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SOWFIA Project - Work Package 3 Interim Report

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Streamlining of Ocean Wave Farms Impact Assessment (SOWFIA) Project

SOWFIA Deliverable D.3.3
Interim WP3 Report

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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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Revision History

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06	09/01/2013	Integration of noise monitoring programme	JOC/DM	DCC

Executive Summary

Wave energy is an innovative and developing technology that could contribute to meeting EU green energy goals and climate change mitigation targets. However, technological and administrative hurdles still need to be overcome in order to establish wave energy as a viable and reliable energy source. A particular issue experienced in the development of the technology across Europe is the lack of knowledge of the potential impacts that Wave Energy Converters (WEC) may have on the environment. The EU union has developed Directives to protect biodiversity, habitats and endangered species. National governments require that the potential effects on the environment be addressed before granting permission for wave converter deployment.

Wave developers must comply with Environmental Impact Assessment (EIA) legislation and consequently are required to supply large amounts of environmental information to facilitate informed decision making. The EIA legislation was not designed with the wave energy industry in mind; national requirements can vary across Europe. As a nascent industry, environmental effects of wave energy projects are largely unknown at this time. Similarly, the socio-economic impacts of wave energy developments are largely unknown, however they are evaluated by authorities in the decision making process..

The aim of SOWFIA is to investigate the current European wave energy industry and provide recommendations for the streamlining of approval processes and impact assessment requirements for wave energy developments in Europe. This should ensure the protection of marine ecosystems while simultaneously encouraging the development of renewable energy. In order to achieve this goal, the SOWFIA project is working in collaboration with six European wave energy test centres located in six different EU countries to gather and share environmental and socio-economic data and information.

Within this context the SOWFIA consortium is undertaking a review of environmental impact studies carried at wave energy test sites in Europe, of the protocol and methodology used for monitoring of environmental receptors and evaluation the likelihood of impacts; with the aim to understand what monitoring is required, how it is undertaken and what type of data are collected and how they are used to reduced uncertainties over potential impacts.

The output of this work is represented by the creation of a data repository, the Data Management Platform (DMP) containing monitoring data from the six test centres and serving as a data repository. The DMP is an interactive tool designed to assist the decision making process by providing information on different wave energy technologies, monitoring activities at the different test centres and allowing direct visualization and downloading of the data. The Data Management Platform is publically available on the SOWFIA website and can be accessed at **sowfia.hidromod.com/**.

This document, written at the interim stage of the work stream "Collection and presentation of environmental data for wave energy test sites", describes the development of the DMP presenting requirements and methodology for the monitoring of different environmental receptors including: wave and current resources, sea birds, marine mammals, noise monitoring, invertebrates and benthos, and fish aggregating devices.

The document presents suggestions and recommendations for the development of common methodologies for the presentation of environmental data to be employed across test centres with the aim to streamline procedure across EU countries to increase the scientific robustness of data.

Contents

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 provide examples of 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 homogenize 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).

The current work will be complemented by the production of Refined Data Products and lead to the identification of practical methodology for determining the likelihood of the impacts of wave farms and ultimately will provide guidance towards the streamlining of wave farms EIA.

1. Introduction

Wave energy is an emerging industry and in many regards it can be considered as a new user of maritime space. The potential of wave energy to contribute towards EU green energy goals and climate change mitigation have been long discussed (Clément et al., 2002; Cruz, 2008; Falcao, 2008). However, technological and administrative hurdles still need to be overcome in order to establish wave energy as a viable and reliable energy source.

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.

Normally, the developer will request the regulatory authority to provide guidance to the developer on what should be included in the EIA (scoping stage). The developer must then provide information on the anticipated environmental impacts. The regulatory authorities, other authorities concerned, the public and other affected Member States must be informed and consulted. Following this period of consultation the competent regulatory authority will make its decision, taking into account the submissions made during the consultation. The public is informed of the final decision and have the option of challenging the decision before the courts.

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 also 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 number of recognised 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 consenting process from the scoping exercise, to the evaluation of the possible impacts, and finally to the design of the monitoring programme. In a recent Workshop 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 scoping of the EIA, e.g. what kinds of data is collected, the resolution required for each type of data, timescale of the monitoring programme (Dominguez Quiroga et al., 2011). These uncertainties can have a great impact on the cost of a project, delaying the development phase of the project.

1.1. Other 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,

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

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 is turn requires protection of habitats and species through site designation and also provides safeguards against potentially damaging developments. These associated Directives 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
- ***The Birds Directive (2009/147/EC)*** provides far-reaching protection for all of Europe's wild birds, including offshore species. The Directive requires Member States to designate Special Protection Areas (SPAs) for plans/programmes which are prepared for energy[3] and which set the framework for future consent of projects listed in the EIA Directive. It is a Member State's duty to carry out an Appropriate Assessemnt (AA) every time significant effects on the environment are likely to take place.particularly threatened species 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.

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 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 the Good aim to achieve "Good water status" in all bodies of surface water and groundwater by 2015. Surface waters include coastal waters until 1 nautic mile. Good surface water status" means the status achieved bya surface water body when both ecological and chemical status is at least "good". Thus, and according to

[3] As well as agriculture, forestry, fisheries, industry, transport, waste/ water management, telecommunications, tourism, town & country planning or land use.

the European guidance documents on the Implementation of the WFD, good status means low levels of chemical pollution as well as a healthy ecosystems.

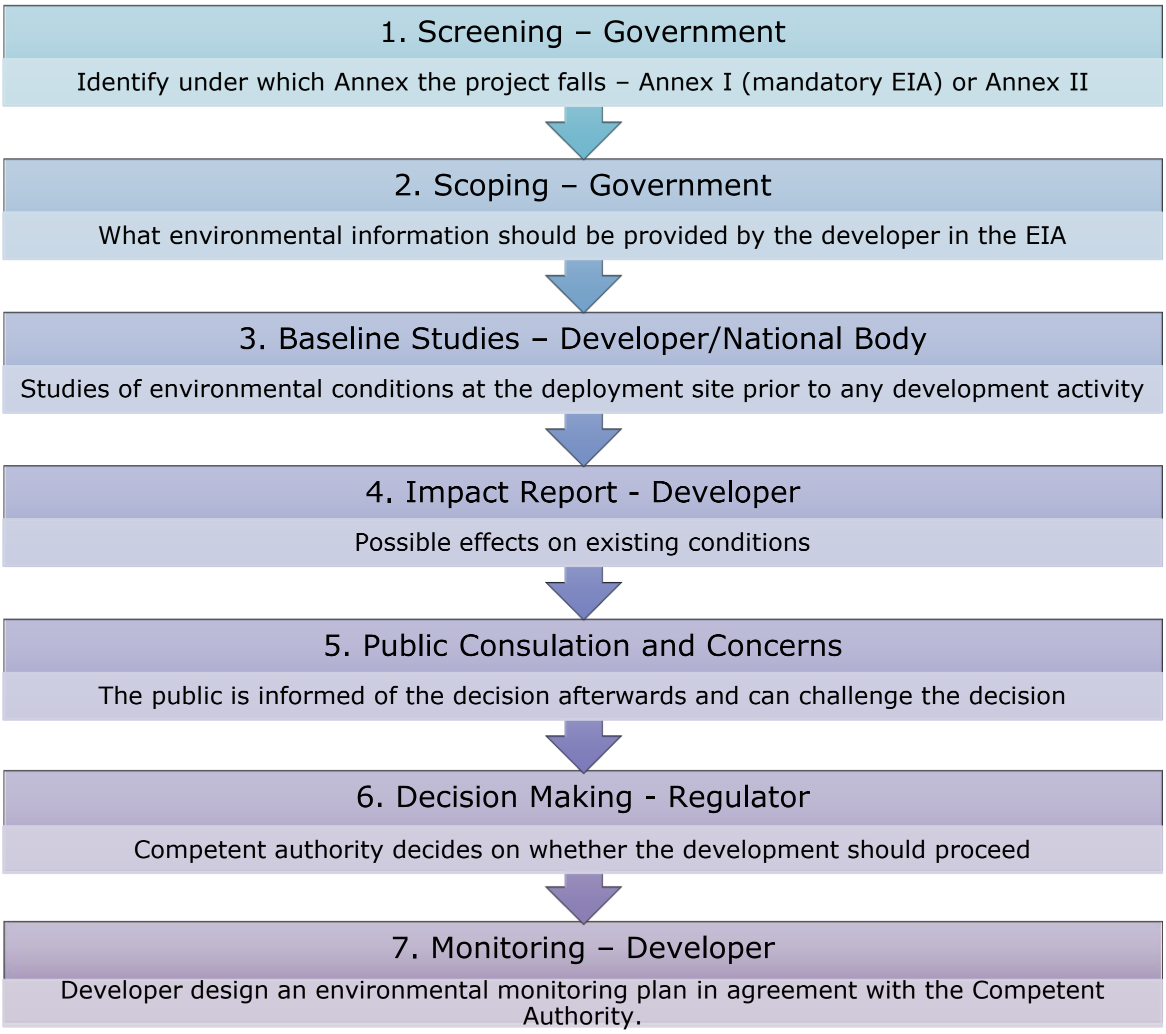

Figure 1 – EIA Process adapted from EQUIMAR (2010b)

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 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[4] 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

[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.

