COMMISSION OF THE
EUROPEAN COMMUNITIES

COOPERATION

Equitable Testing and Evaluation of Marine Energy Extraction Devices in terms of Performance, Cost and Environmental Impact

Grant agreement number: 213380

EquiMar

Deliverable D6.5.2
Analysis of case studies and useful tools

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Project acronym: EQUIMAR

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Analysis of case studies and useful tools

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February 2010

Summary

In this report a review is made to analyze the state of the art of current and practical experience of environmental assessment of marine systems in order to help setting the path to be followed for future ocean energy schemes. Several case studies are presented as well as the description of the applicability of several monitoring tools.

CONTENTS

1 INTRODUCTION

The Environmental Impact Assessment of wave energy projects cannot only be a legislative requirement but also a sustainability proof of the project, a promoter of public acceptance and a benefit for industry, making the project more attractive to investors and governments who traditionally have seen environmental concerns as a barrier.

The environmental and socio-economic effects of operating ocean energy devices are strongly dependant on the technology and location of the project. However, since wave and tidal energy technologies are still in development, the uncertainties regarding the most part of the potential impacts are still assumptions or predictions which need to be evaluated through monitoring. A lack in methodological approaches for environmental and socio-economic impacts evaluation of marine projects is also recognized because these projects have unique characteristics, different from other types of marine projects. A new approach for environmental analysis is needed for offshore energy projects particularly those of wave and tidal energy and this can include a revision of methods and tools used for environmental impact analysis of land projects.

In this report a review is made to analyze the state of the art of current and practical experience of environmental assessment of marine systems in order to help setting the path to be followed for future ocean energy schemes. Several case studies are presented as well as the description of the applicability of several monitoring tools.

2 ENVIRONMENTAL FIELD SURVEY FOR MARINE RENEWABLE PROJECTS

Although few wave and tidal devices have actually been deployed at sea, the experience and know-how acquired by those who have, is very valuable and useful to assess what should be recommended as a protocol of good practices. A comparison of different environmental surveying methodologies used at different device deployment sites / test zones of ocean energy projects is presented in Table 1. This comparison provides an insight into how the impacts of marine renewable energy devices have been assessed.

Table 1 Sampling techniques used for biological component marine mammals in several marine renewable energy EIAs.

Project	Method	Species	Duration	Spatial and temporal resolution	Main Results
Wave Hub[1]	Bibliographic review	All	-	-	List of mammal sightings and likelihood of occurrence
	T-POD deployment on site		3 four month deployment periods	Only on deployment site	T-POD data revealed the species present and how frequently they visited the area
Wave Dragon Wales[2]	Bibliographic review	All	-	-	The project occurred within a SAC and had undergone constant monitoring; specific monitoring was not considered necessary.
Beatrice (offshore wind farm)[3]	Boat based visual transects	All but particularly the bottlenose dolphin and the harbour porpoise	27 surveys over two summers	Deployment site vicinity (covering a total 1930 km)	Species present and their distribution in the deployment area and surroundings.
	Passive acoustic methods (T-Pods)		One on device location and two reference areas	Deployment site vicinity and reference areas	Animal number and distributions in the area
SeaGen (tidal energy project)[4]	Bibliographic review of sightings	All	-	-	List of mammal sightings and likelihood of occurrence
	Telemetry	Harbour seals	Two seasons of tag deployments before device deployment and two during operation	-	The movements of 36 individuals of the populations within Strangford Lough
	Passive acoustic methods (T-Pods)	Harbour porpoises	Several survey periods (baseline, and operation)	4 T-Pods used to cover important sites	Abundance and distribution
	Active sonar tracking	Seals and cetacean	-	80 m upstream from the device	Animal interactions and behaviour in the immediate vicinity of the device
	Aerial sightings	All	-	Vicinity and adjacent coast	Abundance and distribution
	Boat sightings	All	-	Vicinity of the deployment area	
	Marine Mammal carcass survey	Seals and cetaceans	During operation	Area of deployment and adjacent coast	Assessment of device / species interaction that results in mortality
Beatrice (offshore	Day Grab surface samples with camera attached	Infauna and epifauna	-	12 sites with 3 repetitions in total	Species diversity, number, and distribution. The method combines

