009) reviews the noise levels associated with different sized vessels. Small craft and boats produce relatively broadband acoustic signatures with free field source levels approximately 160 to 175dB re 1µPa, although the output characteristics are highly dependent on speed and other operational characteristics. This may be of concern in partially enclosed bays and harbours during time periods when both small vessel traffic and marine animals are particularly abundant.

The sound levels from medium sized and larger vessels are generally in the low frequency band (below 1 kHz) and are generally in the 165 – 190dB re 1µPa range. It appears that a single exposure to this noise is unlikely to be sufficient to damage the hearing of marine mammals; however, long term noise exposure has not been sufficiently examined with regards to cumulative damage. The greatest potential effect is masking for groups of marine animals that produce and perceive sounds primarily within the lower frequencies contained in shipping noise. This includes baleen whales, seals, sea lions and fish as well as the lowest social sounds of some of the toothed whales.

There are a number of available measures to mitigate the impacts of boat noise (Götz *et al.,* 2009). Operational measures such as routing and speed restrictions can be put in place. It might also be possible to place restrictions on the types of vessels to be used in the development as commercial applications of boat quietening technology rapidly advance.

4. Flora and Fauna

4.1. Marine Mammals

Marine mammals are an important component of the marine ecosystem positioned at the top of the trophic chain; as such, they can often act as indicator species for the health of the marine ecosystem. In European waters, marine mammals include pinnipeds (grey seals *Halichoerus grypus*, and harbour seals *Phoca vitulina*) and cetaceans (whales, dolphins and porpoises). These two groups require different monitoring approaches, since pinnipeds are central place foragers and can spend much of their time hauled out on land, whereas cetaceans spend all of their time within the water column. Since MRE devices are likely to be in on-shelf shallow water (< 200 m depth), the main species that they are likely to affect are seals and the coastal on-shelf species of cetaceans. The most widespread and abundant cetacean species in European waters is the harbour porpoise *Phocoena phocoena*, though it only occurs in low densities in the south off Portugal and Spain. Other species common to European coastal waters include: minke whales *Balaenoptera acutorostrata*, killer whales *Orcinus orca*, common dolphins *Delphinus delphis* and bottlenose dolphins *Tursiops truncatus* and in some areas Risso's dolphins *Grampus griseus* and fin *Balaenoptera physalus* and humpback whales *Megaptera novaengliae*. All marine mammals are protected under European legislation; however, harbour porpoises, bottlenose dolphins, grey and harbour seals are specifically protected under Annex II of the Habitats Directive.

4.1.1. Monitoring requirements & methodology

4.1.1.1. Monitoring requirements

There is a range of relevant national and EU legislation which must be considered when planning for MREIs. National legislation is generally restricted to territorial waters, which is defined as within 12 nautical miles (c. 20km) of the coast. EU Directives apply to the Exclusive Economic Zone of the state which extends to 200 nautical miles (c. 370 km) from the shore.

The most relevant EU legislation is the Habitats Directive. The Habitats Directive (Council Directive 92/43/EEC) aims to maintain and, where possible, restore the favourable conservation status of habitats and species across Europe. One specific mechanism of the directive includes the protection of some 220 habitats and approximately 1,000 species. These habitats (listed in Annex I) and species (listed in Annex II) were selected following strict criteria and require the designation of Special Areas of Conservation (SAC) or Sites of Community Interest (SCI) to protect a representative range of these habitats throughout the EU. SACs and Special Protection Areas (SPA), designated under the EU Birds Directive make up a coherent network of sites known as the Natura 2000 network. Each site has a list of qualifying interests for which the site is protected and for which favourable conservation status must be achieved. Favourable Conservation Status is reported on every six years with the last reporting round in 2013.

Some of the relevant marine habitats listed in Annex I of the Habitats Directive include sandbanks which are slightly covered by sea water all the time, large shallow inlets and bays, sea caves and reefs. Marine species on Annex II of the Habitats Directive include: three species of seal - grey seal, harbour seal and Mediterranean monk seal *Monachus monachus;* two subspecies of the ringed seal - *Phoca hispida bottnica* from the Baltic and *Phoca hispida saimensis* from Finland; and two cetacean species- harbour porpoise and bottlenose dolphin. The Mediterranean Monk seal is also a priority species, which means the EU has particular responsibility in view of the proportion of their natural

range. Species listed in Annex IV of the Habitats Directive require strict protection, which includes all species of cetacean and marine turtles recorded in EU waters.

The designation process for Natura 2000 sites was due to be completed by the end of 2010 but some issues remain at several sites. To date (June 2013) there are 1,764 marine SACs covering 179,148 km^2. Designation of a site as an SAC does not restrict all developments within these sites but requires additional environmental impact assessment on the conservation objectives (known as Natura Impact Assessments) and tighter mitigation measures.

Articles within the Directive, which are relevant to developing marine renewable energy, include Articles 6 and 12. Article 6 outlines the obligation to undertake a Natura Impact Assessment with Article 6(3) concerned with the strict protection of sites and Article 6(4) the procedure for allowing derogation from this strict protection in certain restricted circumstances. Article 12 makes it an offence to deliberately capture, disturb or kill any species on Annex II or IV or take actions that result in deterioration or destruction of their breeding sites or resting places. This article addresses issues such as entanglement in MRE devices including moorings, displacement from important habitats including breeding and haul-out sites for seals. Thus a derogation is required to permit an activity (such as the placing of MRE devices) if there is evidence or concern that this activity may impact on a Natura 2000 site or protected species. The need to apply the precautionary principle in making any key decisions in relation to impacts on Natura 2000 sites or protected species has been confirmed by European Court of Justice case law.

Unlike an environmental impact or strategic environmental assessment, where authorities have to only take into account any impacts, the outcome of the assessment procedure under the Habitats Directive is legally binding and conditions the final decision on whether or not to approve the project.

Other relevant legislation includes the Environmental Impact Assessment ((EIA) (Council Directive 85/337/EEC) and the Strategic Environmental Assessment (SEA) (Directive 2001/42/EC), which aims to assess the impact of projects and plans and on the environment. The EIA Directive refers to installations for the harnessing of wind power for energy production (wind farms) as well as industrial installations for the production of energy in Annex II, which lists projects where an EIA is discretionary and dependent on whether the planning authorities considered the proposal to potentially have a significant impact. No explicit reference is made to wave or tidal energy. The SEA Directive relates to public plans and programmes to determine whether they are likely to have significant environmental effects.

The Marine Strategy Framework Directive (MSFD) is another relevant piece of legislation. This is in place to assess and mitigate the impacts of anthropogenic noise in the marine environment. The main aim of the MSFD is that European seas achieve Good Environmental Status (GES) by 2020. Under this Directive Member States hope to reach a balance between utilising the ocean as a natural resource and the ability to achieve and maintain good environmental status (GES) of marine waters. GES will be assessed according to 11 Descriptors, the eleventh of which encompasses anthropogenic ocean noise. As advised by the Commission (1 September 2010), under Descriptor 11, two indicators have been developed with specific criteria in order to measure whether GES has been achieved. These indicators are 11.1.1 Low and mid frequency impulsive noise and 11.2.1 Low frequency continuous noise.

Since all marine mammals are protected by national, European and/or international legislation, consideration should be given as to how any MRE development is likely to disturb or injure these species. Monitoring of marine mammal populations before, during and after deployment of MRE devices is often required as part of the EIA process. The level of monitoring required is very dependent on the location of the renewable energy extraction site, the type of devices to be

installed, the national legal requirements and European legislative requirements that may apply if developments are likely to have an impact on sensitive sites of European importance (such as SACs).

4.1.1.2. Monitoring methodology

Baseline (pre-construction) data will usually include desk studies of historical data for proposed development areas, which may also include field data collected specifically for the purpose of pre-development scoping and EIA studies. Local, regional or national Non-Governmental Organisations (NGOs) and research bodies may also collate data on local marine mammal populations.

Methodologies appropriate for monitoring seals include (Table 6): ground or aerial based counts of hauled out animals (Leeney et al., 2012), photo-ID (Cunningham, 2009), boat or aerial-based line transect surveys (Leeney et al., 2012), land-based point surveys (Cordes & Thompson 2013), telemetry (Cunningham et. al, 2008) and monitoring of stranding data (Leeney et al., 2008; Pikesley et al., 2011). Methods appropriate for cetaceans (Table 6) also include boat or aerial-based line-transect surveys to provide abundance estimates (Buckland et al., 2001), towed acoustic boat surveys (Gillespie et al., 2009), land-based point surveys (Mendes et al., 2002), static acoustic recorders (Brandt et al., 2011), and monitoring of strandings (reviewed in Evans & Hammond 2004). Cetaceans can also be tracked using theodolites (from vantage points) or video-range tracking (land or boat-based) to examine fine scale behaviour in the vicinity of wave energy converters (WECs) (Macleod et al., 2011, SCANS II 2008).

Static passive acoustic methods are increasingly being used to assess impact of MRE developments on vocalising cetaceans (e.g. Brandt et al., 2011). A report from the Collaborative Offshore Wind Research into the Environment (COWRIE) in the UK recommended that Static Acoustic Monitoring (SAM) is used to evaluate the impacts of offshore wind farm construction and operation on harbour porpoise, common dolphin, and bottlenose dolphin populations (Diederichs et al., 2008).

Table 6: Monitoring methods for characterisation of marine mammals close to MREIs. º Applicable to monitoring basking sharks. ✓ Indicates methodologies for cetaceans and ⬩methods for seals (Macleod et al., 2011).

Primary assessment type	Monitoring Objective	Monitoring Method								
		Strandingsº	Vantage Pointº	Line Transectº	Towed Array	Static Acoustic Monitoring	Photo ID	Telemetryº	Aerial surveys of haul outs	Boat counts of hauls
EPS licence, appropriate assessment and EIA	Species present	✓	✓⬩	✓⬩	✓	✓			⬩	⬩
	Density/ abundance		✓	✓⬩	✓	✓	✓⬩		⬩	⬩
	Habitat use		✓	✓	✓		✓⬩	✓⬩		
AA only	Connectivity SAC						✓⬩	✓⬩		

Different methods are appropriate for answering different questions during the impact assessment phase (Table 7). For example, boat based line transect surveys can give an indication of the species found in the area, provide an estimate of abundance (given a large enough sample size), and the distribution of species over the area surveyed. However, it has limited ability to determine behaviour, injury or mortality risk associated with WECs. Connectivity of animals found at wave energy development sites with local SACs can only be determined with a limited range of survey methodologies: photo-ID or telemetry. Photo-ID is only appropriate for a few species such as bottlenose dolphins and seals, which have clear markings on their bodies or dorsal fins and are easily photographed, whereas telemetry at present is only appropriate for seals. It is therefore not currently possible to determine whether harbour porpoises present at a wave energy development site form part of an SAC population (i.e. connectivity).

Table 7: Monitoring methods for impact assessment of marine mammals close to MREIs. º Applicable to monitoring basking sharks, ✓ Indicates methodologies for cetaceans and ⬩methods for seals (Macleod et al., 2011). Barrier effects occur when noise acts as a barrier to marine mammals, excluding them from the vicinity of the WECs.

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	✓⬩		✓⬩	✓⬩	✓	✓⬩	✓	
Distribution	✓⬩	✓	✓⬩	✓⬩	✓		✓⬩	
Behaviour	⬩	✓	⬩				⬩	
Injury/mortality		✓					⬩	✓⬩
Communication/ Masking					✓			
Barrier effects	✓							
SAC connectivity						✓⬩	✓⬩	

Passive acoustic monitoring (PAM) is only appropriate for vocalising marine mammals, so inappropriate for either minke whales or seals since they vocalise infrequently, and usually mainly during the breeding season. In Europe the main on-shelf species that can be detected using PAM/SAM are harbour porpoises and dolphins. However, although harbour porpoises can be easily identified from their vocalisations, it remains difficult to identify different dolphin species from dolphin vocalisations. There are two main types of SAM: automated devices that record echolocation clicks (e.g. the T-POD/C-POD, Chelonia Ltd.), or broadband recorders able to record dolphin whistles and clicks (e.g. SM2, Wildlife Acoustics). Click detectors such as C-PODs have the benefit of being able to monitor echolocation continuously over several months. On the other hand broadband recorders

such as SM2s can only record continuously for short periods of time due to the high quantities of data being recorded (e.g. to record up to harbour porpoise echolocation click frequency would require sampling at 300,000 samples/second). These devices are usually set to record on duty cycles to allow for more long term monitoring. Range is also significantly different for whistles and clicks: clicks tend to be high frequency and highly directional so can only be detected at a range of 100-500m, whereas the more omni-directional broadband whistles can be detected at much larger distances depending on the propagation conditions (1-10km).

The main advantage of SAM is that it is currently the only method available for long term continuous monitoring of vocalising cetacean activity. As a result it has become a standard method for monitoring impacts of MRE developments on vocalising cetaceans, particularly harbour porpoises (e.g. Carstensen et al., 2006, Thompson et al., 2010, Brandt et al., 2011). For example, SAM was used to assess the impact of pile driving on harbour porpoises at the Horns Rev II wind farm in Denmark, showing a resulting displacement of animals away from the pile driving event out to 22 km (Brandt et al., 2011). Very long term monitoring using PODs allows for evaluation of long-term displacement as a result of MRE developments, for example, eight years of acoustic monitoring of harbour porpoises at the Nysted wind farm in Denmark showed a slow recovery towards baseline levels over the period post construction (Teilmann & Carstensen 2012).

Each survey methodology has its associated advantages and disadvantages, but should consider both the spatial and temporal components of marine ecosystems, for example, at Wave Hub repeated surveys of birds and marine mammals have been carried out through time to elucidate seasonal patterns in abundance and diversity or seasonal changes in behaviour (Witt et al., 2012). Boat surveys can often provide very small sample sizes, especially for infrequent visitors, or marine mammals that are difficult to see such as the harbour porpoise. Therefore, Wave Hub has also had continuous acoustic monitoring of dolphin and porpoise activity at the site using C-POD click detectors, allowing for seasonal trends in occurrence at Wave Hub to be evaluated.

Surveying programmes should be designed appropriately and focused towards a specific question and take into account the often changing infrastructure at evolving MRE sites which may impose survey constraints later into the lifetime of development sites (Table 8). A detailed overview of the different methods and the advantages/disadvantages can be found in Macleod et al., (2011).

4.1.2. Monitoring locations

Many wave energy test centres have collected or will be collecting survey data for marine mammals either: as a requirement of the EIA process; due to national, European and/or international legislation; or for scientific purposes (Table 9). Most of the survey data to date has been collected as part of the baseline study either to fulfil the requirements of the EIA or for scientific purposes. Baseline surveys are usually carried out to gain a coherent understanding of the distribution, abundance and behaviour of marine mammals to inform the regulator on which potential mitigation may be required during installation and operation of renewable energy extraction devices. If there were populations at risk, then monitoring would usually continue during device installation, and continue to monitor populations after the devices have been installed. However, due to the low number of actual WECs in the water, there have been very few impact studies on marine mammals conducted.

Table 8: Summary of methods available for the monitoring of MREIS on cetaceans. The methods employed will be dependent on the approach chosen for the specific site. *Sonar methods are still under development (Macleod et al., 2011).

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 spatial and/or temporal factors influencing detection	Seasonally and annually if natural variability is to be established At-least one in each development phase	Very wide range of metrics may be gathered so very dependent upon questions being asked and data being collected
Autonomous Acoustic Data Loggers (AADL)	Presence/ absence	AADL e.g. C-POD Batteries Boat-winch Moorings	Gradient/BACI design	Continuous (need regular servicing)	Regression analyses
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 (zigzag, 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 (tidal turbines, WECs). Impacts	In development	N/A	N/A	

The most common method used for monitoring marine mammals for baseline data is static acoustic monitoring (SAM) which has been adopted by AMETS, BIMEP, Lysekil, Pico, Reunion, Sotenas Wave Dragon, and Wave Hub (Table 9). This often allows for evaluation of noise levels as well as marine mammals if broadband recorders are used (see Section 3). At both Wave Hub and AMETS, SAM has been used for baseline monitoring using C-PODs (Chelonia Ltd.) at the WEC sites as well as control site(s) (O'Brien et al., 2012, Witt et al., 2012). At AMETS acoustic monitoring was carried out at the three WEC berths initially, and subsequently at two control sites 10 km either side of the berths. At Wave Hub, a T-POD was deployed for a year as part of the EIA, but subsequently up to 12 C-PODs have been deployed at Wave Hub (at the 4 corners of the Wave Hub area, and at three depths) as well as up to 12 C-PODs distributed around control sites around the Cornwall coast since September 2009. At BIMEP, a moored sonobuoy with a broadband response (1-80 kHz) was used for acoustic monitoring to monitor both for dolphins and whales and noise events (André et al., 2011).