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 sites specific assessments are determined, as highlighted in the Offshore Energy SEA (OESEA2) prepared by DECC in the UK (DECC, 2011). As a result, in preparing the SEA, DECC has been required to forecasting scenarios of wave and tidal energy installation based on experience obtained from demonstrator sites.

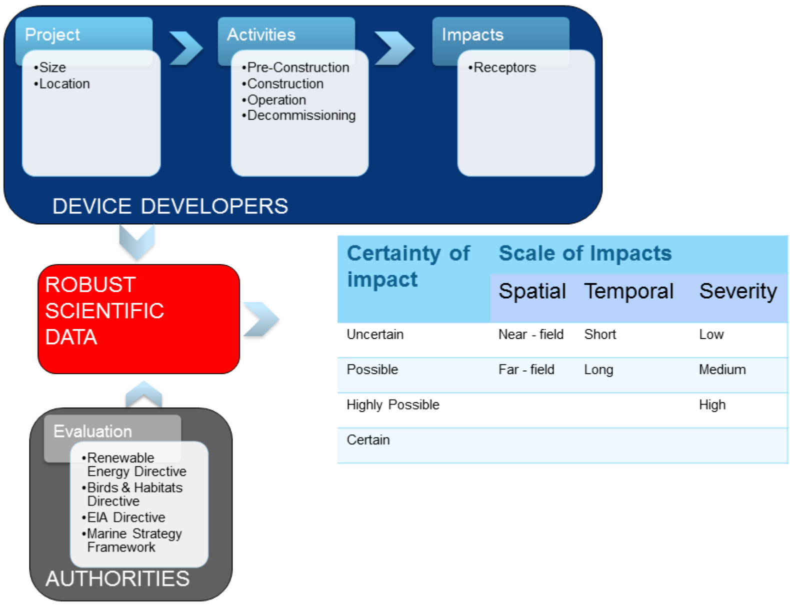

Figure 2 – The role of scientific data in the decision making process

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 of WECs and their components; however, some also monitor the environmental, physical and socio-economic receptors so as to increase knowledge of the impacts of ocean renewable installations on the environment. 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.

To facilitate the process, the SOWFIA project is working closely with seven 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 the Wave Hub in England (Figure 3), gathering data from monitoring activities in order to develop an interactive tool, the Data Management Platform (DMP), designed 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 wave energy test sites.

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 Table 1.

The activities are divided into three main categories:

1. Studies on physical factors such as bathymetry and water quality.
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 envelop for the monitoring of the eleven descriptors of GES of water included in the MSFD. (JRC, 2011)

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 the 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.

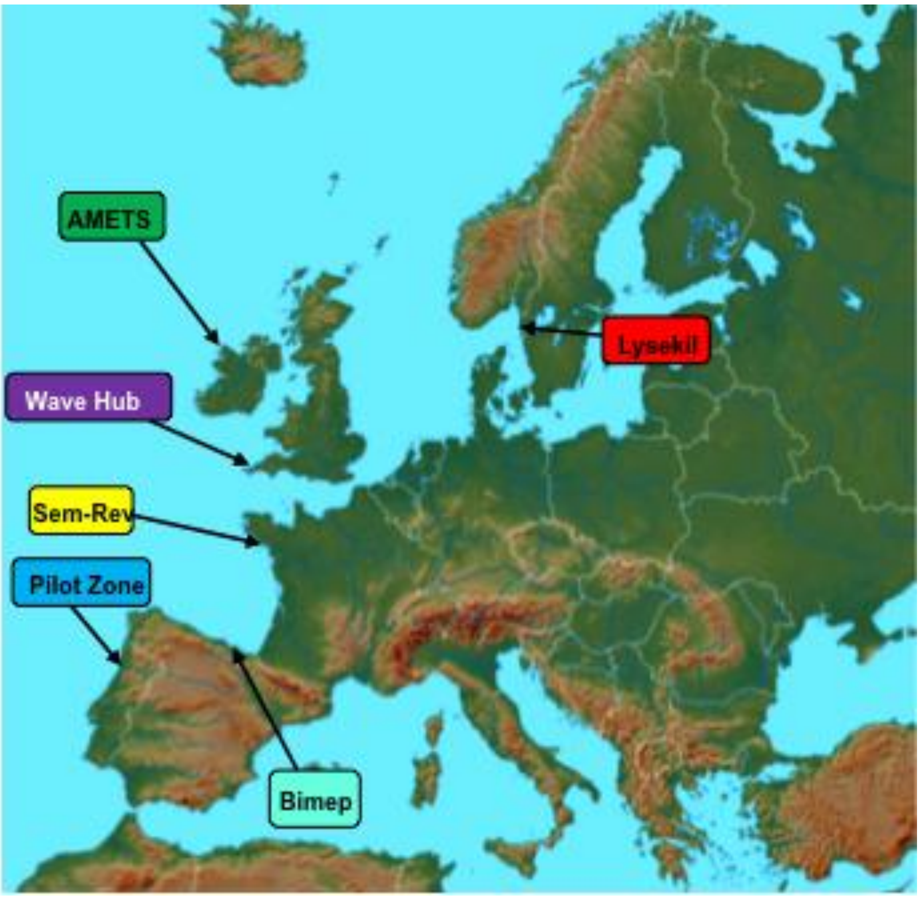

Figure 3 – Test centres providing information to the SOWFIA Project

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	✓	✓		✓	✓	✓
Benthos	✓	✓	✓	✓	✓	✓
Fish & Shellfish		✓	✓			✓
Plankton studies						✓
Marine Mammals	✓	✓	✓	✓		✓
Marine Ornithology	✓			✓		✓
Acoustic and Noise						✓
Landscape & Visual	✓					✓
Archaeology						✓
Navigation and Shipping						✓
Fisheries	✓			✓		✓
Economics						✓
Tourism						✓

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).

1.4. The DMP: Supporting Decision Making

The DMP is an interactive tool designed to assist in the decision making process, providing information on different wave energy monitoring activities at different test centres and allowing direct visualization and downloading of relevant data.

The Data Management Platform is publically available on the SOWFIA website and can be accessed at sowfia.hidromod.com/pivotmapviewer from any computer with an internet connection. The DMP is structured into three main components:

- A *Project* tab, highlighting the different WECs developed and tested in EU waters
- A *Sites* tab, providing information on the environmental monitoring carried out at each test site. This allows for comparison of monitoring techniques and information among the test centres participating in the SOWFIA project
- A Map tab, based on Google® Maps technology, which provides a user interface for visualizing and downloading data. Each test centre is indicated with a place-mark, and from here the user

can access the different type of data available for that site, view time series data, visualise shape files and become familiar with the monitoring requirements for each activity undertaken at specific locations.

The integration of datasets from the six test centres contributing to the DMP creates a data repository of environmental information for different parameters and increases the ability to undertake more powerful statistical analysis of impacts across sites where desired. The development of a database for survey data has been highlighted as a key point towards the streamlining of licensing procedures and consent for energy development by the Scottish Government (2012).

Interactive tools for the support of the decision making process have been widely used for the evaluation of human impacts on the environment, from analysis of water pollution (Foster & McDonald, 2000) to assessment of the benefits of wind energy farms (Aydin, Kentel, & Duzgun, 2010), often based on GIS (Geographic Information System) technology. GIS tools are now being applied to Wave Energy projects, such as the Oregon MarineMap (http://oregon.marinemap.org/); developed by the Oregon Wave Energy Trust (OWET), allowing users to explore and analyse relevant marine geospatial data in order to identify suitable areas for ocean energy development whilst simultaneously considering existing marine uses, users and the conservation of marine resources and ecological functions. Other examples of GIS-based tools are the OES Annex IV project (http://mhk.pnnl.gov/wiki/index.php/Annex_IV_Knowledge_Base), which provides documentation on the monitoring methodologies utilised at different wave and tidal energy test sites around the world; the Scottish National Marine Plan developed by Marine Scotland which provides information on marine protected areas, species and habitats facilitating the move towards the Maritime Spatial Planning (http://bit.ly/RNW4xQ [5]).