[1] Report available at: http://www.southwestrda.org.uk/working_for_the_region/areas/cornwall__the_isles_of_scilly/wave_hub/documents.aspx
[2] Report available at: http://www.waveenergy.dk/files/WDNTS.pdf
[3] Report available at: http://www.beatricewind.co.uk/downloads/
[4] Report available at: http://www.seageneration.co.uk/downloads.asp

wind)					physical samples with images

Table 2 Sampling techniques used for the biological component Benthos in several wave energy EIAs.

Project	Method	Species	Duration	Spatial and temporal resolution	Main Results
Wave Hub	30 seabed samples of 0.1 m^2 using a Hamon grab	Infauna from the surface	-	-	Species diversity, number, and distribution in the area
	Epibenthic samples collected using a 2 m beam trawl with a 20 mm mesh net and a 4 mm mesh code and liner	Epibenthic species	-	-	Species diversity, number, and distribution in the area
	Sediment sampling, beam trawl and underwater photography	-	-	Over the proposed deployment area	Identification of 2 broad habitats, 4 man habitats, 6 biotope complexes and 15 biotopes and sub-biotopes
Wave Dragon Wales	Bibliographic review	All	-	-	As the area was within a SAC there was a great deal of information available
	Standard Day grab with additional weight	All	One day	14 sites selected after viewing geophysical survey, although only 3 yielded results	Species diversity, number, and distribution in the area, although limited due to the rocky substrate
	Image work planned. Divers, remotely operated cameras and video were considered	All, but particularly relevant due to the rocky substrate	-	-	Important to note that images are particularly relevant in rocky benthic environments

3 CASE STUDIES

3.1 *EUROPEAN MARINE ENERGY CENTRE*

3.1.1 Introduction

The UK government has acknowledged the need to increase the quantity of energy generated from renewable sources and has set future targets in this regard. In order to encourage the development of this new industry, which has the potential to bring significant investment and work to some of the less favoured areas of Scotland, Highlands and Islands Enterprise (HIE) proposed to construct infrastructure which will allow wave and tidal energy devices to be tested under working conditions and allow their generating capacity to be verified, in order that further investment can be obtained for establishing this technology on other offshore sites.

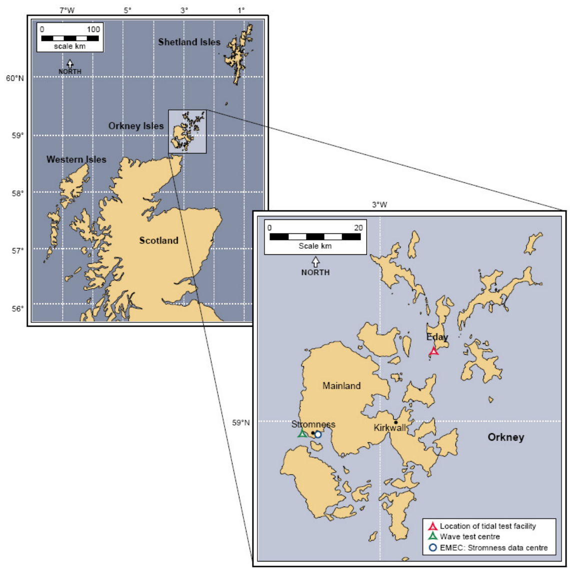

Figure 1 Location of EMEC's test facilities.

Three main drivers governed the design of the European Marine Energy Centre (EMEC): firstly the facility has to function satisfactorily for the purpose for which it is designed; secondly, it has to be constructed to a pre-defined budget; and thirdly, it must minimise adverse impacts on the existing environment.

A site assessment study was commissioned by HIE in 2003 to find the most suitable site for a wave test centre. Hoy Mouth (in which Billia Croo bay is situated) was one of several locations in Scotland to be assessed. This site in Orkney came out on top in several of the 18 categories used to judge the possible locations namely:

- Available energy resources;
- Shortest distance to exploitable offshore resources;
- Availability of offshore support facilities;
- Proximity of sheltered water for construction purposes;
- Suitability of connections to main electrical grid.