Only the Pilot Zone in Portugal have carried out aerial surveys for marine mammals, most other sites having used boat-based line transect methodology (AMETS, Wave Hub, Pilot Zone) or land-based visual observations if the sites are within view from vantage points on land (AMETS, Billia Croo at EMEC). Wave Hub probably has the longest time series of boat-based survey data, which was carried out near monthly since August 2009. However, this appears to be unusual, and yielded very low sighting rates of marine mammals (more suited to seabirds at this site), too few to be able to have the statistical power to detect impacts of WECs. At AMETS seasonal boat-based surveys were attempted since October 2009 but due to the exposed nature of the site, surveys in low sea-states were limited mainly to summer and autumn with only one survey completed during winter months. This is something that is important to consider when selecting appropriate methods for determining impacts of WECs on marine mammals: the method should have the power to detect change. For example, SAM has been shown to have high power to detect impact even with low densities (e.g. Diederichs et al., 2008), but has limited spatial extent. Large scale spatial surveys may not yield enough data to detect change in distributions or abundance but may be the only means (other than a large array of SAM devices) to assess spatial aspects of WECs.

Some sites have thus far only undertaken desk studies and reviews (Galway Bay, Pelamis Farr Point and Pentland Firth). A few sites appear to have no known marine mammal monitoring (Peniche, Runde, SEM-REV). Table 9 provides the information on marine mammal data collection and its availability for each test centre.

Most European wave energy test centres have created a baseline understanding of marine mammal populations coincident to their development sites (either from primary data collection or from desk-based analysis, or both), but many sites lack alternative additional locations in the survey protocols (away from the development sites) that could be considered as statistically relevant control locations. As such, data collected cannot be contextualised with what is happening in the broader marine region (geographically), which limits the findings of any studies. For example, if marine mammal abundance is declining in an area where a renewable energy extraction device is sited, it will be complex to tease apart whether the decline is due to the installation of the device or due to a broader spatio-temporal trend occurring within the region. For example, in a study of harbour porpoise acoustic activity at the Egmond an Zee wind farm site, harbour porpoises increased overall in the area from before installation to post-installation, in line with a general increase in Dutch waters (Scheidat et al., 2011). Since this study used a reference 'control' site, it was possible to identify the general background increase in porpoises in the area from any changes due to the windfarm.

Table 9: Summary of the marine mammal visual survey data for each wave energy test centre and its availability through the SOWFIA DMP.

	Monitoring requirements	Sampling stations and time period	Used methodologies and results	Type of data in the DMP
AMETS (Ireland)	Data collected to satisfy EIA and further baseline monitoring	October 2009-April 2013	Visual and towed acoustic line-transect boat surveys (3), static acoustics and land-based observations and desk-top review of marine mammals in the area. SAM (C-PODs) deployed initially at 3 stations, and at 4 control sites.	Report document. Data to be made available later.
Galway Bay (Ireland)	Baseline data required by EIA& data collected during device deployment	August 2009 – September 2009	Desktop review and collation of existing information on marine mammals that occur in the area. C-POD deployed from OE Buoy WEC at test site along with two C-PODs at control sites.	Data to be analysed and made available at a later date.
Aquamarine Power (Lewis, UK)	Not known	Not known but monitoring started in 2010	Visual observations, methodology unknown	N/A
EMEC (Orkney, UK)	Required by Licensing Authority	July/August 2011 (Billia Croo) Vantage point visual survey 2009- present	Weekly surveys from onshore single vantage point using visual survey technique. MMO monitoring from jack up barge using visual survey technique following EMEC MMO protocol. Also boat-based underwater noise monitoring for cetacean impact Land based marine mammal observations based on Marine Scotland approved methodology	Report document Raw data as MS Excel and MS Access database files.
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).	Not known
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)	Report document

Wave Dragon (Wales, UK)	Acoustic monitoring required for EIA	N/A	Desk based study collating existing information on marine mammals. Acoustic marine mammal monitoring	Not known
Wave Hub (Cornwall, UK)	Applied and fundamental research by UoE Data collected to satisfy EIA	Monthly boat –based surveys August 2008 – present and continuing T-POD Feb-June 2005	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 and behaviour for same time period (up to 12 C-PODs at Wave Hub at 3 depths, plus up to 12 control sites around Cornwall). Desk based study of Cornwall Wildlife Trust sightings database. Acoustic detection of cetaceans in vicinity of the Wave Hub (T-POD)	GIS ESRI shape files& summary C-POD data Not known
Sotenas (Sweden)	-	2012- present	Acoustic marine mammal monitoring only	N/A
Peniche (Portugal)	-	-	No known marine mammal monitoring carried out	N/A
Pico (Portugal)	-	May & September 2010	Acoustic marine mammal monitoring only.	N/A
Pilot Zone (Portugal)	Not known	2010-2012	Boat based and aerial surveys	GIS shape files
Reunion	Required by national, European and International law	January 2012-present	Acoustic marine mammal monitoring only.	N/A
Runde (Norway)	-	-	No known visual or acoustic data collection for marine mammals	N/A
SEM-REV (France)	-	-	No known visual or acoustic data collection for marine mammals	N/A

4.1.3. Suggestions towards a common methodology and data refinement

Although ideally it would be good for all test centres to use the same methodology to monitor marine mammals in the vicinity of the test sites, in reality this is difficult due to the differing legislative requirements, locations of sites, potential to impact SACs/Natura 2000 sites, and funding constraints. Land-based methods are a cost-effective way of monitoring abundance and behaviour of marine mammals but only appropriate if the device is to be placed in a location within view of a land-based vantage point. If renewable energy devices are to be situated further offshore, boat-based or aerial surveys may be the only means of carrying out spatio-temporal monitoring of marine mammals, yet this is expensive to carry out and therefore tends to be carried out over a limited time scale. Boat and aerial surveys do have the benefit of having standardised methods based on line-transect methodology resulting in measures that can be directly compared between sites and surveys (Buckland et al., 2001). However, boat-based or aerial surveys may not provide a large enough sample size to have the power to detect change.

Static Acoustic Monitoring (SAM) is becoming a standard method for assessing the impact of MRE developments on vocalising cetaceans (especially harbour porpoises), and 'there is a pressing need for all scientists and consulting agencies to commit themselves to using a standardised approach to SAM' (Diederichs et al., 2008). Since the methodology is still relatively new it is likely to be some time before a standardised approach is agreed, although experience from the offshore windfarm industry has moved this forward substantially. It is unlikely that there will be a 'one standard approach fits all' but there is the possibility for a number of standardised approaches to be used which vary according to the location (e.g. close to a Natura 2000 population or not), species (more likely to have a standardised approach for porpoises, but less so for other species due to the difficulties in species identification), species abundance (very low densities present more of a challenge for monitoring), size of development, and other factors such as funding.

At AMETS and Wave Hub, Before-After-Control-Impact (BACI) studies are being undertaken, which involves gathering baseline data at the test site and suitable control sites representative of the test site for a duration before deployment, and then gathering data at these sites once a device has been deployed at the test site (Underwood 1994). So far only 'before' data has been collected at both test sites. Most offshore wind farms have used a BACI approach for monitoring harbour porpoises to assess impact of installation or operation (Tougaard et al., 2009, Thompson et al., 2010, Scheidat et al., 2011, Haelters et al., 2012, Teilmann & Carstensen 2012). However, this methodology is dependent on the section of a suitable control site with similar characteristics to the impact site and can be invalidated if poor control sites are selected (e.g. Thompson et al., 2010). Also, the control site should be far enough away from the impact site not to be within the impact zone, for example, pile driving noise has been shown to impact harbour porpoises out to 22 km (Haelters et al., 2012). As a result of the difficulty of selecting a good control site, Thompson et al. (2010) recommended a gradient monitoring approach (e.g. Before-After-Gradient BAG design). This methodology requires monitoring to be carried out at increasing distances from the impact site so that the zone of impact can be assessed (e.g. Brandt et al., 2011). Ultimately, the choice of monitoring design should be question driven so that the results of the monitoring are able to address the uncertainties highlighted within the EIA, and should have sufficient power to detect change.

To undertake a robust European wide analysis of the effects of renewable energy installations upon marine mammals it will be necessary to express all data to common unit (e.g. density) and for the multitude of advantages and disadvantages for each method to be carefully considered. SAM data should be expressed in common units, such as Detection Positive Hours (DPH), or Detection Positive Minutes (DPM) at high encounter sites, per time unit (e.g. days, months, years) and waiting time

between acoustic encounters. With all methods it is important to consider factors such as effort and any factors likely to affect detectability (e.g. sea state for visual surveys, noise levels for acoustic surveys). Using advanced statistical approaches (e.g. Generalised Linear Mixed Effects modelling) and access to extended time-series gathered from development sites along with accompanying data from 'control' sites away from development zones a pan-European analysis may become possible. Currently available data do not, however, allow for such an analysis at this time.

The need for good survey design and methods cannot be overstated, and is discussed in more detail by MacLeod et al., 2011, but some general good practices, that should be considered to provide scientifically robust data, are presented here. Data should be collected (i) over an extended time period – at least two years, so that an albeit short baseline can be constructed for each season before any devices are installed, otherwise it may not be possible to determine whether changes are due to the device placement or seasonal variation in abundance and behaviour; (ii) in several locations, both within and outside in appropriate control sites well away from the device location for similar reasons.

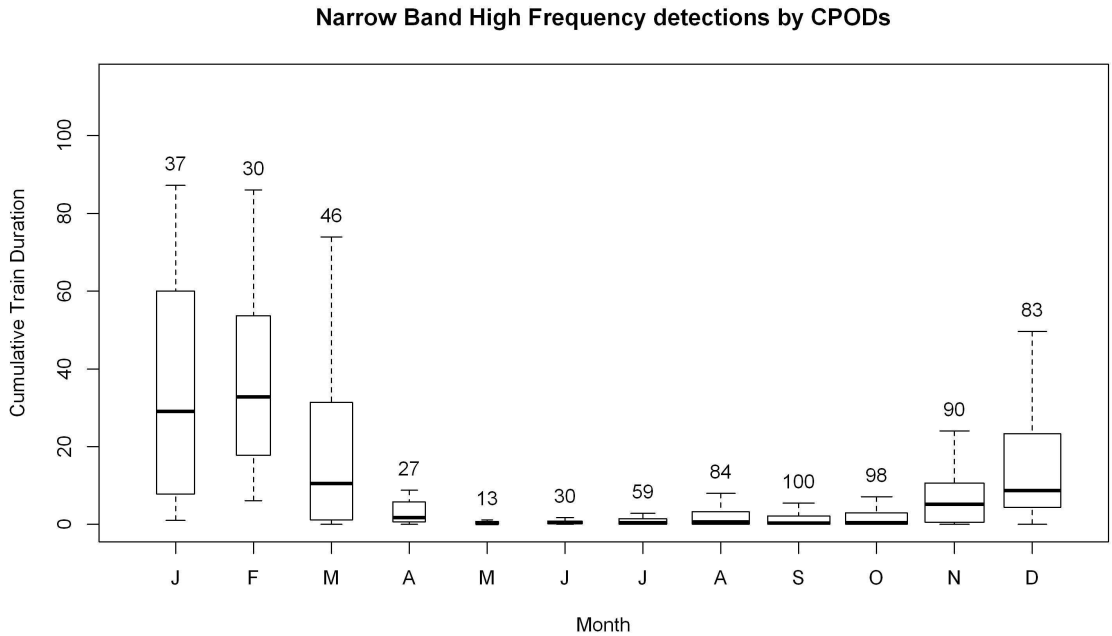


Figure 10: Effort corrected cumulative train duration for harbour porpoise (narrow band high frequency clicks) detected by C-PODs at Wave Hub between August 2009 - December 2012 as monthly averages.

It is also critical to determine whether the survey design method will be able to detect an impact, by carrying out a statistical power analysis at an early stage, preferably using pilot data collected at the site, to provide an indication of the inherent variability in counts of the appropriate species at the site. The power to detect change will depend on a number of factors such as (i) the abundance of the species in the area (the more animals there are the easier it is to detect a change in behaviour/abundance); (ii) the magnitude of any change (small changes are more difficult to detect than larger changes); (iii) survey methodology (boat or aerial surveys generate relatively low levels of sightings over short time periods making it more difficult to detect change than continuously monitoring passive acoustic methods); (iv) duration of monitoring (longer time periods = more data = easier to detect change).

4.1.4. Refined data products

Refined Data Products (RDPs) are available for SAM data collected at Wave Hub and AMETs. SAM is most appropriate for detecting cetacean occurrence at the site of interest. The data can be presented in a number of ways, but will usually show a measure of detection rate (e.g. train duration or Detection Positive Minutes/Hours/Days DPM/DPH/DPD) over a time series (e.g. days, months, years). Since detection rate is dependent on the amount of effort, this should be included, either alongside the detection rate, or with detection rate compensated for effort.

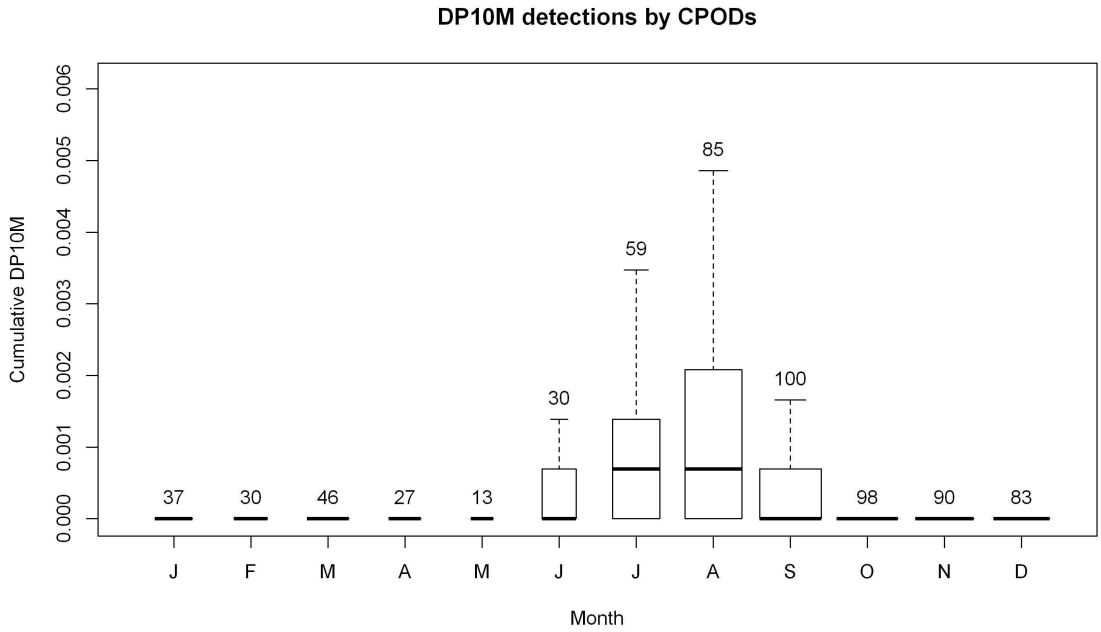


Figure 11: Effort corrected cumulative DP10M (detection positive 10 minutes) for dolphin clicks detected by C-PODs at Wave Hub between August 2009 – December 2012 as monthly average.

Figures 10 and 11 show the variation in harbour porpoise train duration, and dolphin DP10M (Detection Positive 10 minutes) from C-PODs deployed at Wave Hub averaged over a year for all three years data after compensating for effort. Train duration was recommended as a more accurate measure than detection positive time periods for harbour porpoise activity using C-PODs (Tregenza pers com). This reveals clear seasonal variation in porpoise and dolphin occurrence at Wave Hub, with opposing trends: porpoises showing a peak during the winter and low occurrence during summer, but dolphins having peak occurrence in summer and very low during winter.

Data from AMETS presented in the same format also show clear seasonal trends with harbour porpoise detections greater in the winter from December through February and lower during summer (Figure 12). Dolphin detections increased in the autumn and winter and were at a minimum during the spring and summer (Figure 13). These RDPs are examples of how information could be presented from this type of data, however presentation should be suited to the question being addressed by the analysis. In these RDPs the aim was to show general seasonal trends, however the data could also be presented to show tidal variations, inter-annual variations, differences between the WEC site and control sites (e.g. Figure 14), or before during and after construction events. This type of information is critical for understanding potential impacts, especially during construction which is likely to occur during summer months when dolphins are in highest densities. There are a few caveats worth considering with acoustic data: (i) it is dependent on the behaviour of the marine

mammals so cannot detect them when they are silent; (ii) it is not yet possible to distinguish between dolphin species (e.g. at the Wave Hub these are likely to be a combination of bottlenose dolphins and common dolphins).