The innovation of the DMP lies in the fact that it brings together, for the first time, data gathered as part of the EIA process and regular monitoring data from wave energy sites across Europe. The DMP contains information on what is being monitored, in what way, by whom and with what frequency. This is useful to developers as it alerts them to the type of information they may need to collect at a site to fulfil regulatory requirements, it is useful to consultants as it provides background on what has happened elsewhere with the same or similar technologies. The latter is of particular importance given the limited experience to date in device deployment.

Data on the DMP is displayed in a consistent format which enables scientists, engineers and regulators to share, compare and contrast data from different countries and allows for the benchmarking of the impacts across sites. The use of a standardised approach for data collection and analyses allows building confidence in the modelling and consistency in the assessment of the impacts (The Scottish Government, 2012).

1.5. Populating the DMP

The core of the DMP is composed of the data collected at the different test centres during monitoring campaigns. In order to assure uniformity and clarity among the different data providers, each dataset is accompanied by a metadata file that is compliant with the EU INSPIRE Directive (2007/2/EC, http://inspire-geoportal.ec.europa.eu/editor/).

Data are categorised based according to the type of receptors monitored and on the basis of European and national legal requirements. The following sections of this document will present detailed information on monitoring requirements and methodology and, where possible compares the data gathered with other demonstrator sites in EU.

- Section 2: Wave and Current Data
- Section 3: Sea Birds
- Section 4: Marine Mammals

[5] http://www.scotland.gov.uk/Topics/marine/seamanagement/nmpihome/nmpi

- Section 5: Noise Monitoring
- Section 6: Invertebrates and Benthos
- Section 7: Artificial Reefs, biofouling and fish aggregating devices

The report is complemented by two further sections, addressing the technicalities of the DMP and use of the data to facilitate consenting procedures:

- Section 8: Technical Implementation of the DMP
- Section 9: Progressing Streamlined Impact Assessment

2. Wave and Current Data

Monitoring of wave and current conditions at test centres is undertaken in order to assess the energy resource available at the test centre. Through the analysis of wave and current data it is possible to determine the amount of power available at a site and its seasonal variation. Information on the frequency, severity and duration of storms at a site is also provided. Wave and current data are also important to assess changes in the water column, sediment transport and long-term changes to the beach morphology due to presence of wave energy farms.

For both wave and current measurements, the aim is to collect high-quality data on a regular basis in a reliable way avoiding too large gaps in the time-series. Real-time availability of such data, although not always technically possible, is a key advantage because it allows for the implementation of a control system for WECs based on the wave conditions.

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). Alternative devices may, however, be used including bottom-mounted Acoustic Doppler Current Profilers (ADCPs) in moderate depths (< 40m, see below), high-frequency radar etc. 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. drift) as possible. One advantage of using wave buoys are that data can be transmitted in near real-time by VHF straight to the receiver on the coast without any intervention at sea. Also, for most devices, the three-dimensional sensor system permits the estimation of directional wave spectra.

For current measurements, 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 (< 100m). 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 a collection of the device from the sea once the batteries or memory are exhausted.

ADCPs (Hoitink & Schroevers, 2004) also allow the estimation of wave parameters and spectra through water orbital velocity measurements (hourly rate at 2Hz by default on RDI ADCPs for instance). However, the relative brevity of ADCP deployments makes it less convenient for operational use compared to wave buoys.

2.1. Monitoring requirements & methodology

For both wave and current measurements, the knowledge of the local mean water depth (and variations due to tide and storm surges) is a first requirement. Wave buoys, once installed, 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 still be retrieved by collecting the memory card at sea.

ADCPs have to be substituted every 1-2 months according to the batteries' life length and memory card capacity (spare device available). Continuous current measurement campaigns would require setting up direct data transmission through e.g. VHF and independent battery alimentation, which is not technically available from manufacturers yet. For currents, the question of their homogeneity across a typical wave energy site is less clear. Current measurements may be carried out in the vicinity of the wave buoy for ease of maintenance operations and better wave-current data coherence.

2.2. Monitoring Locations

Wave measurements can be carried out anywhere within a test site as long as the sensor location is within a few hundred metres of the limits of the area of interest. From experience, it has been found that resource variability is quite small over such limited extents (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).It may be of interest 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).

Information regarding the monitoring activities undertaken at different test centres including availability of data in the SOWFIA DMP is presented in Table 2.

Table 2 – 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 in 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
EMEC (Orkney, Scotland, UK)	Resource Assessment	2003 – Present for wave site (Billia Croo).	Datawell and Axys technology wave rider buoys installed at both EMEC test site and Nursery site	N/A
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	TBC

Lysekil	Resource Assessment	2006 – present	Wave rider buoys	CSV time series of wave parameters
DanWEC (Denmark)	Resource Assessment	2010 – 2012	Wave rider buoys	N/A

2.3. Suggestion towards common methodology and data refinements

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 buoy often determine 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, synthetic data from directional wave spectra integrated parameters like significant wave height, energy period, mean direction, bandwidth and directional spreading are required, as suggested by the EquiMar protocols (Equimar, 2010b) and by Saulnier et al. (2011; 2012). A list of the wave parameters selected for inclusion in the DMP are presented in Table 3. Appendix A provides further information on wave parameters described in the most recent MaRINET deliverable (Lawrence et al., 2012)[6]. 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, these are provided in the Inspire Metadata form attached to each time series.

Table 3 – 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

[6]Further information MaRINET can be found on www.fp7-marinet.eu

2.4. Refined data products

The refined data products consist of added-value statistics based on the wave and current data referred to in the previous section. Refined data products for wave and current parameters include two-entry occurrences tables (significant wave height/energy period or direction etc.) as well as histograms (marginal distributions) and wave roses. Previous protocols for the assessment of 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 IEC (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.

3. Sea Birds

Seabird communities represent a major component within the marine environment. The diversity of seabird species utilising European marine coastal and offshore habitats is considerable, from small cryptic species such as petrels through to the larger and easier to detect families including gannets and gulls. Seabird diversity is expressed in many forms, including feeding method (from deep diving species such as gannets, to surface foragers such as petrels), preferred flight heights, migratory periods and selected routes, young rearing behaviour, selection of mates and foraging distances from breeding colonies, to name but a few. This diversity in form and function ultimately allows seabird communities to capitalise upon the resources of the marine environment upon which they are so heavily dependent.

3.1. Monitoring requirements & methodology

Surveying seabird distributions for marine renewable energy (MRE) developments can be undertaken using multiple methods, each with their associated advantages and disadvantages. Such survey methods include point counts from land or at sea, boat-based (Tasker, Jones, Dixon, & Blake, 1984) and aerial transect counts using visual census techniques following distance surveying approaches (Buckland et al., 2001), aerial based photogrammetric approaches or radar assessment of birds in flight (Plonczkier & Simms, 2012). Surveying programmes should be designed appropriately and focused on a specific question and take into account the often-changing infrastructure at newly emerging marine renewable energy extraction sites.

It is typical for seabird surveys for MRE developments to involve both a spatial and temporal component; as such surveys are often repeated through time to elucidate seasonal patterns in abundance and diversity or seasonal changes in behaviour. Such knowledge is often required at sites of potential marine renewable energy installations (and monitoring following deployment) and is typically required in Environmental Impact Assessment (EIA) processes. The variation in methodology employed, frequency and specificity of these surveys is considerable and reflects the diverse nature of development sites, habitats in which they are placed and Nation State legal requirements, which are in addition to multilateral conservation agreements that might apply if developments are likely to impact sensitive sites, such as Ramsar designation sites[7] and Special Protection Areas sites.

3.2. Monitoring locations

Several European wave energy test centres have created a baseline understanding of seabird communities 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), 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, collected data cannot be contextualised with what is happening in the broader marine extent (geographically) which limits the findings of any studies (Table 4).

[7] Ramsar sites are wetlands of international importance, designated under the Ramsar Convention. The Ramsar Convention is an international agreement signed in Ramsar, Iran, in 1971, which provides for the conservation and good use of wetlands.