Of the two proposed sites in Hoy Mouth the one at Billia Croo bay was identified as the best option due to the better natural landing point for the offshore cables.

HIE commissioned a subsequent study in 2004 to determine the optimum site for a tidal test facility. This initial work identified eight sites in the Highlands and Islands region for further consideration. Each site was screened based on tidal resource potential, water depths, channel width and integration with the existing EMEC wave test site. The Fall of Warness was selected as the location for the tidal test site in preference to other sites as it offered the right physical resources and was close to EMEC. All sites screened and evaluated were in areas that, by the nature of their physical resources, were also frequented by marine mammals.

Although there are a number of uncertainties associated with the operational phase of the facility these should not be unexpected, given that the facility is to be used for the testing of new technologies. The facility will be used to test not only the technical performance of wave and tidal technologies, but also has the potential to advance understanding of environmental issues.

3.1.2 Wave Site EIA Summary

Site option studies identified a suitable marine energy test site to the west of Stromness suitable for testing devices designed to extract energy from waves. An environmental impact scoping study was prepared for developing the necessary infrastructure at these sites.

Following the initial scoping study, the proposed scheme was further developed by the design team taking cognisance of information provided by two wave energy device developers who were planning to use the test facility. The EIA therefore focussed on the areas of the environment as identified in the scoping study which would be affected by the proposed development, however the exact nature of the test devices that would be moored offshore was not known at that stage. A detailed environmental impact assessment was therefore not carried out on this element of the proposed development. Nevertheless a proposed operational environmental framework was included in the EIA process. This sought to address the principal offshore environmental issues identified during the preparation of the document, to allow permissions/consents to be obtained subject to any additional detailed information requirements being provided, prior to the devices being brought on site.

Utilising the information contained in the scoping study and knowledge of the proposed works, baseline studies were carried out on those elements of the environment which were identified as being of particular significance in the area of the proposed works, namely:

- Offshore Ecology
- Onshore Ecology
- Archaeological Heritage
- Geology

These studies were then used in conjunction with the detailed proposals, to predict the effects – both detrimental and beneficial – that were likely to occur due to the proposed works.

a) b)

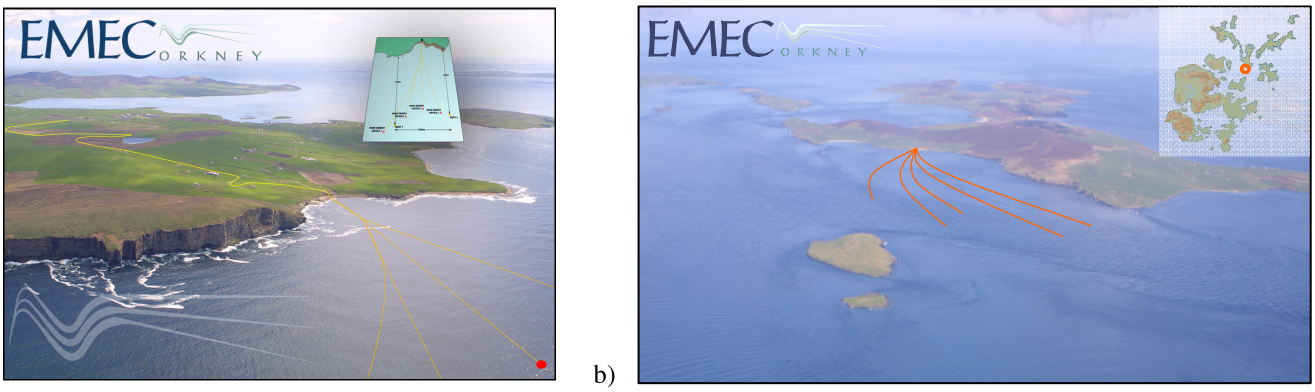

Figure 2 Views over EMEC's a) wave and b) tidal test facilities.