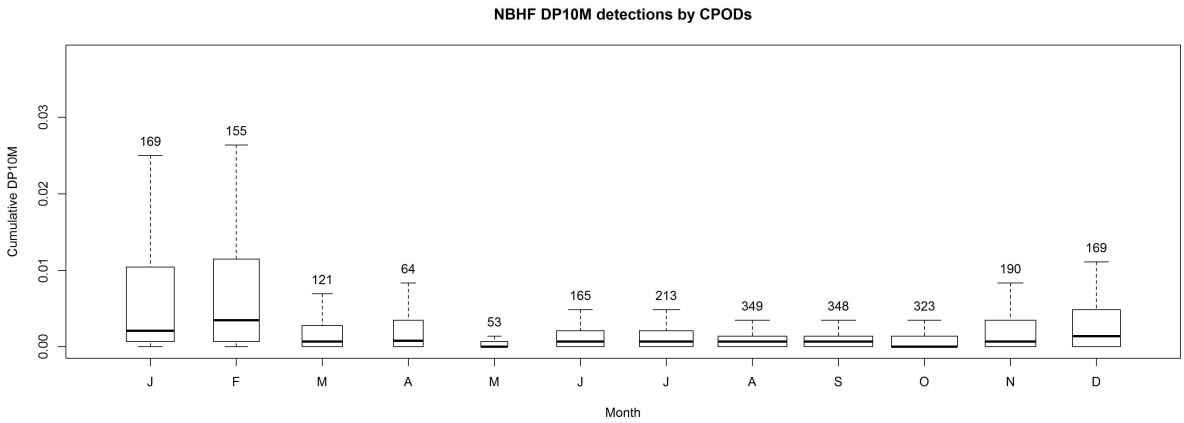


Figure 12: Effort corrected cumulative train duration for harbour porpoise (narrow band high frequency clicks) detected by C-PODs at AMETS between October 2009-April 2013 at monthly intervals.

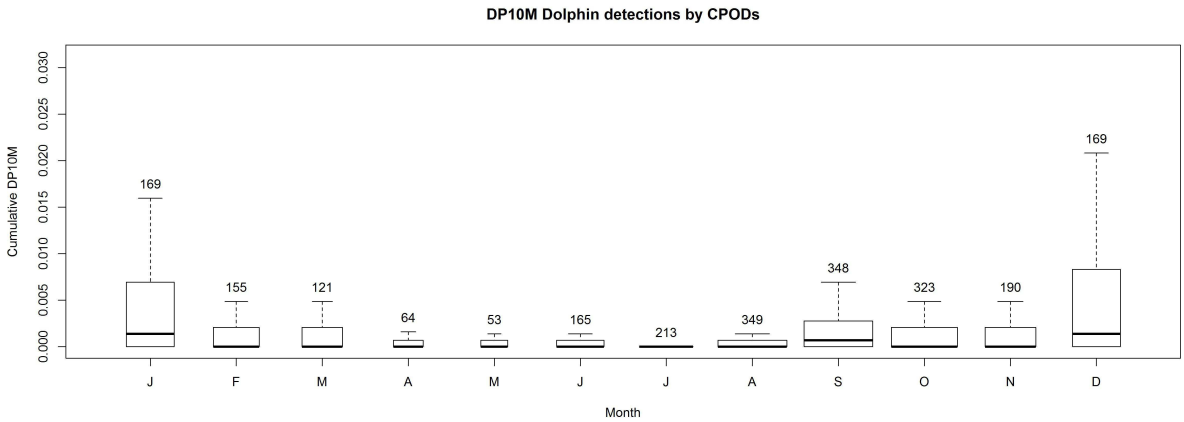


Figure 13: Effort corrected cumulative DP10M (detection positive 10 minutes) for dolphin clicks detected by C-PODs at AMETS between October 2009-April 2013 at monthly intervals.

Static acoustic data can be presented as the proportion of the deployment period with detections. This is known as %Detection Positive Minutes and corrected for effort. The proportion of minutes with dolphin and porpoise detections from AMETS are shown in Figure 15. Note the highest detections of both were recorded at the proposed berths with porpoise detections higher inshore and dolphin detections offshore. Detections of dolphins at control sites to the south of the berths were similar to each other as were the control sites to the north, but were different across the study area with detections greater to the south despite being along the same depth contour. This suggests there can be great variability in detection rates over relatively short distances and this confounds sensitivities of SAM data to detect changes over time.

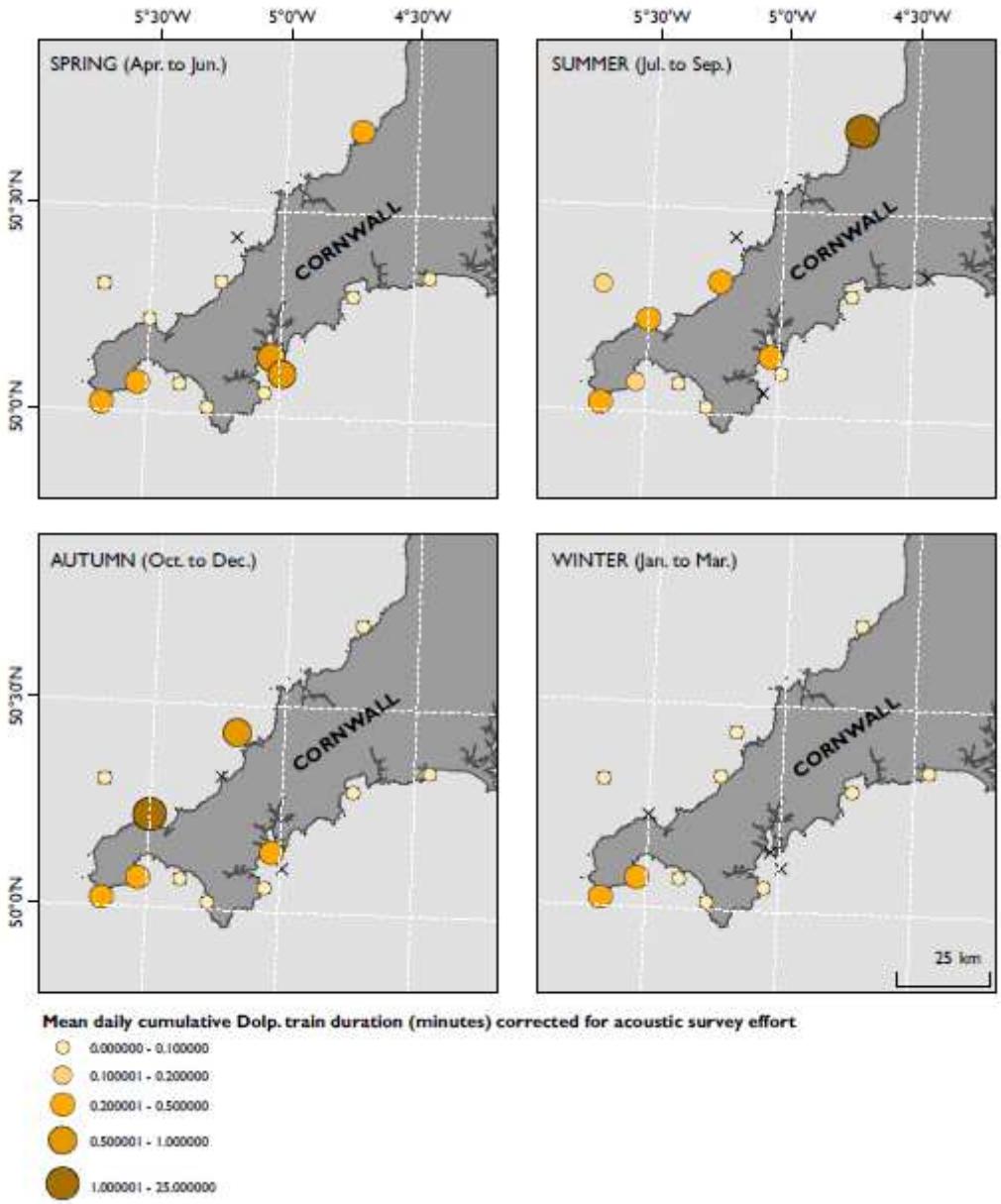


Figure 14: Dolphin daily effort corrected train duration for C-POD data at the Wave Hub (offshore location to the north of Lands End) and 12 control sites around Cornwall for each season.

Refined Data Products (RDPs) from non-acoustic based marine mammal data are only available from AMETS. Sightings data from 12 dedicated boat-based surveys are presented as graduated symbols scaled to group size within a 1km^2 grid (Fig 5a and 6a). Survey effort represented by the length of trackline surveyed in kilometres, is also presented (Fig 5b and 6b) to enable areas with high or low encounter rates to be identified. Similar maps post deployment of WECS may show areas of avoidance associated with the presence of the devices.

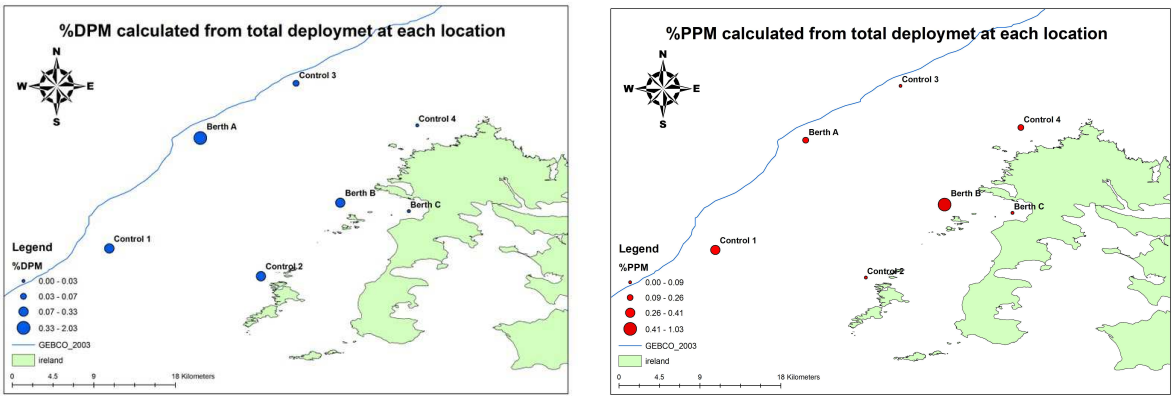


Figure 15: Maps showing the proportion of detection positive minutes for dolphins (DPM) and porpoise (PPM) during the entire deployment period.

The types of data that can be obtained from the survey data include:

- Species composition – number of species per point sample (for point surveys), per unit time (for land-based static surveys), or per unit area (for boat or aerial surveys);
- Species abundance – number of animals for each species per point sample (for point surveys), per unit time (for land-based static surveys), or per unit area (for boat or aerial surveys).

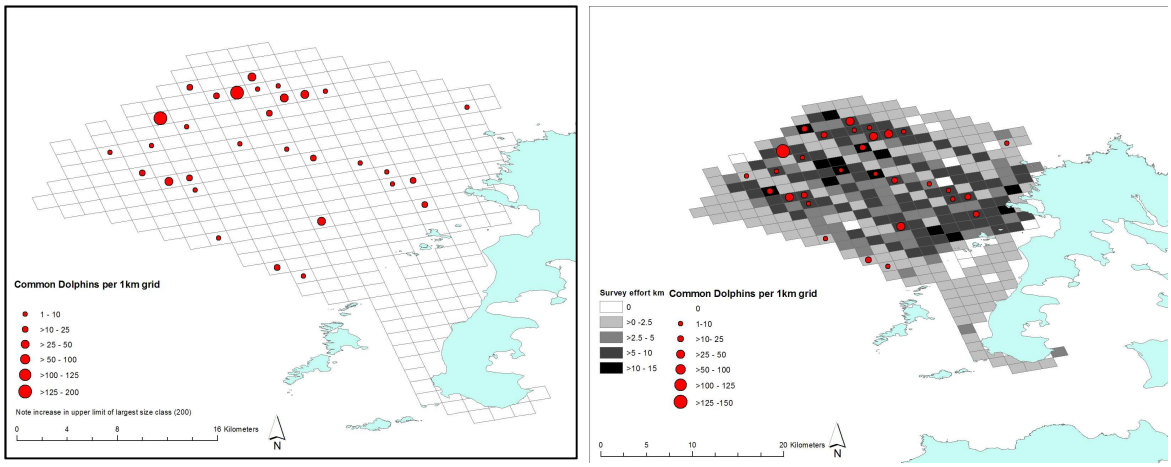


Figure 16: Common dolphin sightings at AMETS from October 2009 to March 2013 presented in a. 1km^2 grid cells and b. with sightings effort overlaid.

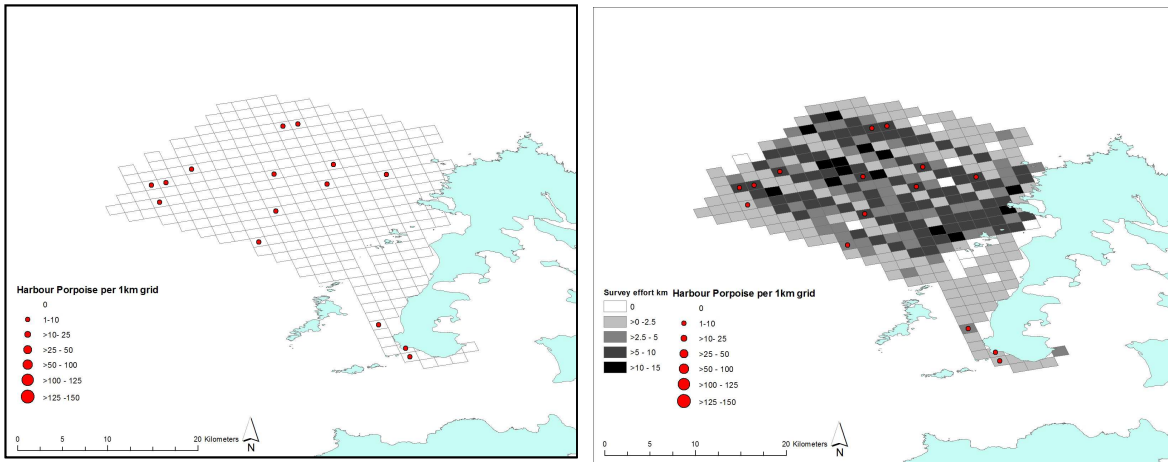


Figure 17: Harbour porpoise sightings at AMETS from October 2009 to March 2013 presented in a. 1km^2 grid cells and b. with sightings effort overlaid.

Spatial data (such as the point counts or boat/aerial-based surveys) are best visualised as mapped products (e.g. Figure 17 for visual and Figure 18 for acoustic boat-based survey data off Ireland), whereas land based counts are usually best visualised as tables or graphs showing abundance over time similar to the RDPs presented here. Land based surveys, if carefully designed, can be used to determine spatial distribution of animals within the range of sight (e.g. using theodolites) and therefore best displayed in both a map & graph format. If there is a long time series of spatial survey data (e.g. for bird surveys at Wave Hub conducted most months over several years), data can be visualised as density or species composition maps per month, season, or year, or before-during-after impact. The method of presentation will depend on the distribution of data (yearly distribution/abundance maps may not be appropriate if surveys have not been conducted evenly throughout the seasons for each year of data), and the study requirements (e.g. seasonal or monthly trends may be useful for planning construction to avoid times of high abundance, before-during-after impact is more appropriate for visually examining potential impacts on distribution).

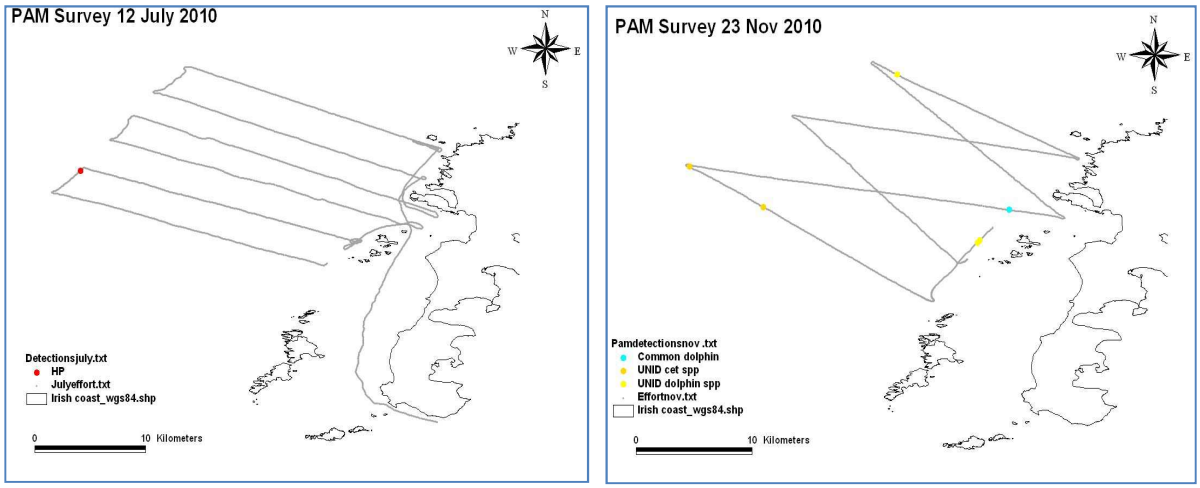


Figure 18: Distribution of acoustic encounters during AMETS in 2010.