Table 4 – Summary of the seabird information for each wave energy test centre and its availability through the SOWFIA DMP. Information on seabird 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	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 years survey effort).	N/A
EMEC (Orkney, Scotland, UK)	Required by Licensing Authority	2005 – present for tidal site 2009 – present for wave site (Billia Croo).	Multiple methods (site dependent) approved by Government regulator. At Billia Croo – weekly visual surveys from single onshore vantage point.	N/A
Ocean Plug – Portuguese Pilot Zone (Portugal)	Data were collected to satisfy the geophysical and environmental characterisation of the site required in the legislation	2004 – 2007 (data from Marine Important Bird Areas monitoring). 2010 – 2012 (data from Future of the Marine Atlantic Environment project) 2011- (data collected during the geophysical and environmental characterisation campaigns of the site)	Multiple methods used	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	2009-2010	Monthly land based visual methods for shore and open water bay habitats, for terrestrial habitats at the landfall site and on Inishglora	Report document

			Island (<3km from the AMETS) Monthly sea based surveys for area surrounding test site (~180km^2) using the European Seabird at Sea standard method	
Pentland-Orkney	Scoping data with respect to Scottish marine environment	Desk-based studies	Techniques review	N/A

3.3. Suggestions towards a common methodology and data refinement

To undertake a robust European wide analysis of the effects of renewable energy installations upon seabirds it will be necessary to express all data in a common unit (*e.g.* density) and for the multitude of advantages and disadvantages for each method to be carefully considered. Using advanced statistical approaches (e.g. Generalised Linear Mixed Effects modelling) and accessing 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.

All monitoring of seabirds should include data collected (i) over a long time period – at least one or two years so that baseline data is available 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.

3.4. 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)

These data may be available over long time periods, for example, at the Wave Hub, point counts of animals are available at 19 points over and in the vicinity of the Wave Hub in most months in the year for several years (Witt et al., 2012). For spatial data (such as the point counts or 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. 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 encompass pinnipeds (grey seals *Halichoerus grypus*, and harbour seals *Phoca vitulina*) and cetaceans (whales, dolphins and porpoises). These two groups require different monitoring methodology, since pinnipeds are central place foragers and hence can spend much of their time hauled out on land, whereas cetaceans spend all of their time within the water column. Since marine renewable energy extraction 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 common cetacean species in European waters is the harbour porpoise *Phocoena phocoena*, though only 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.* 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. Monitoring requirements & methodology

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

The most relevant EU legislation is the Habitat Directives. The Habitats Directive (Council Directive 92/43/EEC) aims to protect 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 favorable conservation status must be achieved. Favourable Conservation Status (FCS) is reported on every six years with the next reporting round due 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 and Reefs. Marine species on Annex II of the Habitats Directive include three species of seal - Grey seal *Halichoerus grypus*, Common or Harbour seal *Phoca vitulina* and *Monachus monachus*, and two subspecies of the Ringed seal, *Phoca hispida bottnica* from the Baltic and *Phoca hispida saimensis* from Finland and Harbour porpoise *Phocoena phocoena* and Bottlenose dolphin *Tursiops truncatus*. 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 supposed to be completed by the end of 2010 but there are still a few outstanding site issues. To date (June 2012) there are 1,764 marine SACs covering 179,148 km2. Designation of a site as an SAC does not restrict all developments within these sites but requires additional environmental impact assessment on the qualifying interests (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 Assessments 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 environment assessments 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 (Council Directive 85/337/EEC) and the Strategic Environmental Assessment (Directive 2001/42/EC) which aims to assess the impact of projects and plans and policies on the environment. The EIA Directive refers to installations for the harnessing of wind power for energy production (wind farms) in Annex II, which are projects where an environmental impact assessment is discretionary and dependent on whether the planning authorities considered the proposal to potentially have a significant impact. No 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.

Since all marine mammals are protected by National, European and/or International legislation, consideration should be given as to how any marine renewable development is likely to disturb or injure these species. Monitoring of marine mammal populations before, during and after deployment of marine renewable devices is often required as part of the Environmental Impact Assessment (EIA) process. The level of monitoring required is very dependent on the specific 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 Special Areas of Conservation SACs).

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. Methodologies appropriate for monitoring seals include: 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 (Mendes et al., 2002), telemetry (Cunnigham et. al, 2008) and monitoring of stranding data (Leeney et al., 2008; Pikesley et al., 2011). Methods appropriate for cetaceans also include boat or aerial-based line-transect surveys to provide density (Buckland et al., 2001), land-based point surveys and monitoring of strandings data in addition to acoustic survey methodology such as towed hydrophone arrays or static acoustic recorders (reviewed in Evans & Hammond, 2004). However, acoustic monitoring methods are to be considered separately within this report. Each survey methodology has its associated advantages and disadvantages, but should consider both the spatial and temporal components of marine ecosystems, for example, at the 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). Surveying programmes should be designed appropriately and focused towards a specific question and take into account the often changing infra-structure at evolving marine renewable energy extraction sites which may impose survey constraints later into the lifetime of development sites.

Most sites are or will be collecting survey data for marine mammals either as a requirement of the EIA process, or due to National, European &/or International legislation. Many sites are fulfilling the marine mammal monitoring requirement solely through acoustic monitoring for noise and marine mammals (Bimep, Lysekil, Pico, Reunion, Sotenas and Wave Dragon).

Many sites are also collecting marine mammal data as part of EIA requirements, providing baseline monitoring data on distribution, abundance and behaviour, and in those sites with installed devices, monitoring populations during and after device instalment. Only the Pilot Zone in Portugal have carried out aerial surveys for marine mammals, most other sites having used boat-based (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).

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). Baseline surveys are usually carried out to gain a coherent understanding of the distribution, abundance and behaviour of marine mammals so 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.

Data formats on the DMP include GIS ESRI shape files (for Ocean Plug/ Pilot Zone, and Wave Hub) or in the form of reports as in the case of the Lysekil test centre and AMETS. Table 7 provides the information on marine mammal data collection and its availability for each test centre. Monitoring locations

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 control locations. As such, collected data 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.

Table 5 – Summary of the marine mammal visual survey data for each wave energy test centre and its availability through the SOWFIA DMP. Information on marine mammals 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
AMETS (Ireland)	Data collected to satisfy EIA	October 2009-September 2010	Seasonal vessel-based line transects, towed hydrophone surveys, static acoustics and monthly land-based observations	Report document
Galway Bay (Ireland)	-	-	Desktop review and collation of existing information on marine mammals that occur in the area	N/A
Aquamarine Power (Lewis, UK)	Not known	Not known but monitoring started in 2010	Visual observations, methodology unknown	N/A
EMEC (Orkney, Scotland, UK)	Required by Licensing Authority	July/August 2011 (BilliaCroo) 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	N/A[8]
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

[8] Report on these activities are available on the EMEC website (www.emec.org.uk/). If you wish to access data sets gathered at EMEC please contact info@emec.org.uk.

Wave Hub (Cornwall, UK)	Applied and fundamental research by UoE Data collected to satisfy EIA	Monthly boat –based surveys August 2008 – present and continuing -	Opportunistic sightings of marine mammals on boat-based point counts of birds at 9 points located in a grid over the Wave Hub, and 10 points in increasing distances away from the Wave Hub in an easterly and westerly direction. Also continuous acoustic data on marine mammal occurrence & behaviour for same time period. Desk based study of Cornwall Wildlife Trust sightings database. Acoustic detection of cetaceans in vicinity of the Wave Hub (TPOD)	GIS ESRI shape files 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
Ocean Plug – Portuguese Pilot Zone (Portugal)	Data were collected to satisfy the geophysical and environmental characterisation of the site required in the legislation	2011	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

4.2. 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, and funding. 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 extraction 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.

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. Using advanced statistical approaches (e.g. Generalised Linear Mixed Effects modelling) and accessing 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.

However, all monitoring of marine mammals should include data collected (i) over a long time period – at least one or two years so that baseline data is available 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.

4.3. Refined data products

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)

These data may be available over long time periods, for example, at the Wave Hub, point counts of animals are available at 19 points over and in the vicinity of the wave hub in most months in the year for several years. For spatial data (such as the point counts or 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.

5. Noise Monitoring

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 (Wilson et al., 2007). 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 sea birds, 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 (Gotz et al., 2009). These changes in behaviour could be avoidance of, or attraction to, the sound source.

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. Marine strategies are to be developed by each Member State which will include measures to prevent and reduce inputs in the marine environment with a view to phasing out pollution.

Included in the definition of pollution in this Directive is the direct or indirect introduction into the marine environment, as a result of human activity, of human induced marine underwater noise which results or is likely to result in deleterious effects such as harm to living resources and marine ecosystems. 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 an EIA is required, the EIA should include an estimate by type and quantity of expected emissions, including noise, resulting from the operation of the proposed project.

5.1. Monitoring requirements & methodology

Noise measurements have been required as part of the EIA for wave energy test centres (e.g. BIMEP – See Section 5.2) and tidal energy projects (e.g. Marine Current Turbines were required to make baseline, construction and operational noise measurements in Strangford Lough 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 MSF Directive (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.