In the EIA process, cognisance was taken of the guidance provide by EEC directive 85/337/EEC (amended as 97/11/EC in 1997) and its specific Scottish form, The Town and Planning (Environmental Impact Assessment) (Scotland) Regulations 1999.

The broad conclusions of the EIA were that, with the identified mitigation strategies in place, the impacts of the construction and installation of the infrastructure for the proposed wave test facility will be minimal. A key recommendation of the Environmental Statement (ES) was measures should be taken to put in place monitoring of the key environmental issues pertaining to the site.

3.1.3 Tidal Site EIA Summary

When EMEC was established by HIE and its funding partners in 2003, it was with the intention of stimulating and accelerating the development of tidal stream prototype energy generating devices. The wave test centre having been established, the next phase was to establish a tidal test site ready for future deployment of the novel tidal energy devices that were being designed and built by independent developers. The proposed test facilities would allow full scale generating devices to be tested under normal operating conditions and allow the generating capacity and performance to be independently verified.

The scope of the EIA undertaken covered the construction and presence of the test site, but not the installation and testing of individual prototype devices. Some future consideration of potential effects was possible, in order to assess the possible impacts of the long-term presence and operation of the site, and there was therefore a consideration of a range of likely potential devices at a generic level. Detailed consideration of individual devices is the responsibility of each developer making use of the site. This level of assessment could not therefore be included in the EIA for the establishment of the site itself. It was also decided that it would be the responsibility of each developer to provide supporting environmental information to accompany individual device-specific licence applications. EMEC subsequently produced a detailed guidance document relating to this process as it applied to its sites [1].

Although the development of the tidal site did not formally require an EIA under the Environmental Impact Assessment (Scotland) Regulations 1999, an EIA was nevertheless carried out as a matter of good environmental practice and to support consent and lease applications. The process for this included an informal consultation and scoping exercise, where a wide range of local and national stakeholders were consulted to ensure the scope of the EIA covered all relevant issues. The responses from the scoping exercise helped to identify areas of potential impacts, and indicated where further studies were likely to be required. Any identified data gaps were addressed as far as possible within the timescale of the EIA.

The broad conclusions of the EIA were that, with the identified mitigation strategies in place, the impacts of the construction and installation of the infrastructure for the proposed tidal test facility will be minimal. The main area of concern is with regard to the potential for otter disturbance at the landfall site. This species has European Protected status, and stringent mitigation measures were developed.

In collaboration with the project team and relevant stakeholders, environmental mitigation and management measures were proposed as part of the EIA process. These measures were assessed and developed further as the site entered into operation. . For example, the need to monitor seal, cetacean and diving bird use of, and movements in the Fall of Warness was identified and a counting programme was instigated. Once the data from this programme has undergone a long term analysis, modifications may be recommended as part of the progressive approach to monitoring at EMEC.

3.1.4 Lessons Learnt

Environmental Management System (EMS): During the EIA process, possible impacts on the environment were identified in the EMS. It was important that, once facilities were in operation, possible impacts were assessed and a robust environmental monitoring strategy be developed and put into practice. However, whilst an attempt has been made to predict the range and character of potential impacts associated with the new technologies, a high degree of uncertainty and many unknowns remain. Particular concerns related to the possible interactions between wildlife and device operation, and the lack of baseline environmental data to inform the impact assessment process.

Hand Over: The EMEC sites were developed by contractors who were employed by the funders. Following the construction and installation phase of the projects, the sites were handed over to EMEC, who became the operator of the test facilities. It was important to ensure that any outstanding issues relating to the EMP were communicated during the project handover.Developer Specific Environmental Statements (ES): It was recognised at an early stage that the ES produced for the establishment of the test facilities, would not necessarily predict all the specific impacts relating to individual test devices. Therefore it was agreed that the developer of each individual prototype device should produce an ES in accordance with EMEC guidance [1]even though a formal EIA may not be required. Some of the baseline data needed to inform this process, particularly with regard to wildlife interactions, is currently being collected by EMEC, and is made available to developers as part of the EMEC service. As part of the consenting process, developers are also required to produce a device specific Navigational Risk Assessment (NRA), which builds upon the EMEC site NRA. Developers also tend to be required by a licence condition to produce an independent verification report and certificate in respect of the safety and integrity of their device. This document and certificate also tends to be required by developers in their process of seeking insurance to cover the deployment of their devices for testing.