4.1.5. Lessons on probable impacts

There are both potential positive and negative impacts of wave energy developments on cetaceans (Witt et al., 2012). There are also a number of useful reviews assessing the potential impacts of MREIs on marine mammals (Lucke et al., 2006; Madsen et al., 2006; Simmonds and Brown 2010; Witt et al., 2012, Inger et al., 2009, Truebano et al., 2013). Nonetheless, studies are still scarce and potential impacts have been largely hypothesised. There is also a high level of uncertainty regarding whether the documented responses may lead to impacts at the population level. The main risks are collision/entanglement, displacement, electromagnetic fields, cumulative effects and noise (which is addressed in Chapter 3). Potential positive impacts are also considered.

4.1.5.1. Evidence for WEC impact on marine mammals

The wide range of WECs being developed and the different construction methods make the identification of potential impacts on cetaceans difficult (see Figure 19). These devices are being designed for areas from the shoreline to deepwater areas (~200m depth). Some will be bottom moored while others will be installed using piles. Some will be mostly above the surface while others will contain many complicated parts moving under the sea surface. Some will require electrical cables to transmit electricity to shore while others will send high pressure water to shore for electricity to be generated on shore. The impacts and noise emissions are likely to vary from device to device.

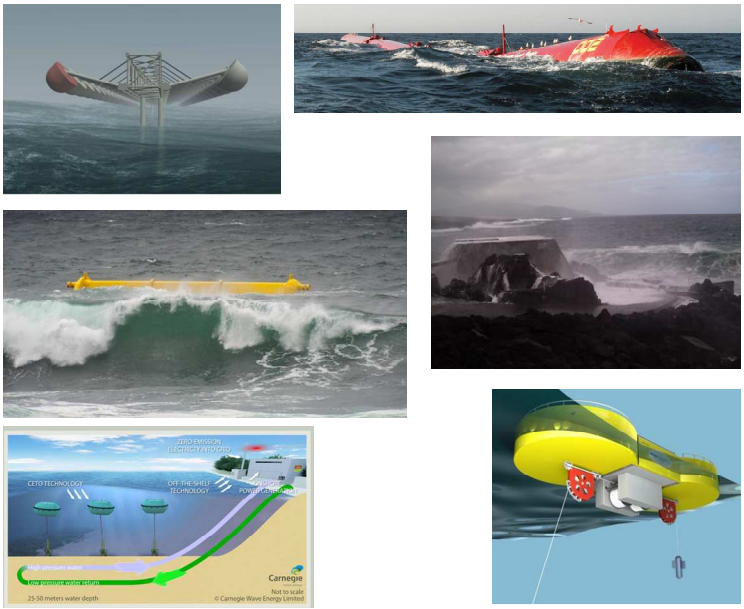


Figure 19: This graphic shows the wide range of WECs which must be considered: Clockwise from top left: Wave Star, Pelamis, Pico shoreline OWC, Ocean Harvester, CETO, Oyster.

So far, there is only very limited information from studies monitoring the impacts of WECs on cetacean abundance. During the deployment of the one quarter scale Ocean Energy Buoy (OE Buoy) floating oscillating water column (OWC) at the Galway Bay Wave Energy Test Site, off the west coast of Ireland in 2009, a C-POD was deployed from the OE Buoy device and for comparison, C-PODs were deployed at two control sites, one 550m to the west of the device and another 1000m from the device (O' Brien *et al.,* 2012). Preliminary results from this pilot monitoring showed no significant difference in detections of vocalising cetaceans at the device and at the control sites (Figure 20).

It should be noted that that this device is only one quarter the size of the full scale OE Buoy and the noise emissions from the full scale model are likely to be different from that of the one quarter scale model. This deployment was carried out as part of a different project and only one wave energy device was deployed. Additionally, no noise monitoring was carried out at the site at this time. Future wave farm developments may consist of tens to hundreds of units. The OE Buoy represents only one type of WEC and different WECs may have different effects on marine mammals. No other studies have been found using acoustic devices to monitor the effect of operational wave energy converters on marine mammals.

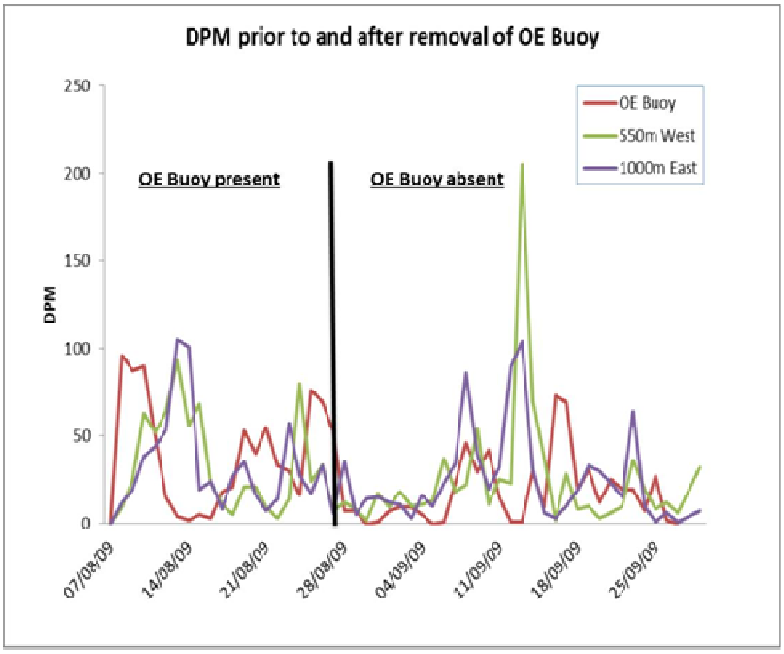


Figure 20: Results of C-POD deployment at OE Buoy and two control sites (O' Brien et al., 2012).

Some indications on the likely impacts of wave energy developments on cetaceans can be taken from the studies on impacts of offshore wind farm construction mentioned in Section 2. Environmental assessments for offshore wind identified pile driving as the activity having the greatest potential impact on local cetacean populations. It should however be noted that pile driving is likely to be required for a limited number of WEC devices.

4.1.5.2. Collision/entanglement

The risk of entanglement of marine mammals with wave energy devices is likely to be much lower than other MRE technologies; however wave devices, especially those with rotating turbines, have the potential to cause injury or death (Inger 2009). Risk of entanglement or collision will vary depending on species, body size, swimming behaviour and device type (Wilson et al., 2007).

There is very little understanding on how marine mammals are likely to react to the structures associated with wave energy devices. However, there was no evidence to suggest collision of marine mammals with the SeaGen tidal turbine in Strangford Lough (Keenan et al., 2011). In this example, animals were shown to move around the turbine, and there was no evidence from animals stranded in the vicinity of blade strikes (although this is only one method of determining effect) - in strong tidal currents a body could be flushed out to sea quickly. This study used active sonar to detect marine mammals approaching the turbine, and shut down the turbine when marine mammals were

within a certain distance. This was gradually phased out as evidence suggested animals were avoiding the turbine. The research suggested that collision is not a risk for marine mammals around tidal turbines at Strangford Lough, however this is only a single study so it should not be generalised to other species, environments or device types.

The risk of entanglement is more difficult to determine. Marine mammals (sharks and turtles too) do become entrapped in fishing nets, and in static lines such as those to crab creels (Berrow and Rogan 1998), so there is an unknown risk of marine mammals becoming entangled in the cables and power lines. If WECs act as fish aggregating devices, marine mammals could be attracted to the area, due to increased available of food (Witt et al., 2012) and thus increase their risk of collision and/or entanglement, as well as prolong exposure to operational noise (Copping et al., 2013).

There are also concerns associated with the use of ships with ducted propellers during the installation of MRE devices, such as on boats with dynamic positioning, using azimuthal thrusters. These propellers are thought to be the cause of 'corkscrew' lethal injuries found on seals washed up around the UK and Ireland (Thompson et al., 2010). Since ducted propellers are common to a wide range of ships, there is the likelihood that such vessels will be used during construction and maintenance of WECs. The impact of ducted propellers on seal populations will depend on a number of factors such as: the number of ships with ducted propellers, length of time the ships are in the area, habitat characteristics (such as depth) and the local seal population size. Low numbers of lethal seal injuries from ducted propellers are not believed to have a significant impact on large seal populations (Thompon et al., 2010). However, with wider scale deployment, there is the potential for the effect to be larger and the impact more considerable.

4.1.5.3. Displacement

Avoidance of MRE installations due to habitat loss, noise pollution, or other factors, can lead to displacement of marine mammals from an area into another which could be less suitable (e.g. displacement from a profitable foraging ground to a less profitable foraging ground). For example, high noise levels during pile driving have been shown to exclude harbour porpoises from Nysted windfarm during construction (Carstensen 2006), and they had not returned to baseline levels after eight years of operation (Teilmann & Carstensen 2012). Although monitoring can determine whether there has been a behavioural displacement from an area, it remains difficult to assess the population level effects (i.e. whether this has a detrimental effect on the local population (or even individual)). Due to the highly mobile nature of marine mammals it is also difficult to measure displacement: for most species it is not possible to determine whether the same or different animals return after disturbance, nor therefore the number of animals impacted. Population level impacts are difficult to assess since they depend on a range of factors including location of the MREI in relation to the species' preferred habitat, installation size (single device or large farm of devices), the species affected, the level of inter-connectivity between population groups (units), and indirect effects such as displacement into areas more or less at risk of human interaction (e.g. fisheries bycatch). However, modelling approaches such as PCOD (Population Consequences of Disturbance) and PCAD (Population Consequences of Acoustic Disturbance) are currently being developed to attempt to assess population level effects on marine mammals from MREs (Lusseau et al., 2012, New et al., 2013). For example, modelling the population effects of increased boat traffic associated with an offshore renewable facility on bottlenose dolphins, suggested that the associated change in behaviour would not be biologically significant and thus would be unlikely to result in population-level effects (New et al., 2013).

4.1.5.4. Electromagnetic fields

Electromagnetic fields (EMF) are produced by cables transmitting power between devices and the mainland (Gill, 2005). There is very little understanding of the potential impacts of these EMF emissions on marine mammals. However, since there is some evidence that marine mammals use magnetic fields for orientation and migration (Gill and Taylor, 2001), the EMF generated by cables has the potential to affect them. Even if marine mammals respond similarly to magneto sensitive teleost fish, by exhibiting temporary changes in swimming direction, it remains unclear whether this represents a biologically significant effect (Gill et al, 2012).

4.1.5.5. Indirect and cumulative effects

WECs will be removing energy from the marine ecosystem, potentially changing water circulation and currents and so impacting the marine ecosystem through the food chain (Wilson et al, 2010). For example, increased turbidity due to this change and the disturbance of the substrate during installation could result in a reduction of light in the water column, and a consequent decrease in algal growth (Witt et al, 2012), thus impacting higher trophic levels and changing community structure (Wilson et al, 2010). There is also the potential for oil spills and leaks, and release of chemicals (e.g. antifouling paints) to impact marine mammals, whether directly or indirectly through the food chain.

The cumulative impacts of multiple large scale developments also cannot be ignored. Interactions with other renewable energy farms, and the cumulative impacts of the large scale of development planned poses considerable uncertainty. It is highly likely that there will be interactions between MREI impacts given the scales of planned developments and the spatial extent of some impacts (SMRU, 2010). However, there will also be cumulative impacts from other anthropogenic stresses such as noise from shipping, fisheries bycatch, climate change, pollution, and habitat degredation. Thus potential impacts at MREIs cannot be considered in isolation. Mitigation of cumulative impacts from a multitude of stressors should be done at the planning stage, requiring an understanding of marine mammal distributions, breeding grounds, migratory routes and the spatial distribution and extent of any other stressors. An SEA of offshore renewable energy was produced in Ireland which considers the cumulative effects of multiple WECs on a broad-scale.

4.1.5.6. Possible benefits

Wave energy converters may act as artificial reefs (Linley et al., 2007) as demonstrated at the Lykesil WEC, sessile marine species colonised the WEC structure with an associated increase in fish, having the potential to attract marine mammals to feed on the prey aggregations. The floating nature of WECs may lend them to become fish aggregating devices, thereby attracting potential predators (Witt et al., 2012). In addition, commercial fishing is likely to be reduced in the vicinity of the devices leading to the establishment of *de facto* marine protected areas (Witt et al, 2012) albeit with significant anthropogenic influence within them. This could also enhance fish stocks and increase prey availability to marine mammals. Although there is evidence that WECs can act as artificial reefs, the knock on effects on fish stocks and prey availability to marine mammals are only likely to be evident after several years of monitoring after the devices are in operation. Also, consideration should be given to the maintenance of these new beneficial habitats beyond decommissioning or negative impacts could be more dramatic than during construction.

4.2. Seabirds

Seabird communities represent a major component of the marine environment. The diversity of seabird species utilising European marine coastal and offshore habitats is considerable, with over 30

breeding species and at least a further 10 migrant species visiting the region. Abundance of birds show strong seasonality, with higher numbers during the breeding period (May to Sept), but many species are present in European waters year round. Species exhibit a range of foraging behaviours (e.g. surface feeders, plunge divers, pursuit divers etc.) and dietary preferences, and therefore are reliant on a variety of marine food resources and habitats. The life history traits of most seabirds (low annual fecundity, delayed sexual maturation, bi-parental care, long life and extended chick-rearing period) also mean populations are unable to respond rapidly to change, which makes them particularly sensitive to changes in habitat and food availability. The installation of wave energy converters (WECs) will result in a change in the marine environment that may affect individual seabird's behaviour and/or their prey availability. In turn this has the potential to impact seabird populations (positively or negatively), and requires pre and post WEC installation assessment.

4.2.1. Monitoring requirements & methodology

Many species of seabirds are protected under national, European and international legislation. The Council Directive on the conservation of wild birds 2009/147/EC (The Birds Directive) provides comprehensive protection for wild birds within Europe, and combines with the Council Directive 92/43/EEC on the Conservation of natural habitats and of wild fauna and flora (The Habitats Directive), to create the Natura 2000 network of Special Areas of Conservation (SACs) and Special Protection Areas (SPAs), the latter are specifically designated for vulnerable and migratory bird species.

The statutory drivers that require baseline data and/or monitoring of seabird (and applies to other marine organisms) distribution and behaviour in relation to marine renewable energy developments are Environmental Impact Assessment (EIA), Habitat Regulation Appraisal (HRA - UK) and Appropriate Assessment (AA). In the UK, an EIA is required for any development with greater than 1MW generating capacity and should provide the consenting authority information on likely significant effects on the environment to enable informed decisions on MREI proposals. It is a requirement to establish a development which will not compromise the integrity of Natura 2000 sites before approval. If a WEC development is likely to affect bird species from a SPA in the UK, a Habitat Regulation Appraisal (HRA) is needed to assess whether it will be significant. If considered to be, an Appropriate Assessment (AA) must be conducted to determine the implications for the site. Seabirds are often very wide ranging, so a development may affect the viability of more than one designated site, potentially under the jurisdiction of other countries. Evaluating the connectivity between SPAs and the proposed development site is an important component of assessing whether designated sites will be affected, but can be difficult to establish (potential methods are discussed below). In an HRA and AA, priority is given to species with high Nature Conservation Importance, which is determined from a combination of legislative protection (such as the EU Birds Directive), inclusion in conservation lists (e.g. Birds of Conservation Concern and IUCN threatened species) and geographical context.

Extensive resources and information exist on the abundance, distribution and behaviour of many seabird species within Europe. These consist of government (e.g. JNCC seabird databases) and non-government databases (e.g. RSPB, BTO, European Seabirds at Sea Data Base Co-ordinating Group), reference books and the academic literature. All are important resources that can provide local and/or wider ornithological information for EIA assessment and pre-consent scoping studies, although they are unlikely to be detailed or recent enough to include as specific site baseline survey data.

Surveying seabird abundance, diversity and distribution for baseline data and monitoring in relation to marine renewable energy (MRE) developments has been undertaken using multiple methods,

each with their associated advantages and disadvantages (Sutherland et al., 2004). Survey methods include point counts from land or sea, boat-based (Tasker, Jones, Dixon and Blake 1984) and aerial transect counts using visual census techniques (Buckland et al., 2001), aerial based photogrammetric approaches and radar assessment of birds in flight (Plonczkier & Simms 2012). The variation in methodology, frequency and specificity of these surveys is considerable, and reflects the diverse nature of development sites, habitats in which they are placed and different national and international legal requirements. Survey programmes need to be designed appropriately for the proposed site and flexible enough to account for the often-changing infrastructure at newly emerging MRE extraction sites. For example, Wave Hub's seabird survey method was restricted to point counts to provide the flexibility of collecting baseline and post-installation monitoring data at a site that will contain WECs of unknown dimensions and number.