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 noise monitoring of wave energy deployments. Recently there are examples of underwater noise monitoring at tidal energy sites (Broudic et al., 2012; Keenan et al., 2011; Norris, 2009) from which some guidance can be drawn for wave energy sites. Noise monitoring at wave energy test sites does have additional challenges to those found at tidal sites. There are many requirements that need to be considered when designing a noise monitoring programme for a marine renewable energy test site:

Before assessing the noise contribution of marine renewable devices, 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 the 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. At present, there is little data available for the noise from wave energy converters overall operating conditions.

The instrumentation used for measurement of noise is based on the two components of soundwaves; pressure and particle motion, the amplitudes of which are related. Marine mammals detect the pressure component of sound waves while pinnipeds apparently detect particle motion (Riedman, 1990). The instrumentation and methodology used needs to be capable of distinguishing between noise from the marine renewable device installation and operation, and other noise, such as that mentioned above and from turbulence. Drifting hydrophones, which measure the scalar pressure component of soundwaves, have shown some success at tidal sites (Broudic et al., 2012; Keenan et al., 2011; Norris, 2009). Alternatively particle velocity detectors (PVDs), which can measure the pressure and particle motion as well as the direction of the sound, can be used.

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 an EU designated Special Area of Conservation)

5.2. Monitoring locations

Some, but not all of the wave energy test centres have been required to undertake baseline and construction and operational noise monitoring as part of the EIA process (See Table 6). At BIMEP in Spain, a baseline noise monitoring programme using a hydrophone is being conducted at the same time as an acoustic monitoring programme to monitor for the presence of marine mammals. At Lysekil in Sweden a baseline noise monitoring programme is being conducted as part of the EIA as well as a noise monitoring programme with a device in place. Both of these programmes are using hydrophones. For Wave Hub, the EIA has recommended a noise monitoring programme to be undertaken for installation works of piled and drilled foundations and once a wave energy device is in operation at the site as well as a baseline monitoring programme. For other wave energy test centres (e.g. AMETS in Ireland), no noise monitoring programme has been included as part of the EIA.

There are also a number of research projects monitoring noise levels at test centres. One such example is at the Galway Bay Test Site in Ireland where a noise monitoring research project has been underway since September 2012 (See Kolar, 2012). Initially this will involve baseline monitoring. 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. It is hoped that this project will contribute towards the standardisation of methods for measuring underwater noise from wave energy developments. Another example of this is at EMEC where noise monitoring programmes have been undertaken at the tidal and wave sites. The aim of these programmes was to provide a baseline dataset for noise levels at EMEC and to develop a methodology and procure equipment for characterising the acoustic output of devices.

Table 6 – 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.

Test centre	Monitoring requirements	Sampling stations and time period	Used methodologies	Type of data in the DMP
AMETS (Ireland)		-	No noise monitoring programme to date	N/A
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
Aquamarine Power (Lewis, UK)	Requirement for noise to be considered as part of EIA	-N/A	Noise modelling undertaken along with desktop studies to assess potential impact	N/A
Bimep(Basque Country)	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
EMEC (Orkney, Scotland, UK)	Research purposes	Wave Sites: Billia Croo (Full Scale): 2011-2012 Scapa Flow (Sub-prototype scale): 2011-2012	Programme aimed to develop a methodology and procure equipment for characterising the acoustic output of devices	N/A
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. Frequencies covered: 2Hz-22kHz	Data not available at present

Wave Hub (Cornwall, UK)	Academic research purposes by the University of Exeter	1no.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
	Baseline underwater noise monitoring recommended in EIA as well as construction and operational phase monitoring	-	-	-
Ocean Plug – Portuguese Pilot Zone (Portugal)	-	-	No known noise monitoring programme	-
Pico Plant (Portugal)	Only airborne noise is required in the EIA	Two days campaign in May 2010, for the characterisation of the noise source Two days campaign in September 2010 for noise propagation characterisation	Noise source characterisation: the hydrophone was moored at 10 m from the plant; Noise propagation campaign: meaured in 3 transects until 3 km distance from the plant in different directions	Data under processing; will be soon available in the DMP
Peniche (Portugal)	Only airborne noise is required in the EIA	One campaign for ambient noise characterisation (for baseline characterisation) A campaign for device noise characterisation and propagation is expected to be carried out in the Spring of 2013.	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)
SEM-REV (France)			No known noise monitoring programme	

5.3. 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. It is likely that noise monitoring methodologies will be dependent on the site location, legislative requirements, species present at the site and funding available as well as the type of device which is to be deployed and the device installation methods.

Until more is known about the increase in underwater noise caused by marine renewable developments, it is recommended that baseline noise monitoring programmes are 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.

For installation of wave energy devices, the level of monitoring may depend on the installation methods being used. For example, piled foundation installation is likely to result in far more noise than gravity based foundation installation and larger diameter pile installation results in greater Sound Exposure Levels (SEL) than smaller diameter piles (Matuschek & Betke, 2009).

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. It is likely that a long duration noise monitoring programme will be required for initial developments until the noise profile is understood. The extent of the area where noise measurements are to be made needs to be considered. Measurements may be required at the device and at a distance from the device in different directions and possibly at different depths. The cumulative effect of multiple WECs will also need to be considered for wave energy arrays.

Any underwater noise monitoring programme at a site would need to be carried out in conjunction with marine mammal surveys to try to gain an understanding of the frequencies which should be covered as part of the noise monitoring programme and whether the additional underwater noise from marine renewables was effecting the species present.

5.4. Refined data products

Most noise monitoring programmes at the wave energy test centres which are providing data to the SOWFIA project DMP are at a relatively early stage at present (as of December 2012) and so there is a lack of data available from these programmes to create refined data products. It is likely that data products would be based around the potential exposure of animals to underwater sound based on a number of parameters:

1. Sound pressure level (SPL): A logarithmic measure of the effective sound pressure of a sound relative to a reference value. It is measured in decibels (dB) above a standard reference level relative to a specific pressure level. Variations on this include:
    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.
    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 measurement combines the maximum sound measurement with the duration of time for which the sound level is greater than a sound relative to a reference value, It is measured in dB/s relative to the relative to the specific pressure level. Variations on this include:
    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
3. Power Spectral Density graphs showing the frequency band where noise occurs at a location. This would provide a good indicator of which species are likely to affected by the addition of noise from a wave energy converter at a site.
4. 1/3 octave band level: one tenth of a decade with centre frequencies defined in the international standard IEC 61260:1995.

6. Invertebrates and Benthos

Benthos is the community of organisms which live on, in, or near the seabed, also known as the bentic 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.

6.1. Monitoring requirements

Benthos characterisation (and monitoring after deployment) is usually a required parameter in Environmental Impact Assessment processes. Most of the wave energy test centres have undertaken a baseline characterisation of benthos both based on a desk studies 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, a desk-based study, using data collected under other investigations, may be expected. 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 Lysekil test centre in the form of downloadable papers or reports. Table 7 provides the information on benthos data collection and its availability for each test centre.

6.2. Monitoring locations

The Sampling stations used for the baseline studies carried out at the wave energy test sites usually cover not only the area designed to deploy the 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 7).

Table 7 – 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 literature published on the subject for the or nearby the deployment area The replicates of 0,0625m2 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
EMEC		Monitoring of berths and deployment locations.	ROV surveys: Pre- and post- installation and post-decommissioning surveys. ROV footage, still photographs and reports.	N/A

Lysekil				Several reports and papers are 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 0,25m2 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

6.3. Monitoring methodology and types of data

Since species are recognised as the essential baseline for understanding diversity, 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 ROVs. However these are either mostly incapable of 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. A summary of the methods used as well as the type of sediments and benthos data collected for each test centre is shown in Table 7. 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.

6.4. Suggestions towards a common methodology and data refinement

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 identify adequate sampling and data analysis methodologies to optimize monitoring efforts and costs.

There is extensive literature on standard methods for benthos sampling and data processing and analysis. However, decisions on the methodology, equipment and analysis are strongly dependent 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.

Nevertheless, based on the analysis of benthos assessment for wave energy test sites or centres carried out so far, suggestions of suitable methodologies are presented for benthos sampling for each type of habitat (Table 8). For the data analysis methods and representation (refined data products), the information compiled in Table 9 is common to almost all test sites meaning that it is already standardised allowing, if needed, a comparative analysis among test sites.

Table 8 – Sampling equipment and methods for benthos assessment in wave energy test centres (adapted from Pohle and Thomas, 1997).

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.

6.5. Refined data products

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 9.