Monitoring: In order to be able to adequately address the actual environmental impacts, the EIA processes highlighted that data gathering is required to provide sufficient knowledge of the background environmental conditions. In close discussion with environmental consultees of the regulatory process, EMEC has been progressively developing a monitoring programme that seeks to address the impacts of devices on the sensitive populations at or in the vicinity of its test sites. EMEC is also involved in plans with a number of other research institutions to identify the knowledge gaps and initiate research aimed at addressing these issues. Such research data will be important to developers in order to support future applications for the development of larger scale commercial projects elsewhere, beyond their testing at EMEC sites. However as the EMEC test facility was not set up with a monitoring budget, this has meant that developing these monitoring projects has been extremely challenging and has progressed more slowly than may have otherwise been possible.

Budgetary Provision for Environmental Monitoring: Having the benefit of hindsight, it is apparent that the budgetary provision for baseline environmental monitoring was insufficient, and the need for further provision became progressively clearer as site operations progressed.

3.1.5 Land based wildlife observations

3.1.5.1 Summary

The purpose of the land based wildlife observation programme is to provide as accurate a characterisation as possible of the surface-visible wildlife presence, distribution and behaviour at the EMEC wave test in order to assess potential displacement. Displacement of key wildlife species (e.g. marine mammals and seabirds) from their normal range of habitats is one of the key factors that need to be addressed by regulators and developers of marine renewables. Although a number of approaches have been taken when recording the presence and location of marine mammals and birds in localised areas, the lack of standardised best-practice methodologies for carrying out such monitoring in such exposed areas, could lead to mis-directed conclusions. This case study provides a summary of a field protocol used at EMEC since March 2009. The data collected feed into a statistical framework that has the capacity to examine changes in distribution that may be caused as a result of wave devices deployed at the test site [2].

3.1.5.2 Background

The potential for wildlife displacement is one of the environmental issues that EMEC is monitoring at the wave and tidal test sites, however assessing the populations of marine species associated with particular marine areas is an extremely challenging task. At its most basic, this involves measuring the surface presence of marine mammals and seabirds in areas where there could be a direct interaction and providing a statistically valid assessment of the effect of device operation on the distribution and presence of animals within the region.

A number of survey methods have been developed for assessing populations of seabird and marine mammals at sea (e.g. [3], [4]), however these methods are specifically aimed at surveying large areas of ocean and are not designed to detect fine-scale changes associated with industrial development of a site. A range of approaches have been taken for recording the presence and location of marine mammals from land (e.g. [5], [6], [7]). However, the lack of standardised best-practice methodologies for carrying out such monitoring could lead to mis-directed conclusions.

The methodology outlined in this case study builds on previous work by Sea Mammal Research Unit (SMRU) and EMEC which developed an analytical method for the Fall of Warness tidal test site [2]. The statistical framework has been designed for use at the EMEC wave test site, but aims to be sufficiently robust to potentially be applied in a variety of locations. Each site's data collection requirements will be informed by the regulators and should be addressed on a case by case basis.

3.1.5.3 Aims

The methodology outlined here provides a field protocol which feeds into a statistical framework that has the capacity formally to examine changes to distribution that may be caused as a direct result of devices deployed at the EMEC wave test site. This augments standardised statistical methodologies already developed that permit sightings data from a land based observation point to be analysed in a General Additive Modelling (GAM) framework. Due to the coastal location of the EMEC test site, land-based visual observations are considered to be suitable as the primary data collection technique.