Standard seabird diversity and abundance surveys do not help establish connectivity of development sites with SPAs, which is an important component of the impact assessment process. Alternative methods, such as analysing observed flight direction or tracking individuals with GPS devices, can help infer levels of connectivity. Tracking data can provide detailed information on individual movements and foraging behaviour that can be used to determine whether birds from SPAs are regularly using the proposed site. The method is limited by the number of birds (and populations) that can be tracked, which raises issues of representativeness, but the technology is becoming smaller and more affordable so may lose these limitations in the near future. Other technologies to monitor the effect of WEC on seabirds, such as remote cameras and radar, will potentially become important once more installations are tested and approved.

The surveys and monitoring methods mentioned above need both a spatial and temporal component; as such they should be repeated through time to elucidate seasonal patterns in abundance and diversity or seasonal changes in behaviour. Many seabirds are migratory and will show very distinct seasonal patterns, which are important to capture for baseline data and assessment.

4.2.2. Monitoring locations

Several European wave energy test centres have created a baseline understanding of seabird abundance and diversity coincident to their development sites (either from primary data collection or from desk-based analysis, or both) *e.g.* Wave Hub (Witt et al., 2012) and AMETS, although many sites lack alternative additional locations in the survey protocols (away from the development sites) that could be considered as control locations. As such, these data cannot be contextualised with what is happening in the broader marine extent (geographically) which limits the findings of any study (Table 10).

Table 10: Summary of the seabird information for each wave energy test centre and its availability through the SOWFIA DMP.

Test centre	Monitoring requirements	Sampling stations and time period	Used methodologies and results	Type of data in the DMP
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.	ESRI shape files
Wave Hub, (Cornwall, UK)	Data collected to satisfy EIA	2004 – 2005	300 m line transects to ascertain bird density by month (one year's survey effort).	N/A
EMEC (Orkney, UK)	Required by Licensing Authority	2005 – present for tidal site 2009 – present for wave site (Billa Croo).	Multiple methods (site dependent) approved by Government regulator. At Billa Croo – weekly visual surveys from single onshore vantage point.	N/A
Pilot Zone (Portugal)	Unknown	2004 – 2007 (data from Marine Important Bird Areas monitoring). 2010 – 2012 (data from Future of the Marine Atlantic Environment project)	Multiple methods used	ESRI shape files
Western & Northern Scotland	Applied and fundamental research. In fulfilment of MaREE	2011 – present	Visual surveys, tagging and tracking of individual birds	N/A
Runde (Norway)	Unknown	2009-2010	Unknown	N/A
AMETS (Ireland)	Data collected to satisfy EIA	Various (2009 -2013)	Dedicated line transects using EASA methodology and including control sites. Land based monitoring on inshore sites and breeding bird surveys.	Report document available
Pentland-Orkney	Scoping data with respect to Scottish marine environment	Desk-based studies	Techniques review	N/A

4.2.3. Suggestions towards a common methodology and data refinement

Ideally baseline data collection and monitoring of seabirds (and other marine organisms) for WEC proposals and installations would be conducted using the same survey methods and design, and the data archived on a central database to be shared and allow large scale pre- or post- construction cumulative analyses. Due to the variation in proposed devices, development site and legal requirements this is unlikely to be possible, but it is important to develop common methodologies that are practical and scientifically robust to answer the questions relating to whether these installations, in isolation or cumulatively, will have significant effects on seabirds (positive or negative). Currently, to undertake a robust European wide analysis of the effects of renewable energy installations upon seabirds it would be necessary to express all data in a common unit (*e.g.* density) and for the multitude of advantages and disadvantages for each method used to be carefully considered. Using advanced statistical approaches (e.g. Generalised Linear Mixed Effects modelling) to analyse extended time-series data gathered from development sites and 'control' sites away from development zones, a pan-European analysis may become possible. At present the available data do not allow for such an analysis to be conducted.

The high natural variability associated with both marine habitats (sites) and seabird abundance and behaviour means attributing change to one source (i.e. a WEC installation) can be difficult. The need for good survey design and methods cannot be overstated, and is discussed in more detail by Jackson and Whitfield 2011, but here we list some general good practices that should be considered to provide scientifically robust data.

- Baseline surveys and monitoring (before WEC installation), should include data collected;
  - I. over an appropriate length of time – two or three years would provide data on annual variation in abundance and behaviour;
  - II. at regular intervals during the year - monthly intervals would provide data on seasonal variation in abundance and behaviour;
  - III. in several locations inside and outside (control) the proposed site (see below, BACI & BAG);
  - IV. at the appropriate number of locations to provide the required power to detect significant change (see below, power analysis).
- Surveys and monitoring design.
  - I. BACI (Before-After-Control-Impact) survey design is suitable when;
    - enough comparable (similar environmental conditions) control sites can be found for the species of interest
    - control sites can broadly be termed independent from the proposed site
  - II. BAG (Before-After-Gradient) survey design is suitable when;
    - independent and comparable control sites are too few
    - assessment of magnitude and spatial scale of impact is of interest
  - III. A power analysis should be conducted as part of the survey design to inform how many surveys are required to give enough power to detect "significant" change.

4.2.4. Refined data products

The types of products that can be obtained from bird survey data include:

- Species composition – number of species per point sample (for point surveys), per unit time (for land-based static surveys), or per unit area (for boat or aerial surveys);

- Species abundance – number of animals for each species per point sample (for point surveys), per unit time (for land-based static surveys), or per unit area (for boat or aerial surveys).

An example of long term collection of these data is at Wave Hub, where 19 point counts of birds (within site and controls) have been conducted monthly throughout the year for over 4 years (Witt et al., 2012). For spatial data such as the point counts (boat/aerial-based surveys) these are best visualised as maps (GIS ESRI shape files), whereas land based counts are best visualised as tables or graphs showing abundance over time.

4.2.4.1. Wave Hub refined data products

Since Wave Hub was the only test centre with data in the DMP from multiple surveys (28 surveys to date), this is the only dataset considered within the proposed refined data products. The multiple survey data can be presented as GIS maps (Figure 15 & 16) allowing visualisation of temporal trends. The high number of auks observed in winter compared with autumn (Figure 15) is an example within these data that indicates seasonality for this species and a potential period of high impact of a WEC installation. However, this is one species and, as seen by the less marked seasonality for Procellaridae (Figure 16), impacts need to be considering across all species (particularly those that are most likely to be negatively impacted).

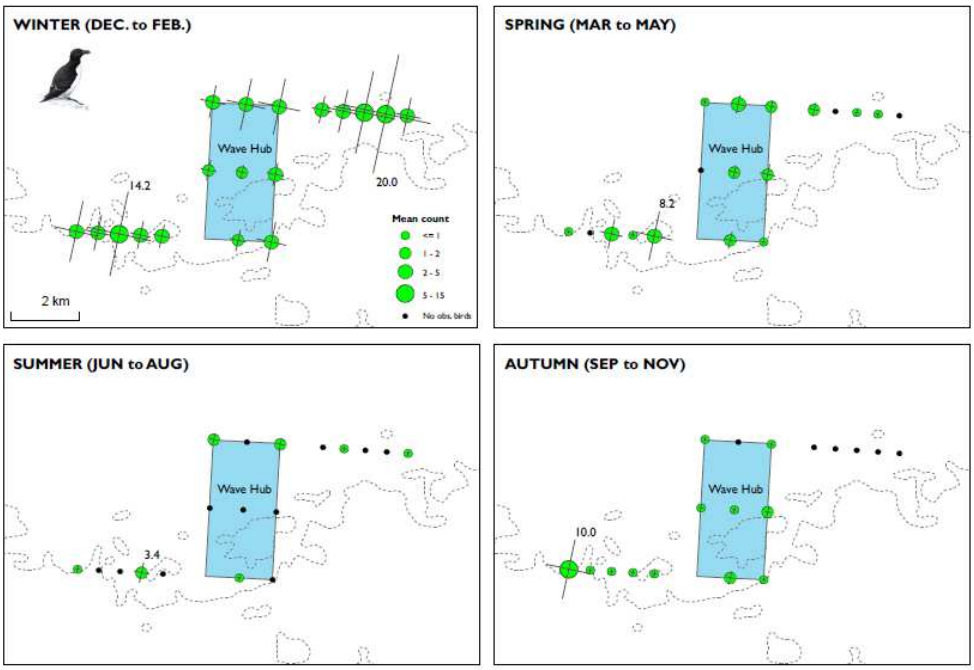


Figure 21: Auk (*Alcidae*) distribution and relative abundance at Wave Hub derived from monthly boat-based surveys between 2008 and 2013 (28 surveys). Standard deviation for counts indicated by error bars (cross hairs), Arabic numbers provide indication of error. Based on five minute counts of birds within 300 m of survey vessel at each location

This RDP is just one means of visualising the large data set, and is only suitable for datasets with multiple spatial surveys – which generally appears to be uncommon for most WEC sites (e.g. the single baseline survey at AMETS & OceanPlug). It should also be emphasised that even with the

survey design used at Wave Hub, power analysis suggested the power to detect change was small. For example, examining the number of surveys required to detect a change between the average number of birds at the impact site (Wave Hub area), and the control site (in a 5km buffer around Wave Hub) suggested that a 35% change in bird abundance could be detected with 80% power with 10 surveys (Grecian et al., 2010). Smaller changes or higher precision would require more surveys. This suggested that with non-replicated designs (i.e. single surveys), a graduated design (BAG) rather than a BACI would be a better method for detecting any impact.

4.2.5. Lessons on probable impacts

The environmental impact of wave energy installations and other MREIs is poorly understood. It is vital to monitor and assess the impact of WEC installations if an ecologically sustainable development of the technology is to be achieved. WECs could impact seabirds (especially sea ducks, divers and grebes) through direct (e.g. collision & displacement) and indirect (e.g. prey abundance) effects. Since seabirds are so reliant on the marine environment, especially during breeding and migration, many species are likely to come into direct contact with WECs with potentially detrimental effects. The recent expansion of marine renewable developments has raised the question about the population level impacts of MREIs, and so resulted in recent and continuing research on the impacts of MREIs on seabird populations.

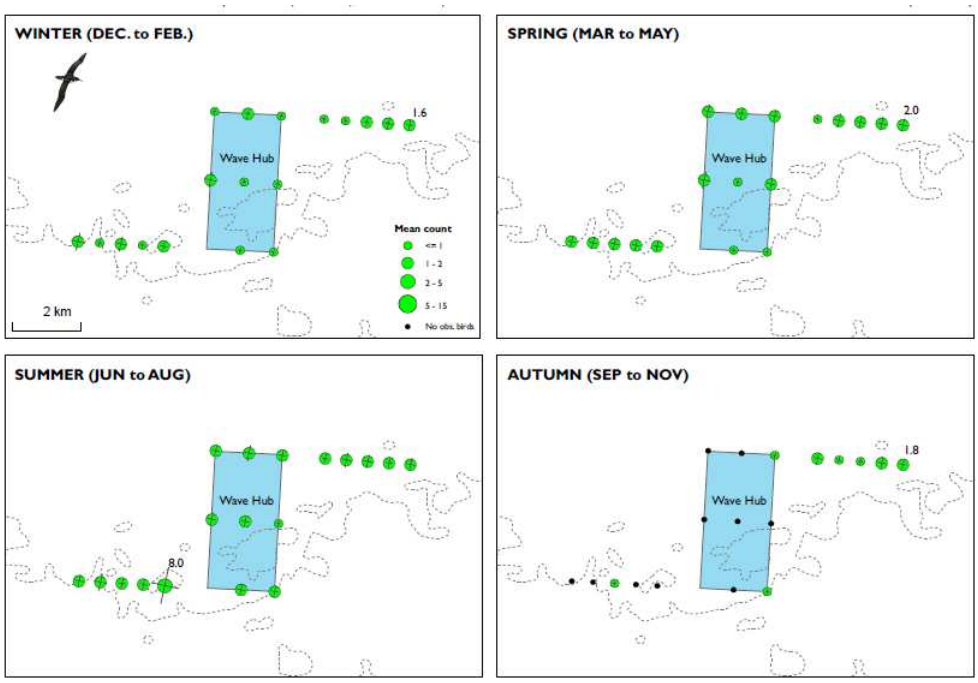


Figure 22: Petrel & shearwater (*Procellariidae*) distribution and relative abundance at Wave Hub derived from monthly boat based surveys between 2008 and 2013 (28 surveys). Standard deviation for counts indicated by error bars (cross hairs), Arabic numbers provide indication of error. Based on five minute counts of birds within 300 m of survey vessel at each location

Assessing whether WECs would have an impact at the population level (increase or decrease) should be the ultimate aim of an EIA or AA, but can be very difficult to determine. Abundance, distribution and diversity surveys can provide data to look at the effect of an installation, but not its impact on the population. Fitness consequences for individuals that are affected by a development (e.g.

increased/deceased survival or reproduction) are difficult to measure and/or accurately quantify, but colony and energy expenditure studies have the potential to elucidate such impacts.

Impacts on birds are considered at the population level, and can be considered to fall into three main categories: direct (collision, entrapment, displacement), indirect (noise, habitat enhancement, de facto MPAs), and cumulative. Most of these issues were addressed within the extensive review carried out by Grecian et al., (2010). Here we highlight important direct and indirect effects on seabirds but consider whether they could have population-level impacts.

4.2.5.1. Collision/entrapment

Mortality of birds through collision with WECs may have direct population-level impacts. However, as with marine mammals, quantifying collision rates (inferred mortality) for different species at offshore installations is a major constraint to assessing its impact (Inger et al., 2009). Research based on wind farms indicates the risk of collision is likely to be species and site specific (Stewart et al., 2007), and that age and reproductive stage may affect collision risk resulting in different mortality between age classes and thus different population-level impacts (Votier et al., 2008). WECs have a much smaller above-water profile than wind turbines, and so are likely to have much lower risk of collision (Grecian et al., 2010). However, they do have a considerable underwater structure which may provide a collision or entrapment risk (Wilson et al., 2007). It is thought that fixed underwater structures are likely to pose little risk due to the ease of navigation, but the moving parts such as anchor chains and elements of the WECs themselves may pose more of a risk (Wilson et al., 2007). Sensitivity of birds will depend on a range of factors such as distance from colony, diving depth range, target prey depth at the WEC site, avoidance ability (plunge divers have little avoidance ability), and factors that reduce visibility such as turbidity (Grecian et al., 2010).

Entrapment of birds could occur in WECs that have enclosed chambers that are partially open to the sea (e.g. oscillating water columns). Marine birds may enter the chamber, get trapped and/or killed by turbine or water movement within the chamber. This could be mitigated by covering the openings with a protective mesh (Grecian et al., 2010) although it is not certain whether this would have implications for the operation or efficiency of some WECs.

Further work is required on the collision and entrapment risk with WEC installations. Meta-analysis of impacts over multiple sites could be achieved if a standardised assessment framework was used. To date the current evidence suggests that the collision/entrapment impact is likely to be low and, in isolation, will be unlikely to have population level impacts. However, the impact on vulnerable species should not be underestimated (Hotker et al., 2006) and may contribute to potential cumulative effects which could be mitigated by careful siting of MREIs (wind, tidal and wave).

4.2.5.2. Displacement

Displacement (effectively habitat loss) due to the presence of WECs is the most likely direct impact on birds and would be detrimental to birds if they are displaced from foraging habitats and they are not able to compensate by feeding elsewhere. This is particularly acute for species that are restricted to foraging in specific habitats where the ability to find alternatives could be limited, so they may be disproportionately impacted (Snyder & Kaiser 2009). For example, shallow coastal waters are important for wintering sea ducks (e.g. common eiders *Somateria mollissima* and scoters *Melanitta spp*.), which show strong avoidance responses to wind turbines (Larsen & Guillemette 2007), and are also one of the species considered most sensitive to WECs (Furness et al., 2012). Displacement from the WEC area may affect their ability to exploit winter food resources and potentially have consequences for subsequent breeding performance (Guillemette et al., 1999). However,

displacement may be short term: evidence from wind farms suggested that sea ducks and other species became habituated to the wind turbines (Guillemette et al., 1999; Madsen & Boertmann 2008). Other species may instead be attracted to WECs due to increased prey aggregations and their use as resting/foraging platforms, so effects are likely to be species-specific and potentially positive (Inger et al., 2009, Lindeboom et al., 2011, Krijgsveld et al., 2011). However, there is a lack of well controlled and long term assessments of displacement for any MREIs, and no studies of the displacement effects of WECs, so research has yet to determine any effects on productivity or survival of bird populations.