Table 9 – Types of data products for the benthos analysis in wave energy test centres.

Parameters	**Data products**
Sediment characteristics	Sediments composition per sampling station: % of each particle size class
Species composition and abundance	• Number of species per sample • Percentage of each taxonomic group per sample • Total biomass per unit area • Organisms density • Photographs of dominant species • Videos
Indices application	Tables with the results (per sampling station) of the application of the following indices (used to extract universal features of communities which are not a function of specific taxa; i.e. these methods are species independent): • Species richness • Shannon-Wiener • Equitability

7. Artificial Reefs, biofouling and fish aggregating devices

The installation of marine energy equipment, such as wave or tidal energy converters, raise a number of environmental questions and concerns (Gill, 2005; Inger et al., 2009; Langhamer et al., 2010), issues that may result in a negative impact on the local environment and on specific species. However, the use of wave and tidal devices may result in effects that can benefit the local environment, and may positively affect species or species groups. At the Uppsala University test site, in Lysekil, early consideration on biofouling, i.e. the “unwanted” growth of marine organisms on equipment, was taken. In this chapter, concepts such as biofouling, “artificial reefs”, “fish attracting devices” and “no take zones, will be discussed within the context of marine renewable energy developments.

7.1. Artificial reefs

Artificial reefs (ARs) can be defined as purposely constructed structures, or objects, left on purpose in the ocean an placed on the seabed deliberately, to mimic some characteristics of a natural reef (Jensen, 2002). ARs can be created using many different objects such as by sinking oilrigs or on shipwrecks or built from stone or concrete blocks on the seabed. The aim of ARs is to achieve one or more of the following objectives:

• To improve fishing or diving opportunities by providing a structure on and around which plants and animals can aggregate

• To improve surfing by changing wave patterns

• To protect the coastline from storm surge and erosion by altering coastal processes such as sediment transport.

ARs can have a variety of specific objectives, including:

• Enhancing commercial fishing or recreational fishing

• Assisting in the rehabilitation of degraded fisheries

• Providing underwater tourist attractions for diving

• Restoring, mitigating or offsetting damage or loss of natural reefs or other habitats

• Supporting aquaculture or marine ranching

• Providing research opportunities.

Marine renewable energy constructions are not primarily built to enhance marine life and ecosystems but positive side effects may become secondary influences of the build-up of marine renewables. By adding new man-made structures, and material, into the oceans creates new surfaces and more structural complexity will be added. 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.

In the Lysekil project the foundations of the wave energy converters have been made of concrete. Approximately half of the foundations were constructed with holes/cavities and the remaining was 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. Also, smaller schools of fish are commonly seen swimming around generators indicating that seabed placed wave energy converters show clear features of AR, with the expected positive effects (Langhamer et al., 2009)

There are still questions on 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.

7.2. Fish attracting 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 are similar to that of ARs (see above) and their importance has since 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 parks especially are likely to experience an increase in fish species number and biomass concentration compared to random control areas.

7.3. No-Take Zones

In several countries, over-fishing and how to deal with it has been a common and important topic in debates on marine reserves and reduced fish stocks. No-take zones are in growing demand from most conservationists and ecologists as most seas have been overexploited. A total cessation of fishing in an area may therefore be positive for fisheries management (Sanchirico et al., 2006), although disliked by the fishing industry and fishermen particularly.

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 with its entire species setup.

Marine reserves are still a rarity globally and the need for more reserves is regularly emphasised by conservationists. Marine renewable energy sites, wind-, wave- or tidal, do all have the function of preventing commercial fishing from within the area of the site, mainly due to security reasons. Fishing by 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 parks, 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 study topic in future marine renewable energy projects in order to confirm the above theory. More recently, ideas on how to utilize marine offshore installations for multiple uses including fish farming have been raised, especially including fish farms as part of offshore wind farms.

7.4. Biofouling

Biofouling is the unwanted growth of marine organisms on structures or objects placed into the ocean. The problem of biofouling is perhaps most significant in relation to shipping where biofouling adds billions of euros to the cost of fuel every year as barnacles, mussels and algae growing on the hull cause extra drag and reduce the speed of vessels.

Biofouling may become a problem for marine renewables, especially wave and tidal devices, as the settling of marine organisms may increase the weight, harm mowing parts, make devices less buoyant and also increase the rate of corrosion.

Historically, biofouling has been dealt with using toxic anti fouling paint attached on the hull of boats and ships. Most of the effective paints contained heavy metals and other substances harmful to the environment and have thus been banned from, or are in the progress of being removed from the market. New paints, less harmful to the environment, have been developed but usually are not effective. Intense research is on-going worldwide in order to develop new and effective means of preventing biofouling while at the same time having little effect on the surrounding environment.

In the case of offshore wind farms biofouling will not affect energy production negatively as only the foundations are located in the water. Foundations are thus the only part of an offshore wind turbine to experience biofouling. Future floating wind platforms may face problems but the amount of biofouling is unlikely to affect such large structures. For wave and tidal devices biofouling may be more problematic. Wave and tidal devices are relatively small and may thus be affected more severely. Tidal turbines have moving parts and unwanted growth on turbines may reduce rotation thereby decreasing energy absorption.

In the Lysekil test site biofouling was recognised early on as a potentially large problem. The wave energy converters deployed at the site use relatively small buoys on the sea surface as the energy absorbents. At priori calculations and field tests showed that brown and green algae, barnacles and blue mussels (the most common bio foulers) could add several hundreds of kilograms in weight to a buoy thereby changing the absorbing properties of a buoy. Further studies and results were somewhat surprising as the energy absorption did not decrease but rather increased somewhat.

In Northern Europe the period of settling of larvae of various species of marine organisms is commonly in late spring and early summer although settling of larvae may occur at other time periods. At the Lysekil site, new buoys set out in the spring were commonly full of biofouling by early autumn, often with an excess load of several hundreds of kilo. The same buoy would have lost much of its growth by next spring as winter storms removed much of the previous year’s growth.

In short, the natural colonisation by marine organisms onto new substrates may result in an increase of species or biomass in an area, or both. The colonisation of bacteria, algae, barnacles and mussels will enhance the local habitat and thereby aid the colonisation of other species such as *Crustaceans* and *Asteroidea*, and soon also by fish as they can find shelter and food. As ARs attract fish this in turn may provide food for marine mammals and birds that may gain benefits by foraging in renewable energy parks.

7.5. Summarising Experience

Biofouling is a “phenomenon” that inevitably will occur, and different energy devices such as wave and tidal generators will therefore function as ARs and FADs. This should be considered when planning marine renewable developments. Species involved will vary greatly with location and region, but will also be influenced by a number of other physical and biological factors, such as depth, temperature etc, and original fauna and flora at a site. The positive effects should be mentioned in and during the consenting and EIA-process as the result may be positive for a locality, enhancing the local marine life and even fisheries in the long run. However, the effect of ARs and FADs on a grand scale, in future marine installations with hundreds of units and covering large areas, is unknown. Consequently, more studies are needed both on a basic level as well as in practise as new and larger installations of marine energy are constructed.

It should also be noted that the implementation of new structures in the marine environment may have other detrimental or at least negative effects. In the light of the spread of unwanted, invasive species, new structures may act as “stepping stones” (Petersen & Malm, 2006) for such species, thereby improving the chances of further spread. Data or indications of incidents where stepping stone-events have actually happened within renewable energy sites are not known but this remains as a potential issue which may need to be considered in the future.

8. Technical Implementation of the DMP

8.1. Common Platform of data management

8.1.1. DMP Structure

The Data Management Platform (DMP) has two components, front office and back office.

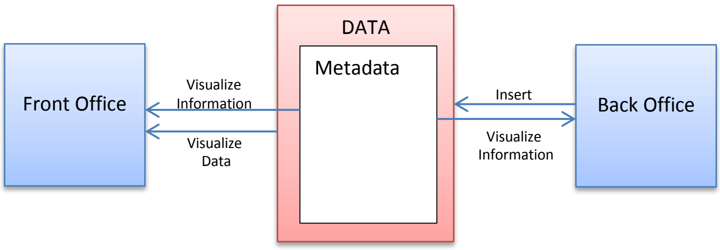

Figure 4 – Scheme of the SOWFIA Data Management Platform

The Front office is used to interact with the data by applying filters over it and viewing its information. Its address is: http://sowfia.hidromod.com/PivotMapViewer/
The Back office enables the management of the data, namely its upload and deletion. Its address is: http://sowfia.hidromod.com/ManageData/

8.2. Back Office

DMP's back office (Sowfia.Hidromod.com/ManageData/) is focused in the management of data, test sites, institutions and projects. It also has the management of users, for back and front office. This component is secured by a username and password, also used on the front office. Back office functionalities and architecture are described in the next points.

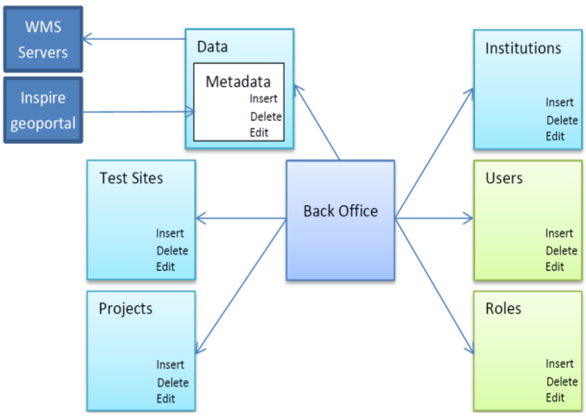

Figure 5 – DMP Back Office Structure

8.2.1. Functionalities

8.2.1.1. Data Management

- Enables the creation, modification and visualization, of test sites, projects, institutions and data.

- Modification, edition or deletion, is only enabled for users who create the information or for administrators.
- The creation of data is made according to the European directive INSPIRE, through the uploading of a metadata file generated in the site http://inspire-geoportal.ec.europa.eu/editor
- The uploaded data is classified into categories and sub-categories, which are also used to query data in the front office for visualization and/or download.

8.2.1.2. User Management

The administrators have access to the creation, modification and removal of users and also to enable the role administration.
All users can change their password.

8.2.2. Architecture

The back office is implemented with Microsoft MVC 4 technology to create the web site, and data is persisted on server database.

8.2.2.1. Data Management

The uploaded data are stored on server disk, under an user folder.

8.2.2.2. User Management

The user manipulation and authentication is implemented with ASP.NET Membership.

8.3. Front Office

The DMP front office (Sowfia.Hidromod.com/PivotMapViewer/) is used to view, filter and search data, test sites and projects. This component is secured by username and password; normal users don't have access to back office. Front Office functionalities, architecture and data service is described below (Figure 6).

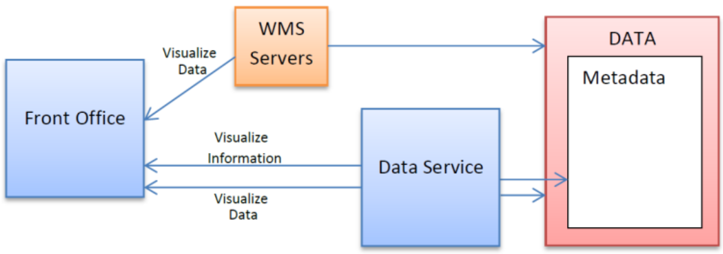

Figure 6 – DMP Front Office Structure

8.3.1. Functionalities

8.3.1.1. Data Queries

- Query test site data by category, period and location, presenting the results by groups.
- Query projects by their properties, and presenting the results by groups.

8.3.2. Data Visualization

8.3.2.1. GIS

Test site location and its respective georeferenced data can be viewed here, over a map. The chosen data is connected with the results of the query to the test site data, if any filter is applied on the test site. The GIS will also filter geographically the presented results.
The GIS is also used to visualize uploaded data over map, like shapefiles and model results.

8.3.2.2. Visualization of Specific Data Formats

The data that can be visualized, like CSV time series, are presented in a graphic, in a new web browser tab which opens within the data web site. Data formats like shapefiles are shown directly on the GIS map.

8.3.2.3. Metadata Visualization

Test site and test site data information can be seen in a popup dialog.

8.3.2.4. Data Download

When data is available at the platform, it can be downloaded by any user.

8.3.2.5. User Data

In this area users can change their password.

8.3.3. Architecture

The front office is based on Microsoft MVC 4 technology, and supported by one WCF Data Service that returns the data to be presented.

8.3.3.1. Data Queries

Data query and filtering is implemented with Microsoft Silverlight Pivot Viewer.

8.3.3.2. Data Visualization

The data visualization is based on EXT JS, which collect information from WCF Data Service through JQuery REST invocation.

8.3.3.2.1. GIS

The map is implemented with GeoEXT, which, by using OpenLayers, can show data layers based on GeoServer. It is therefore possible to represent ShapeFiles and, based on WMSServer, represent numerical model results. There are several background maps available, from two suppliers: Open Street Maps and Google Maps. The use of Google Maps is possible because the username and password on the Front Office have free access; everyone can create an account and use it (https://developers.google.com/maps/terms#section_9_1)

8.3.3.2.2. Visualization of Specific Data Formats

Jqplot is used to represent the time series and the scatter plots .

8.3.3.3. Data Download

To download the data, a request is made by asking the WCF Data Service to return the file stream, which is opened through a web browser new tab, creating a save file dialog.

8.3.4. Data Service

The data service is implemented under Windows Communication Foundation technology and collects data inserted by back office on Sowfia's Database.

8.3.4.1. User Management

The verification of users' login and access methods are validated through ASP.NET Membership and database. Some methods also send notification emails.

8.3.4.2. File Management

Data is read from the file system and prepared for visualization or download.

8.3.4.3. Programs Configuration

3rd party programs were configured in order to visualize complex data like shapefiles.

8.4. Infrastructure

The DMP is supported by a server with an Intel i7 hexacore, enabling 12 threads, containing 64GB DDR3 RAM, with storage of 2 x 3TB.
Over this hardware is a Windows Server 2008 R2 Enterprise 64Bits operating system, with the following software: SQL Server 2008 R2 Enterprise as database, Internet Information Services 7.5 as web server, Apache Tomcat 7 with GeoServer to support shapefiles.
This server contains a backup system from the 3TB data drive, to the 3TB operating system drive.

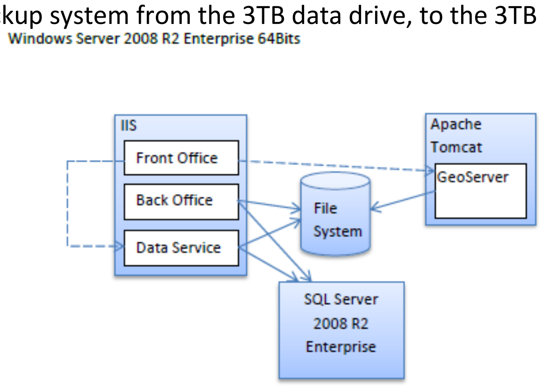

Figure 7 – Structure of the SOWFIA DMP Server

9. Progressing towards Streamlined Impact Assessment

The Data Management Platform developed by the SOWFIA project is a tool aimed at facilitating decision-making and assisting in the consenting process for wave energy installation through sharing of datasets and information on monitoring activities; leading ultimately towards a reduction of the uncertainties related to specific impacts on a defined receptor. It is well recognize that understanding the potential environmental impacts of WECs is a critical step in granting consent for wave energy installations.

The aggregation of data from monitoring activities plays a key role in providing information on how the different receptors are affected by the presence of one or multiple wave energy converters. Due to the limited number of operational test centres and demonstration sites in Europe, knowledge and experience of EIA for wave farms is still limited. Through the provision of datasets from different test centres in a standardised and easy to interpret way, the SOWFIA DMP leads the way in providing easy-to-read data for inter-comparison and benchmarking.

A necessary step that needs to be undertaken in the assessment of the likelihood of impacts is to contextualise the data collected at a specific location with information collected over a wider area as part of broader monitoring undertaken by other industries or governmental association. Through this comparison it is possible to derive specific information on particular receptor. For example, in the context of flora and fauna, one can determine population, distribution and geographical extent of the population and so on.

In order to process towards the streamlining of wave farms impacts assessment the following steps are being undertaken by the SOWFIA consortium within the current work package:

- Comparison with EIA requirements for Offshore Wind (OW) energy, and review of the lessons learnt both in terms of consenting process and of impact assessment. Review of guidelines for OW presented by industry bodies and EU.
- Investigation on databases available containing information on monitoring activities for marine renewable energy and other activities of receptors such as:
    - Annex IV database: information on monitoring methodology
    - EU- EMODNet and Horizon 2020 network, set up at EU level for sharing marine data
    - OBIS and OBIS SeaMap providing historical datasets for marine monitoring of seabirds, mammals and other species
- Review of risk-based methods to determine the likelihood of impacts developed for offshore development (wind and gas and oil energy sectors)
- Generation of refined data products in collaboration with key stakeholders.