MREIs may also act as barriers to movement and force birds to navigate around the MREI area, increasing both distance travelled and energy expenditure (Masden et al., 2009; 2010b). Although this is less likely for WECs, which are mostly low profile, than for wind turbines, which can be over 150m in height, some devices such as the Fred Olson Buldra/FO3 device which will be 24m high and so more likely to impact on bird flight paths (Grecian et al., 2010). This could be most critical for breeding birds if installations are sited between feeding, breeding, and roosting grounds and navigated around frequently (Masden et al., 2010a).

The impact of any displacement will be highly dependent on the species and location, size, and number of MREIs (whether wave, wind or tidal). A site- and species-specific approach needs to be taken to assess the effects, but sensible development planning to avoid sensitive foraging areas will help mitigate possible population impacts (Masden et al., 2012).

4.2.5.3. Noise

Noise is being considered separately within this report (Section 3.2). However, it could have an indirect effect on seabirds by negatively affecting their fish prey species. For example, pile driving during construction of some WECs produces a level and frequency of noise that can impact fish (Inger et al., 2009). A reduction in fish abundance due to noise could be detrimental to birds that rely on this resource. The marked decrease in clupeid fish abundance at the Scroby Sands wind-farm, Norfolk was attributed to noisy pile driving during construction and resulted in a reduction in foraging success of little terns *Sternula albifrons*. This then led to high abandonment of eggs and low hatching success of the local colony (Perrow et al., 2011). Operation noise of wind farms has not been shown to impact fish, and it seems unlikely that WEC operational noise would impact fish, so any effects from noise are likely to be short-term.

4.2.5.4. Indirect and cumulative effects

Cumulative impacts must be considered given the scale of MREI development currently in progress. Impacts that, alone, are minor, can combine over multiple MREI sites to produce significant population impacts (Masden et al. 2009; 2010a). Also, other pressures on seabirds outside of MREIs need to be factored into this consideration (e.g. due to fisheries bycatch, pollution, climate change, etc.). Effective mitigation of negative cumulative impacts can be done only at the planning stage so it is essential developers are aware of vulnerable species, important habitats, breeding areas and migratory corridors when making these decisions. Consideration of these cumulative effects is most logically dealt with in Strategic Environmental Assessment (SEA) (Masden et al., 2010a) although it must also be considered in EIA.

4.2.5.5. Possible benefits

There are several potential benefits of WECs that may result in positive benefits on biodiversity and hence birds. The above water components of WECs may act as roosting sites for birds, potentially increasing the foraging range of some species. They are also likely to act as artificial reefs and/or fish

aggregating devices (FADs). The likely increase in fish density and recruitment around WECs (Wilhelmsson et al., 2006, Grecian et al., 2010) will provide increased foraging opportunities for piscivorous birds with consequences for breeding success and survival. In addition, the hard structures will provide habitats for sessile organisms, such as mussels (Wilhelmsson et al., 2006), an important food resource for wintering common eiders.

Since boat traffic will be limited in and around WECs, they could act as *de facto* marine protected areas (MPAs) by reducing or ceasing fishing activity in the area. This is likely to result in an increase in fish abundance through lack of exploitation, and therefore increasing food availability for piscivorous species that are insensitive to the presence of WECs (such as terns, gulls, and cormorants). However, this simply displaces fishing activity to other areas outside installations, potentially leading to overexploitation of fish stocks and effecting prey availability for species that avoid installations. Thus WEC effect on fish abundance and hence on bird species has the potential to be both positive and negative. Attraction of birds to WECs due to either roosting sites or increased prey availability also increases collision risk especially if large numbers of birds are attracted to WECs in search of food.

Table 11: List of existing marine habitat types for different Member States (Pohle and Thomas, 1997) P means Present; A means Absent; ? means that no data is available. The analysis includes presence, absence or "not-applicable" (-) for both inshore and offshore habitats.

Habitats type			European Union Countries						
			Belgium	France	Greece	Portugal	Spain	Sweden	United Kingdom
Number	Description		Inshore/Offshore						
1110	Sandbanks	Baltic	-	-	-	-	-	P/?	-
		Atlantic / North Sea	P/P	P/P	-	P/P	P/?	-	P/P
		Mediterranean	-	P/?	P/?	-	P/?	-	?/-
1120	*Posidonia* beds	Mediterranean	-	P/A	P/A	-	P/A	-	?/-
1130	Estuaries	Baltic	-	-	-	-	-	P/-	-
		Atlantic / North Sea	P/-	P/-	-	P/-	P/-	-	P/-
		Mediterranean	-	P/-	P/-	-	P/-	-	A/-
1140	Mudflats and sandflats not covered by sea water at low tide	Baltic	-	-	-	-	-	P/-	-
		Atlantic/North Sea	P/-	P/-	-	P/-	P/-	-	P/-
		Mediterranean	-	P/-	P/-	-	P/-	-	?/-
1150	Coastal lagoons	Baltic	-	-	-	-	-	P/-	-
		Atlantic/North Sea	A/-	P/-	-	P/-	/-	-	P/-
		Mediterranean	-	P/-	P/-	-	P/-	-	?/-
1160	Large shallow inlet and bays	Baltic	-	-	-	-	-	P/-	-
		Atlantic/North Sea	A/-	P/-	-	P/-	P/-	-	P/-
		Mediterranean	-	P/-	P/-	-	P/-	-	?/-
1170	Reefs	Baltic	-	-	-	-	-	P/?	-
		Atlantic/North Sea	A/A	P/P	-	P/P	P/P	-	P/P
		Mediterranean	-	P/P	P/?	-	P/P	-	P/-
1180	Submarine structures made by leaking gases	Baltic	-	-	-	-	-	A/?	-
		Atlantic/North Sea	A/?	A/?	-	A/?	?/?	-	?/-
		Mediterranean	-	A/?	A/?	-	?/?	-	-
8330	Submerged or partially submerged caves	Baltic	-	-	-	-	-	P/?	-
		Atlantic/North Sea	A/?	P/?	-	P/?	P/?	-	?/-
		Mediterranean	-	P/?	P/?	-	P/?	-	-

4.3. Benthos

Benthos is the community of organisms which live on, in, or near the seabed, also known as the benthic zone. The benthos is normally divided into three functional groups, the infauna, the epibenthos and the hyper-benthos i.e. those organisms living within the substratum, on the surface of the substratum and just above it respectively. There are differences in the sampling techniques for each of these groups, as well as for the type of habitats they occupy: the soft-bottom habitat (e.g. silty or sandy habitat) and the hard-bottom habitat (e.g. rocky habitat). The benthos designation includes both plant and animal components although the infauna, as the name suggests, contains no plant species. In general, hard bottom habitats have both a higher abundance per unit area and greater species diversity since many benthic organisms can support a second, diverse, community of organisms living on the surface of them.

In temperate waters, the intertidal and subtidal hard bottom benthic communities frequently colonise up to 100% of the area of available substratum (Pohle & Thomas, 1997). The benthos usually plays a major role in the strategy for biodiversity conservation since the study of it helps the understanding of changes in biological diversity caused by natural or anthropogenic factors.

4.3.1. Monitoring requirements and methodology

4.3.1.1. The legal context

Some of the habitats listed in Annex I of the Habitats Directive (Council Directive 92/43/EEC), include marine habitats and thus benthic communities which need protection by means of the creation of Special Areas of Conservation (SAC) or Sites of Community Interest (SCI) (Table 11). The Habitats Directive also includes a list of species to protect which in the case of marine benthic communities include a number of algae, seagrasses and invertebrates. A number of such habitats and species have already been identified, described and classified in each European country in the Natura 2000 network (which includes sites designated under the Habitats Directive and the Birds Directive) (see Table 12). The proximity to a site designated under the Natura 2000 network will be a significant factor to assess the impact of the proposed marine renewable energy project and in some cases whether an EIA is required. Nevertheless, if the project is to be located within a Natura 2000 site an Appropriate Assessment must be carried out if it is deemed to be likely to have a significant effect on the site.

The benthos characterisation (and monitoring after deployment and post-deployment) is usually a required parameter in Environmental Impact Assessment processes. Most of the wave energy test centres under study in the SOWFIA project have undertaken a baseline characterisation of benthos both based on a desk study review of collected data in the area and field data collected specifically for that purpose. Ocean Plug is the exception, since the required geophysical and environmental characterisation report has not yet been released and the collection of data carried out in 2011 to produce it didn't include benthos samples' analysis. However, given the general importance of this topic for the complete environmental baseline characterisation, further baseline data collection is under planning and its results may be expected to be made publicly available.

4.3.1.2. Approaches to benthic surveys

Benthic species composition is recognised as the essential baseline for understanding diversity and thus sampling and identification methods and procedures are generally based on reliable measurements of species richness and diversity. Some of these methods and procedures are suitable for simultaneous assessments of both parameters. The degree of benthos sampling difficulty

increases with depth. The intertidal zone is accessible at low tide, the immediate subtidal zone (down to 30m) can be sampled and observed by dive surveys but between 30 and 100m depth the seabed is usually observed through video cameras on remotely operated underwater vehicles (ROVs). However these are either mostly incapable of sampling or have limited sampling ability. Soft-bottom habitats can be sampled relatively well (with grabs or corers lowered from a boat) by retrieving quantitative samples of sediment and sieving them to extract the fauna.

There is extensive literature on standard methods for benthos sampling and data processing and analysis. However, decisions on the methodology, equipment and analysis will strongly depend on the particular aims of a study, on the nature of the habitat involved, on the staff and facilities available and on historical or personal preferences. A list of reports (examples shown in Table 12) have been produced to serve as guidelines to assist developers, environmental consultants, regulators, decision-makers and consultees in the design, review and implementation of environmental data collection and analytical activities associated with stages of marine projects (including offshore renewable energy developments).

Table 12: Examples of available reports on benthic survey techniques and data analysis.

Title	Project / Entity	Reference
Monitoring protocol for marine benthos: Intertidal and subtidal macrofauna	Huntsman Marine Science Centre, Canada	Pohle and Thomas, 1997
Review of standards and protocols for seabed habitat mapping	Mapping European Seabed Habitats (MESH)	Coggan et al., 2007a
Recommended operating guidelines (ROG) for underwater video and photographic imaging techniques	Mapping European Seabed Habitats (MESH)	Coggan et al., 2007b
Seafloor Video Mapping: Collection, analysis and interpretation of seafloor video footage for the purpose of habitat classification and mapping	Mapping European Seabed Habitats (MESH)	White et al., 2007
Guidelines for the conduct of benthic studies at marine Aggregate Extraction sites	Marine Aggregate Levy Sustainability Fund (MALSF)	Ware and Kenny, 2011
Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects	Centre for Environment, Fisheries and Aquaculture Science (CEFAS)	Judd, 2012
Methods for the study of marine benthos	Ąellenic Centre for Marine Research and Department of Biology, University of Crete both from Heraklion, Crete, Greece	Eleftheriou, 2013

A summary of the methods used as well as the type of sediments and benthos data collected for each wave energy test centre is shown in Table 13. The monitoring methodologies varied little among test sites including sample collection through grabs and corers (for the soft-bottoms) and dives (for collection of samples from hard-bottom substrates), videos and photographs. For all other test centres, reports on baseline characterisation were provided and are available for download in the DMP. A summary of the monitoring results during wave energy devices' deployment is also available for the Lysekil test centre in the form of downloadable papers or reports.

Table 13: Summary of the benthos information for each wave energy test centre and its availability through the SOWFIA DMP.

Test centre	Monitoring requirements	Sampling stations and time period	Used methodologies and results	Type of data in the DMP
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 macrofaunal identification, using standard procedures (NMBAQC) Sediments were classified as infralittoral or circalittoral fine sands.	Report available in the DMP
	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 subtidal stations (4 on soft-bottom substrate and 4 on hard-bottom substrate) were sampled in April 2008 The sampled areas correspond to the two cable route alternatives	Desk based study using published literature relevant for the area surrounding the deployment site The replicates of 0.0625m^2 area and 0.15m depth were taken for each station. Replicates were sieved and preserved 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	The EIA report is available in the DMP for download

Test centre	Monitoring requirements	Sampling stations and time period	Used methodologies and results	Type of data in the DMP
Lysekil				Reports and papers available in the DMP for download
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.			Metadata information on shape files are available in the DMP for consultation
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)	The section of the benthos characterisation is available in the DMP for download
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.	Species list and habitat type

4.3.2. Monitoring locations

The sampling stations used for the baseline studies carried out at the wave energy test sites usually cover not only the area designated for deployment of devices but also the different options for the cable route to shore. This means that the established sampling points covered both intertidal and subtidal areas as well as different types of substrates and depths. The number of sampling points varies according to test centre dimensions and cable route extension (Table 13).

4.3.3. Suggestions towards a common methodology and data refinement

Although, as mentioned above, decisions on the methodology, equipment and analysis of the benthic community depends on factors and conditions, there is a need for the uniformity in procedures that will make data from different test centres more readily comparable. This comparison will help to define relevant monitoring requirements as well as adequate sampling and data analysis methodologies to optimise monitoring efforts and costs.

Based on the analysis of benthos assessment for wave energy test sites or centres carried out so far, suggestions of suitable methodologies for benthos sampling regarding each type of habitat have been summarised and are presented (Table 14). In terms of data analysis and representation (refined data products), the information compiled in Table 15 is based on almost all test sites which demonstrates that some form of standardisation already exists and, if needed, a comparative analysis among test centres is possible.

Table 14: Sampling equipment and methods for benthos assessment in wave energy test centres.

Intertidal areas	Soft-bottom	Hard-bottom
Sampling methods	Manual sample collection, during low tide, with quadrats (usually with 0.1m^2) pushed into the sediment (0.1m^2). The use of transects is possible and samples can be taken in precise locations. Five to ten replicates are normally taken.	Samples should be collected at a series of standard tidal levels. The use of transects at the shoreline is recommended from extreme low tide to the top of supra-littoral fringe. With the use of quadrats the rock surface can be scraped.
Subtidal areas	**Soft-bottom**	**Hard-bottom**
Sampling methods	Collection of samples from ships equipped with cranes and winches capable of hauling wire ropes for dredges, grabs and corers. Integrity of samples should be guaranteed ensuring the vertical set down and lift up of the grab at right angles to the bottom.	Almost all hard-bottom benthic sampling relies heavily on the use of underwater cameras (video and photograph) hand-held or mounted on Remotely Operated Vehicles.

4.3.4. Refined data products

Since the data available to the SOWFIA project is mostly in the form of reports no refined data products could be tested and made available through the DMP. However, after the analysis of the benthos assessment for each wave energy test centre, a summary of the types of data representation (refined data products) used is shown in Table **15**.

It should be noted that final refined data products on benthic communities are more realistic if long term data sets are used especially in areas known to experience wide variations in oceanographic conditions. This is the reason why oceanographic data on variations between neap and spring tides and summer and winter conditions should be considered along with the analysis of benthic species composition and abundance. Furthermore, repeat surveys should be set for preferred seasons/periods to allow inter-annual comparison.

Table 15: Types of data products for the benthos analysis in wave energy test centres.

Parameters	Data products	Support of data products
Sediment characteristics	Sediments composition per sampling station: % of each particle size class	Tables with the percentage values for particle size classes for each sampling station
Species composition and abundance	• Total number of species per sample • Total biomass per unit area (fresh and/or dry) • Percentage of each taxonomic group per sample • Organisms density • Photographs of dominant species • Videos	- Column charts each column representing one sampling station for: • Total number of species • Total biomass per area • Total abundance • Density - Cumulative column charts with percentage of each taxonomic group, per sample - Photographs and videos
Indices application	Tables with the results (per sampling station) of the application of the following indices: • Species richness • Shannon-Wiener • Equitability	Tables with the indices' values for each sample for evaluation of species diversity and dominance

4.3.5. Lessons on probable impacts

The hydrodynamic regime, in combination with sediment source, determines the characteristics of seabed sediments distribution and this ultimately determines a significant part of broad scale community patterns observed (Judd, 2012). The removal of energy from the marine environment due to the presence of wave energy devices has been identified as a potential negative effect of this group of technologies. Changes in the water flow energy may influence the transport of sediments, gases, nutrients and food for some species and interfere with the distribution of others with dispersive juvenile stages reliant on transport by currents (e.g. Nowell and Jumars, 1984; Koehl, 1996; Abelson and Denny, 1997; Gaines et al., 2003; Gaylord, 2008). Furthermore, the long shore transport of material (and thus the sites where sediment accumulates or erodes) is dependent on the size and direction of incoming waves. Thus, by reducing waves in general and particularly those from a specific direction (i.e. downstream of the device), long shore drift of material and ultimately beach morphology, shallow water bathymetry and substrata may be altered (Defeo et al., 2009; Shields et al., 2011). Theoretical models of wave energy parks (consisting of 270 devices; about 200 MW total installed power; moored in 50 to 70 m water depth off the coast of Portugal) indicated that wave height at the 10 m depth contour (approximately 10 km down wave) may be reduced by 5 cm and the relative percentage of wave energy removal by the devices will be greatest during the summer (Palha et al., 2010). A study of the beaches in the shadow zone of the Wave Hub (Poate et al., 2012) determined that significant change in beach morphology would require changes in the incident wave height of greater than 30%, far greater than the 6% change which is predicted.