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A. Appendix: Important Wave Characteristics

This section is extracted from the FP7 Project MaARINET, deliverable D2.1 “Wave Instrumentation Database” published in November 2012. MARINET is an EC-funded network of research centres and organisations that are working together to accelerate the development of marine renewable energy technologies - wave, tidal & offshore-wind - by offering periods of free-of-charge access to their world-class testing facilities and conducting joint activities in parallel to standardise testing, improve testing capabilities and enhance training and networking. The SOWFIA project and MaRINET both work to facilitate the development of the wave energy sector and collaboration on different part of the work programmes have been developed. Five of SOWFIA partners are involved in the MaRINET Project.

This section present a short overview of the most important wave characteristics that can be determined by the different wave measurement equipment available within the MaRINET facilities. Wave parameters can be derived from the time-series analysis (time domain or wave by wave analysis) or through a spectral analysis in the frequency domain.

A1. Time domain

Time domain characteristics of waves are determined through a wave by wave analysis of the surface elevation at a given location. Through this type of analysis it is possible to determine both individual and integrated wave parameters.

A1.1. Significant Wave Height

The significant wave height, normally represented by $H_{1/3}$ or H_s is defined as the average of the 1/3 largest wave in a record. The determination of $H_{1/3}$ is on the based on the zero up-crossing method.

A1.2. Significant Wave Period

The significant wave period, represented by $T_{1/3}$ or T_s is defined as the average period of the 1/3 largest waves in a record.

A1.3. Mean Wave Height

The mean wave height, H_{mean}, is defined as the average of the wave heights in a record.

A1.4. Mean Wave Period

The mean wave period, T_z, is defined as the average of the wave periods determined by a zero up-crossing analysis of the time series. T_z. is normally preferred to T_s.

A1.5. Maximum Wave Height

The maximum wave height, H_{max}, represents the maximum value of the wave height measured over a given period of time.

A1.6. Maximum Wave Period

The maximum wave period, T_{max}, represent the maximum value of the discrete wave periods measured.

A1.7. Wave Steepness

The wave steepness, s, relates the wave height of the waves with the wavelength (L) associated to its relevant period. It can be determined on a wave by wave base or as H_{mean}/L_{mean}.

A2. Frequency domain

The determination of wave parameters in the frequency domain is obtained through a spectral analysis of the wave records, based on the energy spectrum of the wave records. This relates the spectral density (m^2s) with the frequency. The energy spectrum, *S*, can be represented as a discrete function of the frequency *f*, discrete spectra; or as a function of global wave parameters, parametric spectra.

A2.1. Spectral Moments

The spectral moment are the foundations of the spectral analysis and most wave characteristics can be determined through them. The n^{th} spectral moment can be defined as follows:

$$m_n = \int_0^{\infty} f^n S(f) df$$

The most commonly used moments are m_{-1}, m_0, m_2, and m_4 ; with the zero-th spectral moment m_0 representing the variance of the elevation time series.

A2.2. Significant Wave Height

H_{m0} is the representation of the significant wave height in the frequency domain. It is determined assuming narrow banded Gaussian wave process. H_{m0} is related to m_0 as follows:

$$H_{m0} = 4 \cdot m_0^{1/2}$$

A2.3. Mean Wave Period

There are two main ways to represent the mean wave in the frequency domain. The mean energy period can be determined through the following relationships:

$$T_{01} = \frac{m_0}{m_1} \text{ and } T_{02} = \sqrt{\frac{m_0}{m_2}}$$

T_{02} provides an approximation of the time domain mean wave period T_z.

A2.4. Peak Wave Period

The peak period T_p represents the dominant wave system in a given sea state. Tp is given by the following conditions:

$$T_p = 1/f_p$$

$$S(f_p) = \mathrm{Max}[S(f_p)]$$

A2.5. Energy Wave Period

The energy period T_e is determined from the spectra and it is used to describe the wave reseources for wave energy applications. T_e can be considered as a representation of T_{02}, but its value is less influenced by the higher frequency energy.

T_e is given by the following relation:

$$T_e = \frac{m_{-1}}{m_0}$$

A2.6. Spectral Bandwidth

The spectral bandwidth allows assessing the wave resources in a given area with higher accuracy. The spectral bandwidth is characterized through a number of dimensionless parameters, however the use of the narrowness parameter υ is recommended; accounting for the bandwidth of the sea state process. The spectral bandwidth parameter is somewhat sensitive to the high-frequency contents of the spectrum. The following formulation for υ is suggested as it mitigates higher orders:

$$\upsilon = \left[\frac{m_0 \cdot m_2}{m_1^2} - 1 \right]^{1/2}$$

A2.7. Wave Power

The wave power P_w provides an indication of the power available per unit of crest length in an undirectional sea. Pw is given by:

$$P_w = \rho \cdot g \int S(f) \cdot c_g \, df$$

where cg represents the wave group velocity.

For deep water cases,

A2.8. Wave Steepness

The wave steepness ξ is used to characterize a particular sea stat e. The peak steepness is given by the following relation:

$$\xi_p = \frac{H_{m0}}{L_p}$$

The wavelength L_p is determined through the dispersion coefficient and is associated to T_p.

A3. Direction and spreading

The energy spectrum can be provided in both directional and non-directional form. The non-directional form of the spectrum is conventionally described as S(f), whilst the directional spectrum E(f,θ).

The directional spectrum is derived by adding the directional distribution (D(f, θ)) to S(f) as follows:

$$E(f,\theta) = S(f) \cdot D(f,\theta)$$

Whilst the energy of the spectra provides information on the mean energy available at a given frequency, by including the directional distribution component it is possible to determine the direction of the energy propagation. The directional distribution D(f, θ) describes the proportion of the energy propagating in a given direction for a particular frequency of the spectrum. The directional distribution provides a more accurate indication of the waves prediction. Mono directional spectra can over predict the significant wave height of over 20% compared to directional spectra models.

D(f,θ) can be defined by a matrix providing a set of discrete values over a range of frequency and directions; however the directional distribution is more commonly described as a Fourier series for a particular frequency:

$$\hat{D}(f,\theta)=\frac{1}{2\pi}+\frac{1}{\pi}\sum_{n=1}^{N}[a_n\cos(n\theta)+b_n\sin(n\theta)]$$

The Fourier coefficients a_n and b_n are normally obtained from a buoy or other single point measurement device; with the devices usually providing only four coefficients: a_1, b_1, a_2, b_2.

The directional distribution function is estimated from measured data; a variety of methods have been developed to determine D(f, θ).

These can be separate in three main groups:

1. Fourier Series Decomposition Methods: Truncated and Weighted methods are used.
2. Parametrical methods: direct and statistical fitting
3. Maximum Likelihood Methods: Bayesian Directional Methods (BDM), Maximum Likelihood Method (MLM), Maximum Entropy Method (MEM).

Fitted spreading function such as the cos2s function can be used to determine D(f, θ) when measured data are not available:

$$D(f,\theta)=N(s)\cos^{2s}\left(\frac{\theta-\theta_m}{2}\right)=\frac{2^{2s-1}}{\pi}\frac{\Gamma^2(+1)}{\Gamma(2s+1)}\cos^{2s}\left(\frac{\theta-\theta_m}{2}\right)$$

Where Γ represents the Gamma function and s is the spreading parameter, θ is the wave direction and θ_m the mean wave direction. s is a function of the wave frequency and wind speed. Three main formulations are used to derive the spreading parameter: the Longuet-Higgins (1963) method which assumes s as a constant, the Mitsuaysu et al. (1975) method and the Hasselman et al. method (1981). When s is assumed constant the cos2s formulation reaches the limit of the cosn model:

$$D(f,\theta)=\begin{cases}\dfrac{\Gamma\left(1+\frac{n}{2}\right)}{\sqrt{\pi}\,\Gamma\left(\frac{1}{2}+\frac{n}{2}\right)}\cos^n(\theta-\theta_m) & for -\pi/2<\theta-\theta_m<+\pi/2\\ 0 & elsewhere\end{cases}$$

An alternative description of the of the directional distribution is provided by the Wrapped-Normal distribution given by:

$$D(f,\theta)=\frac{1}{\sigma\sqrt{2\pi}}\exp\left(\frac{(\theta-\theta_m)^2}{2\sigma^2}\right)$$

where σ= σ (f) is the root mean square angular spread.

The composite direction spectra provides useful inputs for shallow water spectral transformation, allowing the calculation of the of directional spectra in the near shore region, accounting for effects such as refractions and non-linear interaction to mention a few.

The spreading function can be combined with either measured or empirical one dimensional spectra such as the JONSWAP or Bretscheineder to provide input for one numerical and physical modelling of wave energy converters.