In general potential effects on benthic receptors may be expected during construction and operation phases. During construction the impacts most likely to occur are those related with habitat disturbance, increased suspended sediment, sediment deposition, scour and abrasion and release of contaminants from dredged sediments. During operation, as explained above, changes in hydrodynamics and the introduction of new habitat types from foundation structures and/or other

submerged equipment (promoting both positive and negative effects) are the most relevant effects associated with marine renewable energy projects.

The available EIA reports from test centres (see SOWFIA Deliverable 4.4) conclude that the effects of the deployment of wave energy converters on coastal processes and geology would be insignificant in comparison to the natural processes occurring at the sites. In such reports, seabed disturbance from construction is generally considered to be local, temporary and similar in magnitude to common natural occurrences in the marine environment (e.g. storms). Due to the dynamic nature of the sites, it is assumed that the local marine environment will fully recover in a short period of time.

The greatest potential for impact on communities associated with the seabed (benthos) is the creation of artificial reefs. These reefs could fragment benthic communities or provide habitats for predatory species which could impact benthic communities. The creation of artificial reefs could also increase biodiversity in the area. In some EIA reports the extent of this effect has been evaluated to be small in the context of the total available habitat. In other reports the accumulation of mooring structures on the seabed is classified as a major change to the local natural substratum and thus represents a severe impact which may change sediment transport in the area, interfere with the height of waves and consequently decrease coastal biomass.

4.4. Fish and Shellfish

The construction and the operation of wave energy farms could affect the fish fauna and result in changes in their abundance and distribution close to a wave farm. Changes to the ichthyic fauna can also have implications on fishing activities which need to be assessed (e.g. Simas et al., 2013). Some fish species are protected under the Habitats Directive (92/43/EEC) which aims to protect a wide range of rare and threatened endemic species, including offshore species, animals, plants and characteristic habitats. Several fish species of community interest are listed under Annex II such as benthic sharks, elasmobranchs and catfish. In planning for renewable energy converters, relevant other Directives to be considered are the Environmental Impact Assessment (Directive 85/337/EEC) which aims to assess the impacts of projects on the environment and the Strategic Environmental Assessment (Directive 2001/42/EC) which aims to assess the impact of plans and programmes.

The potential impacts from the development of offshore wave farms on fish include: collision mortality, physical habitat modification, acoustic trauma and barrier effects due to electromagnetic effects (EMF). An overview of the potential impacts is presented in Table 16.

Table 16: Potential impacts on fish fauna from the development of wave farms.

Impact	Physical changes	Collision mortality	Acoustic trauma	Barrier effects
Cause	Periods of turbidity during the construction phase (this depends on the type of wave energy converters adopted)	Fish collide with wave devices	Underwater noise from construction and operation	Electromagnetic field exposure
Effects	Damage or displacement	Reduced survival	Displacement Temporary and permanent damage to hearing Masking which could affect navigation, communication etc?	Damage or displacement

4.4.1. Monitoring requirements and methodology

The specific site for planned wave farms should be investigated through a multi-annual baseline study before and after installation to provide an analysis of impacts on fish. The guidance document developed by SNH (Trendall et. al, 2011) suggests that the minimum length of monitoring for baseline conditions should be two years. Whilst two years may not provide a sufficient time frame to evaluate the abundance of the population this timeframe should at least permit the detection of changes due to the presence of wave farms.

Baseline site characterisation should include a wide scale description of fish distribution and abundance. Such a study must include the identification of important or sensitive species or habitats,

identification of a species spawning or nursery ground in the area or migration pathways through the area. Early evaluation of such factors in the planning cycle of wave farm development can avoid costly mitigation activities at a later stage. Considerable quantities of data for fish in coastal zones already exist. For instance, in the UK they can be found and consulted on the Marine Management Organisation fisheries web page or on Scottish Marine fisheries web page, and these sources should be investigated at first (Judd, 2012).

Three surveys pre and post construction, are recommended by CEFAS (Judd, 2012) (one during the spawning season and two at other times of years, depending on the seasonality of the major fisheries) and extended over the entire footprint of the project. The methodology should be selected for the relevant species on site and should be appropriate to the fishery that is being surveyed. If commercial species are of concern the equipment used should be similar to that used in local commercial fisheries. The involvement of local fishermen in survey design and data collection is strongly recommended.

Different monitoring methodologies can be applied to the monitoring of fish such as those highlighted by CEFAS (Judd, 2012) and summarised below:

- Desk study: an investigation of the available facts and information relevant to the specific issue;
- Commercial gears (pots, trawls, fixed nets, lines etc): Trawls will indicate which species are present but all types of trawl will miss some species and the fishing gear used should be appropriate to the type of fish expected in the area. It may be appropriate to use more than one type of trawl and would probably include otter trawl and/or beam trawls.
  Pots and fixed nets may be more appropriate for sampling some species of interest.
- Acoustic Ground Definition System (AGDS): AGDS are based upon single beam echo-sounders and are designed to detect different substrata by their acoustic reflection and absorption properties. Hard surfaces result in strong echos while soft surfaces absorb sound and give weak echos.
- 'Scientific' Echo-Sounder: is a kind of AGDS which can provide high quality data relative to standard single beam echo-sounders but they do cost more than an echo-sounder. They were initially designed for use in fisheries research but are proving useful in habitat mapping predominantly for the detection of marine algae.
- Sidescan Sonar: (SSS) is a swath based system which insonifies a wide track of seabed generating an image analogous to a monochrome aerial photograph. The high resolution of images makes them an ideal tool for the detection of fine scale features, such as biogenic and geogenic reefs.

At Wave Hub a passive acoustic tracking monitoring technique was used in order to assess individual fish behaviour and space use over large spatio-temporal scales (Witt et al., 2012). This involved attaching acoustic transmitter tags on hundreds of fish, which are then detected as they move within range of acoustic receiver data-loggers placed in an array within the Wave Hub footprint. Data which can reveal fish residency and movement patterns are available for remote upload using a vessel mounted underwater acoustic modem every few months.

For monitoring mobile species or species, that cannot be adequately instrumented with tracking technologies, HD wide angle cameras were used at Wave Hub. Census data of mobile species presence, diversity and abundance were then determined. Cameras were deployed on the seabed and at mid-depth in the water column within the study site. At each sampling station vertical upcasts

of temperature against depth were recorded using a 1 Hz CTD (conductivity-temperature-density) probe (Witt et al., 2012).

4.4.2. Monitoring locations

Monitoring of fish is needed, not only to detect direct impacts of the wave farm, but also to assess the socio-economic impacts on commercial activities. In addition changes in bird and marine mammal distributions around the wave farm might result from local changes in abundance of their food. Fish monitoring activities at other test centres are detailed in Table 17 with various reports available on the DMP.

Table 17: Summary of the fish species occurrence information for each wave energy test centre.

Test centre	Monitoring requirements	Sampling stations and time period	Used methodologies and results	Type of data in the DMP
AMETS	N/A	N/A	N/A	N/A
BIMEP	Available only in Spanish	Available only in Spanish	Available only in Spanish	Available only in Spanish
Lysekil	Academic research	Sampling around 21 foundations installed in 2007. One sample July-August 2007, 2-3 months after deployment	Visual census by scuba diving on the structures, including the holes where present, and on the surrounding bottom within 1 m distance. Low densities of mobile organisms, but a significantly higher abundance of fish and crabs on the foundations compared to surrounding soft bottoms.	
Ocean Plug	N/A	N/A	N/A	N/A
SEM-REV	N/A	N/A	N/A	N/A
Wave Hub	Fish classification and biodiversity assessment	Along northeast-southwest axis of the development zone Continuous	Assessment of mobile species diversity and abundance with increasing distance from the development site at a nearly constant depth	N/A
		Continuous	Passive acoustic tracking. Identification of mobile species spatial footprints, residence times and visitation patterns	

4.4.3. Suggestion towards common methodology and data refinement

In order to perform cross site comparisons as well as robust European wide analysis of the effects of renewable energy installations upon fish it would be necessary to express all data in common units. The limited experience that has been obtained to date means that recommendations on that arena have not been developed although the principles discussed under section 4.1 and 4.2 have relevance.

4.4.4. Lessons on probable impacts

4.4.4.1. Physical habitat modification

During the construction phase of a wave farm fish communities are likely to be displaced or damaged. The UK Department of Energy and Climate Change (DECC) in its Draft National Policy Statement for Renewable Energy Infrastructure (EN-3), which provides the primary basis for decisions by the Infrastructure Planning Commission (IPC), states that: "during construction, 24 hour working practices may be employed so that the overall construction programme and the potential for impacts to fish communities is reduced in overall time."

Marine renewable energy constructions are not primarily built to enhance marine life and ecosystems, but positive side effects may result with structures forming artificial reefs (ARs) and/or fish aggregating devices (FADs). In the Lysekil project, half of the concrete foundations of the wave energy converters were constructed with holes/cavities and the remaining were constructed with plain sides. Larger cavities were preferred significantly over smaller ones and were commonly occupied by crabs or fish, e.g. young cod. Moreover, vertical sides showed higher biomass compared to horizontal surfaces. In addition, smaller schools of fish are commonly observed swimming around generators indicating that wave energy converters located on the seabed show clear features of artificial reefs (ARs), with expected positive effects (Langhamer et al., 2009). It has been suggested that floating offshore energy devices may function as fish attracting devices, or fish aggregating devices (FADs) for pelagic fish.

The preliminary data collected at Wave Hub through passive monitoring tracking suggest that, if the areas around wave energy devices are designated as no take zones, it is possible to provide long term refuge to fish during important stages of their annual cycle (Witt et al., 2012).

A more detailed discussion regarding FADs, ARs and no take zones is presented in Section 4.4.4.4 and 4.4.4.5.

4.4.4.2. Collision mortality

The collision risk is a function of the characteristics of the wave energy device e.g.:

- The size and shape of the device and the extent of the device located below or close to the water surface;
- Level of underwater noise associated with wave device;
- Visibility of the device.
- Whether the device has underwater moving parts

There is a general lack of information on relevant environmental characteristics of devices that might inform the evaluation of collision risk. Where information is available, it relates to single prototype devices and there is little if any information available on the environmental characteristics of multiple devices. The analysis carried by ABP Marine Environmental Research Ltd (ABP Marine Environmental Research, 2010) , suggests that hearing sensitive fish (such as herring) may be able to detect and avoid individual operational wave energy devices at distances between approximately 35 to 200m (depending on the depth of the water). For hearing insensitive fish, the projected source noise levels for wave and tidal devices are likely to be below levels at which these species might exhibit an avoidance reaction. It is thought that the short range ability of fish to evade a single device is high in daylight conditions but that collision risk has the potential to be much higher at night. (ABP Marine Environmental Research, 2010). The increase in night time collision risk is linked to poor visibility conditions so bright paint or the addition of lighting, which are both used to reduce boat

collision risk, would increase the visual clarity of the device where such an effect is high. Nonetheless any potential adverse impact to marine fish species is largely unknown.

Most wave devices have very low or no potential to cause physiological damage to fish. The exception is overtopping devices where if a fish became trapped in the collector the primary exit is through the turbine (although this is protected by a screen through which most fish would not pass). Due to the position of the collector at the very surface of the water and ease of evasion by most fish, entrapment in overtopping devices is unlikely (ABP Marine Environmental Research Ltd, 2010).

4.4.4.3. Electromagnetic fields (EMF)

Anthropogenic EMF is introduced into the marine environment whenever electricity is transmitted. The strength of emitted EMF increases proportionally to the electrical current and decreases with distance from the source of the field. A number of marine species including fish, marine mammals, sea turtles, molluscs and crustaceans are sensitive to electromagnetic fields and use them for e.g. orientation, migration and prey detection (see Poléo *et al.,* 2001; Gill *et al.,* 2005; OSPAR 2008). Power cables, transformers, ac/dc conversion devices, rotating turbines, and generators associated with ocean energy development could potentially expose marine life to EMF levels that alter their behaviour and/or physiology. Several studies have shown that EMF are detected by electrosensitive species, such as benthic sharks (COWRIE, 2010). Mesocosm experiments by Gill et al. (2009) using EMF emission intensity (8 µT; 2,2 µV m^{-1}), which was towards the lower end of the range of detection for elasmobranches, demonstrated no significant effect on the species studied.

A further study of the consequences of any impact of EMF shows that fish assemblages do not differ between energised and non-energised AC submarine power cables. There may however be differences in invertebrate communities with sea pens exhibiting higher densities near energised cables compared to non-energised cables, and sea stars exhibiting lower densities near energised cables (Schroeder and Scarborough, 2011). The effect of a 130 kV AC power cable on migrating European eel, *Anguilla Anguilla* (L.) in the Baltic Sea was small from the point of view of environmental impact assessment and there was no evidence that the cable was an obstruction to migration (Westerberg and Lagenfelt, 2008*).* A review of the Horns Rev Offshore Wind Farm, Denmark where the wind turbines are interconnected to the transformer platform with a 36kV cable and the transformer platform is connected to land by a 150kV cable concluded that the migration direction of eels was not influenced by the electromagnetic field produced by the offshore wind farm (DONG Energy and Vattenfall A/S., 2006*).*

The Draft National Policy Statement for Renewable Energy Infrastructure (DECC 2012), which provides the primary basis for decisions by the UK Infrastructure Planning Commission (IPC) on applications it receives for renewable energy infrastructure, finds that: " Where it is proposed that the offshore export cables are armoured and buried at a sufficient depth to reduce EMF (greater than 1.5 m below the seabed), the effects of EMF on sensitive species from cable infrastructure during operation are unlikely to be a reason for the IPC to have to refuse to grant consent for a development. Once installed, operational EMF impacts are unlikely to be of sufficient range or strength to create a barrier of fish movement."

4.4.4.4. Artificial reefs

Artificial reefs (ARs) can be defined as purposely built structures, or objects, deliberately left on the seabed, to mimic some characteristics of a natural reef (Jensen 2002). ARs are typically created using many different objects such as by sinking oil rigs or on shipwrecks or built from stone or concrete blocks on the seabed. Marine renewable energy developments are not primarily built to enhance

marine life and ecosystems but positive side effects may result when structures act as artificial reefs. Introducing new man-made structures and material into the oceans creates new surfaces and more structural complexity. This is commonly found to be positive for marine organisms as new surfaces can be colonised by sessile species and the added structural complexity attracts e.g. different mobile species, such as many fish species that more than likely use the structures for protection but also as feeding places.

There are still questions as to whether ARs do increase species number and/or biomass on a larger scale, or as some argue, only create a local attraction thus concentrating biomass around AR to the commensurate detriment of surrounding habitats.

4.4.4.5. Fish aggregating devices

Fish attracting devices, or fish aggregating devices (FADs), are moored or free-floating devices designed to attract and/or aggregate fish, often to provide recreational fishing opportunities. FADs are generally smaller than most artificial reefs, and are often installed seasonally to attract some pelagic species. Even free floating clumped debris may be considered FADs as large number of fish commonly aggregate underneath. A good example of a FAD is a newly constructed pier that soon after construction starts to host large numbers of fish, often juveniles, which seek shelter underneath the structure. The aim of constructed FADs is similar to that of ARs (see above) and their importance has long been recognised (Ibrahim et al., 1996). Clearly, any wave energy converter with parts on or near the ocean surface has the potential to act as a FAD. This suggests that wave energy farms especially are likely to experience an increase in fish species number and biomass concentration compared to random control areas.

4.4.4.6. No take zones

Overfishing is one of the major current conservation issues of our time. Marine reserves where fishing is reduced or banned have been shown to have beneficial impacts on fish and the marine ecosystem they encompass, and thus benefits fisheries (Sanchirico et al 2006).

Activities such as dredging and fishing, and bottom trawling in particular, have severe effects on marine habitats. Not only are fish removed from an area but disturbance of the seabed is considerable and affects the whole sea bottom community.

Marine reserves are still a rarity globally and the need for more reserves is regularly emphasised by conservationists. Marine renewable energy sites, offshore wind, wave or tidal, all have the function of preventing commercial fishing from within the area of the site, mainly due to safety reasons. Fishing using nets or trawling is likely to be forbidden in most cases, thereby indirectly causing the marine renewable site to function as a no fishing area. Marine renewable energy farms, thus, will have the potential of acting as “no take zones” where positive effects on local/regional fish stocks could be expected. This should be an important area of research in future marine renewable energy projects in order to confirm this theory. More recently, ideas on how to utilise marine offshore installations for multiple uses including fish farming have been raised, especially including fish farms as part of offshore wind farms.

5. Test Centre EIA Experience

This section summarises the experience acquired by the SOWFIA consortium on the review of the EIA reports for each of the six European test centres (where they are available) and /or on information available, presented in SOWFIA D.4.4 Interim Report (Simas, et al., 2013). Table 18 summarises the results of the survey and monitoring activities carried out for the EIA requirement at each of the test centres. Because of large variance in the descriptions of potential impacts across the different EIAs, an attempt to homogenize the perceived magnitudes of these impacts as reported in the site EIA is performed by adapting the following classification across all EIAs:

- Compatible environmental impacts: impact that can be recovered immediately after the cessation of the activity and that doesn't need any protective measure;
- Moderate environmental impact: impact that can be recovered without any protective or corrective intensive practices and in which reaching the initial environmental conditions take some time;
- Severe environmental impacts: impact that needs some adequate protective and corrective measures to recover the initial environmental conditions and for which the recovery requires significant time;
- Critical environmental impacts: impact whose magnitude is superior to the acceptable threshold. It produces permanent impairment the environmental conditions.

Table 18: Summary for different environmental receptor's magnitudes as reported in the EIA report of each European test centre.

Receptors		AMETS	BIMEP	LYSEKIL	OCEAN PLUG	SEM REV	WAVE HUB
Physical Environment	Water quality and ground water	MODERATE	COMPATIBLE	COMPATIBLE	N/A	MODERATE	COMPATIBLE
	Physical processes	MODERATE	SEVERE	COMPATIBLE	N/A	COMPATIBLE	COMPATIBLE
	Air quality and climate	COMPATIBLE	N/A	N/A	N/A	N/A	N/A
Flora and Fauna	Marine mammals	MODERATE	SEVERE	COMPATIBLE	SEVERE	COMPATIBLE	COMPATIBLE
	Seabirds	MODERATE	MODERATE	COMPATIBLE	SEVERE	COMPATIBLE	COMPATIBLE
	Fish and shellfish	N/A	Noise --> MODERATE EMF --> SEVERE	COMPATIBLE	N/A	COMPATIBLE	COMPATIBLE
	Benthos	MODERATE	Increased Turbidity -->MODERATE Anchors and moorings dragging --> SEVERE	N/A	N/A	COMPATIBLE	COMPATIBLE

Table 18 highlights the different evaluation of the impacts between the European test sites, which depends on a complex mixture of factors discussed in the preceding sections including; differences in regulatory requirements, the environmental conditions at each site, the presence of protected

species and habitats at each site and the location of each site relative to protected areas. A brief analysis of these differences is discussed below.

At the AMETS test centre, the receptors considered for the physical environment were water quality and groundwater, physical process, air quality and climate: the impacts on water quality, and groundwater were *moderate* because the main effects are expected to be due to suspended sediments during cable burial and anchoring operations; the impact on the Physical Process, was *moderate* because it is expected that the impact of wave energy converters when deployed at the test area would be insignificant in comparison to the natural processes occurring in the bay; the impact on the air quality and climate was deemed negligible both in the national context and in the immediate receptor area.

Within flora and fauna the environmental receptors assessed at AMETS were marine mammals, seabirds and benthos: the impact on the marine mammals was *moderate* because, though construction phase is likely to be the most disruptive to marine mammals due to increased noise and boat traffic, they are expected to return to the area once construction has been completed. Operational impacts aren't deemed to be significant; the potential impacts on the Seabirds, which came from physical disturbance, risk of collision and noise disturbance, are speculative and they are expected to be minimised so the cumulative impact was classified as *moderate*; the general effects of the development on benthos, due to increased sediment transportation, is unlikely to have any more effects than a natural storm. The greatest potential impact is due to the creation of artificial reef, which can on one side increase biodiversity in the area but on the other may fragment benthic communities. Nonetheless the extent of this was expected to be small in the context of the total available habitat so the impact was classified as *moderate*.

At the BIMEP test site, the impacts assessed regarding the physical environment were water quality and groundwater and physical process: the impact on the water quality and groundwater was considered compatible because the possible damage caused to the water during the installation, functioning and decommissioning of the WECs is considered minimum; the impact on the physical process was severe because the device moorings were not expected to be removed following the testing period.

For the flora and fauna the descriptors considered by BIMEP were marine mammals, seabirds, fish and shellfish and benthos. The impact on the marine mammals was assessed as severe because the impacts on marine mammals as a consequence of the vibrations and noise produced mainly during the installation and decommissioning of WECs and cables and, to a lesser extent, during the operation of the WECs. The impact on the seabirds was moderate because the birds can be affected by noise and vibrations during the installation, operation and decommissioning of both cables and WECs. Impact on the fish and shellfish due to vibrations and noise of installation and decommissioning was classified as moderate while the impact due to electromagnetic fields was classified as severe. The increase in suspended sediments in the water was deemed a moderate impact on benthos while the dragging of the mooring and or the anchors was considered a severe impact.

The Swedish test site Lysekil, deemed the overall impact on the physical environment, including water quality and groundwater and physical process, compatible because both the increased sedimentation and the biofouling effect around and nearby the WECs were considered to be local only and should be compared with other, similar and common natural occurrences in general. For the flora and fauna the impact on the receptors considered, marine mammals, seabirds and benthos was considered compatible: in fact the Lysekil site and its surroundings do not host species of special interest or at least none which would be affected by the project.

At the Portuguese test centre Ocean Plug, only the flora and fauna sensitivities was assessed at and the impacts were deemed severe on both marine mammal and seabirds because of the presence of critical endangered species which can possibly be affected by the deployment and operation of wave energy devices. This example highlights the dramatic effect that project siting can impart on the EIA process.

The analysis carried out at the French SEM-REV test centre under the physical environment include water quality and groundwater and physical process descriptors. The impact on water quality and groundwater was moderate because the water quality alteration due to fluid industrial waste and turbidity was deemed moderate and temporary using conventional mitigation measures. The impact on the physical processes was compatible because the modification of sedimentary dynamics was deemed moderate to negligible due to the limited footprint of impacted area, the low number of anchors and the weak nature of local sediment transport. For the flora and fauna the receptors considered were marine mammals, seabirds, fish and shellfish and benthos. The impact on marine mammals, seabirds and fish and shellfish have been classified as compatible because disturbance during installation and operation is considered negligible due to short duration of the works and limited number of WECs to be tested. Noise and electromagnetic effects are moderate to minor/negligible using suitable mitigation measures. The impact on the Benthos was compatible, because the destruction of benthic species and micro and macro algae on the submarine cable's route and on the test site itself, have been classified as reversible and negligible.

Analysis carried out at the Cornish test site Wave Hub under the physical environment including water quality and groundwater and physical process, indicates that the impact on the water quality and groundwater was compatible, because the survey of water and sediment quality carried out to determine the baseline showed that no impact on water, soil or sediment quality will take place during construction, operation or decommissioning. The impact on the physical processes was compatible, because results of monitoring showed that waves at the coast could be impacted up to 13% but more typically on the order of 5%, and a minimal impact due to changed sediment transport on beaches should be expected along the northern Cornish coast.

Considering flora and fauna, assessed receptors were marine mammals, seabirds, fish and shellfish and benthos. The impact on marine mammals was compatible, because the installation of WEC anchors or moorings is likely to involve either pile driving or seabed drilling for some types of WECs. The impact of construction noise on marine mammals was considered to be of minor adverse significance, the impact on the seabirds was compatible, because no significant impacts on all birds present at the site are expected if appropriate mitigation measures are employed. Regarding fish and shellfish the most frequently recorded sensitive species is the basking shark and the main impact of concern was the electromagnetic fields generated by cables which was considered unlikely to cause damage. Nonetheless, considering the sensitivity of the species, the impacts were deemed compatible. The impact on the Benthos was compatible because any disturbance to intertidal seabed communities from installation and decommissioning of the cable was considered to have minimal impact due to rapid recolonisation from the surrounding seabed.

This review provides some vivid examples of the principles discussed in the preceding sections as well as supporting observations and recommendations developed in other aspects of the SOWFIA process. These include:

- The heightened role that protected species play in the EIA process. In one example (Ocean Plug), the presence of critical endangered species led to severe assessments for receptors (Seabirds) which were assessed as moderate or compatible in all other cases;

- The variability of sensitivity to various receptors under different regulatory regimes where 5 of 7 receptors were not assessed in at least one centre and no centre was required to assess all receptors;
- How the local environmental/political/regulatory landscape can shape potential impacts. This is seen in the fact that the 6 test centres which are potentially hosts to the same devices exhibit impact magnitudes for the same receptors which range from compatible to severe;
- Air quality and climate and water quality and ground water are uniformly perceived as the lowest magnitude potential impact followed by physical processes;
- With one exception, impacts from EMF were not considered significant across the test centres.

6. Discussion and Conclusions

Wave energy projects in Europe do not have a specific requirement to undergo EIA but due to the unknown nature of the technology and because of national legislation, it is highly probable that such a process will be required. The EIA process in Europe is regulated by the *EIA Directive* 85/337/EEC (as amended by Directives 97/11/EEC, 2003/35EC and 2009/31/EC[8]) and is influenced by *the Strategic Environmental Assessment Directive (2001/42/EC), the Birds Directive (2009/147/EC)*, *the Habitats Directive (92/43/EEC)*, the *Renewable Energy Directive* (2009/28/EC), the *Marine Strategy Framework Directive* (MSFD,2008/56/EC) and the *Water Framework Directive* (2000/60/EC).

Workshop discussions and the analysis of test centre EIAs performed during the course of the SOWFIA work package 3 have indicated that the key environmental receptors of concern for wave energy EIA include the physical environment (waves and current, morphology) and flora and fauna (marine mammals, seabirds, benthos and fish and shellfish).

Waves and currents are the physical drivers that shape the environment in which ocean ecosystems exist and in which human users of the ocean operate. Ocean energy developments by definition remove energy from these drivers and unquestionably have an effect. Whether that effect has a significant impact is a question that is to be determined during wave energy EIA. Currently this question is investigated through numerical simulation. The current understanding is that arrays of wave energy devices will lead to alterations in the energy level and spectral nature of incident waves in the lee of such arrays but these effects will diminish with distance from the arrays. Preliminary studies suggest that the magnitude of the effects from projects studied so far are of order 10% or less. In general these studies suffer from untested assumptions of energy removal by the arrays as well as overly conservative estimates of the level energy removal. Validation of such studies and confirmation of the results will come from monitoring of waves and currents largely from surface buoys and ADCPs. Common data formats have been defined and implemented on the SOWFIA DMP and refined data products from such data are available.

The introduction of noise into the underwater environment from the deployment of marine renewable energy devices is of growing concern because of the potential for disturbance to marine species which use sound for communication, navigation, finding prey and evading predators. Key aspects of assessing the impacts from introduced noise include identifying the baseline noise signal at the site of interest, the noise signature of the planned devices and the auditory sensitivity of species present. Baseline noise is dependent of the characteristics of the site, the sea state and anthropogenic activity. Device noise signal is dependent on device design, number and layout of deployed devices and device activity level as well as the site characteristics. While ocean noise measurement methodologies are well established, there is very limited experience in measuring noise emissions from wave devices. Limited measurements from deployed WECs confirm that the emitted noise would likely be limited to frequencies below a few tens of kHz, that the signal strength varies with sea state and that the noise emitted would be detectable by marine species. Suggested methods of presenting noise data include overlays of the measured data with the noise sensitivity of species of interest and/or spatial maps of zones of influence for those species.

The impacts of wave energy on marine mammals was of significant concern at all the test centres in the SOWFIA project reflecting that all marine mammals are protected by national, European and/or international legislation. Monitoring of marine mammal populations before, during and after deployment of marine renewable energy devices is often required as part of the wave energy EIA process. There are a wide range of methods for monitoring marine mammals and the methods utilised will be determined by the questions to be assessed. Whatever methods are employed, it is critical to determine whether the survey design method will be able to detect an impact at an early stage. It is suggested that data presentation be designed to reflect detection rate relative to effort. Examples of Refined Data Products for Static Acoustic Monitoring of vocal cetaceans are available on the SOWFIA DMP.

Limited experience to date with MRE devices suggests that marine mammals may avoid such devices but further experience with different technologies in different settings is needed. Experience with nets and static (but slack) fishing gear indicates that entanglement is a potential issue although the risk associated with wave energy devices is likely to be much lower than other MRE technology. This risk is potentially aggravated by the increased availability of food arising from the FAD potential of WECs. Because of the highly mobile nature of marine mammals, cumulative effects from increasing MREI developments as well as other anthropogenic activities are of a special concern which must be carefully considered primarily during SEA and secondarily in planning.

Many species of seabirds are protected under national, European and international legislation and baseline data and/or monitoring of seabird distribution and behaviour is a universal component of wave energy EIA. There are however extensive resources and information available on the abundance, distribution and behaviour of many seabird species within Europe. Survey methods include point counts from land or sea, boat and aerial based transect counts, aerial based photogrammetric approaches and radar assessment of birds in flight. An essential feature of this work is the understanding the connectivity of development sites with SPAs which can be achieved only through tagging studies. Data presentation for the temporal variation in species composition and species abundance information available from repeat surveys of best presented as GIS maps allowing visualisation of temporal trends. Examples of such RDPs are available on the SOWFIA DMP.

Population level impacts on birds can be summarised in three main categories: direct (collision, entrapment, displacement), indirect (noise, habitat enhancement, de facto MPAs), and cumulative. WECs have a much smaller above-water profile than wind turbines, and so are likely to have much lower risk of collision but their considerable underwater structure may provide an enhanced collision or entrapment risk particularly moving parts. The most likely direct impact of WECs on birds is displacement. Species that are restricted to foraging in specific habitats may be particularly vulnerable but sensible development planning to avoid sensitive foraging areas will help mitigate possible population impacts.

Assessment of impacts on benthos is a standard component of all marine developments but expected impacts from wave energy developments are largely limited to the construction phase of development and relate to habitat disturbance, increased suspended sediment, sediment deposition, scour and abrasion and release of contaminants from dredged sediments. Potential operational impacts include changes in hydrodynamics and the introduction of new habitat types from foundation structures and/or other submerged equipment. The experience provided from test centres EIA suggests that the effects of the deployment of wave energy converters on coastal processes and geology would be insignificant in comparison to the natural processes occurring at the sites. Similarly, seabed disturbance from construction are generally considered to be local, temporary and similar in magnitude to common natural occurrences in the marine environment.

The evidence to date is that the potential impacts to fish and shellfish from wave energy developments are limited and of a short duration. The greatest potential for displacement effects is limited to construction phase and can be mitigated by keeping this phase as brief as possible. Entrapment and, to a lesser extent, collision remain as viable threats during the operation phase but can be mitigated by appropriate protective measures.

Fish and shellfish represent the receptor for which some of the "positive" or benign effects of wave energy are most apparent. While not designed to enhance marine life and ecosystems, wave energy developments have potential to exhibit the same advantages as fish attraction devices, artificial reefs and no take zones. At the Swedish Lysekil test centre, WECs were judged to exhibit clear features of artificial reefs (ARs), with expected positive effects. The ability to actively design the WECs to enhance this effect was successfully demonstrated.

A review of the EIAs performed at all of the test centres represented in SOWFIA confirms several features of the wave energy EIA process covered in the SOWFIA project. While the selection of receptors discussed in this report is confirmed by this experience, there is clear evidence that the receptors of primary interest are dependent on factors such as the local environmental landscape, the presence/absence of protected species and the regulatory authority under which the EIA is performed. Across all test centres, the impacts which were perceived as lowest significance were air quality and climate and water quality and ground water with physical processes as the next least significant.

In the analysis of all the receptors to be considered which has been presented in this report, there are a few common themes which are evident and deserve separate attention. The first of these is the appropriate length for baseline studies. While there is considerable variation on the frequency and density of sampling, wherever recommendations are provided on the amount of time required to provide a baseline sufficient to detect changes attributable to the presence of WECs, a minimum time of 2 years is proposed.

Another common theme is that for almost all biological receptors electromagnetic fields was identified as a matter of concern. Research has identified the biological significance of electromagnetic fields to certain marine species. EMF radiation from undersea cables and generation systems is often identified as a concern. Nonetheless there has been no documented evidence of significant behavioural effect on a species level from existing installations and one national regulator has declared that EMF radiation from properly buried cables would not qualify as justification for the denial of any ocean energy development.

In a related matter, it has been repeatedly suggested that for wave energy EIA monitoring purposes, a BAG design may be preferred over a BACI design. The reasons for this are both: the BACI requirement for a similar but independent control site, as well as the additional resources necessary to acquire a sufficient number of replicate surveys to achieve the desired level of impact detection sensitivity.

Finally, throughout this report, a matter of concern has been the cumulative impacts from a hopefully rapidly expanding level of wave energy development taking place in a background of growing utilisation of the marine environment. While there is some room for developers to partially mitigate this impact in the early stages of project development, this is a complex matter which is both technically and financially largely outside the ability for any single developer to address adequately. For this reason, it is felt imperative that the issue of cumulative impacts be comprehensively addressed at the national level as part of SEA and that it should be continually reassessed.

7. References

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