3.1.5.4 Data collection

Land based visual observations are carried out by an experienced observer on a hilltop overlooking the Billia Croo wave site in Orkney (Figure 3). The study area encompasses the whole of the Billia Croo wave site area and surrounding water (Figure 4), although the area very close inshore is not directly visible from the vantage point. The study area is scanned continually in a systematic manner during a four hour long session and the time and location of any marine mammal or seabird sightings are recorded at set intervals. Where possible the geographic location of each marine mammal or seabird group is recorded using the horizontal and declination angle measurements from 'Big-Eye' binoculars (e.g. [4]). Marine mammals and seabirds are identified to species whenever possible. Group size is estimated if animals are seen in groups and the location of the centre of the group is recorded. If there is information about direction and speed of movement then this is included along with behaviour records.

Figure 3 Wildlife observers situated in Black Craig lookout.

Surveys encompass all states of tide and where possible survey effort is varied between days, time of day and state of the tide in a systematic manner to ensure there is appropriate sampling of all environmental states. Tide state is defined in relation to total time since the previous high tide recorded at Kirkwall. Data on several weather variables including precipitation, sea state, cloud cover, and wind speed and direction is also collected.

3.1.5.5 Analysis

For analysis, this methodology uses GAM which is a modern regression technique [8]. It assumes that the number of animals present changes smoothly, but not necessarily linearly, with environmental conditions. Its use is appropriate where similar numbers of animals can be expected to be present on consecutive days and in nearby areas, but the patterns of change are complex or difficult to predict.

Power analysis was conducted on fauna observation data collected at the Billia Croo site for the period 13/03/2009 to 14/03/2010 [9]. The power analysis was based on simulations, and investigated the ability of the current monitoring scheme to detect various potential sized reductions in the underlying abundances of cetaceans, seals and birds. The power to detect changes in animal abundances was found to be generally low for the collection period. Reductions in underlying animal abundances of 10%, or less, would be effectively undetectable over a 6 month monitoring window. However the power to detect changes is expected to increase with a longer time-series of data. The methodology and associated data set are under review and outputs may lead to modifications in 2011.

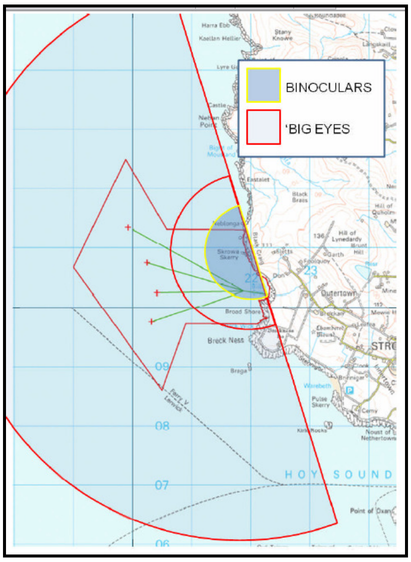

Figure 4 Total observations scan area.

3.1.6 Tidal Test Site Drifting Acoustic Methodology

3.1.6.1 Summary

The purpose of the drifting acoustic methodology is to provide as accurate a characterisation as possible of the acoustic properties the EMEC tidal test site in order to assess any acoustic output of tidal energy converters under test. The concept behind the drifting acoustic methodology is to maximise the advantages of recording ambient sound from a drifting platform and minimise the disadvantages of interference associated with taking measurements from a surface vessel. The hydrophone is fixed relative to the body of moving water so that other constituents do not impart artificial noise into the recordings. This equipment has been developed by the Scottish Association for Marine Science [10] and is being utilised at the EMEC tidal test site (Figure 2) to build up a baseline data set. Developers who wish to undertake their own subsequent monitoring of their devices operating *in situ* then have access to the data collection equipment and the baseline data, and can use this in their comparative analyses.

3.1.6.2 Background

Measuring ambient sound in strong tidal flows raises a significant problem. Recording from a fixed platform will expose the hydrophone (underwater microphone) to substantial water flow and spurious sound not present in the ambient environment. In most studies of marine acoustics, the problem is negligible but, because sites suitable for tidal-stream energy extraction are specifically chosen because of their high flow speeds, this factor is of prime consideration when monitoring ambient sound or acoustic output from tidal energy devices.

Potential solutions to this problem include attempts to shield the hydrophone, subtraction of flow noise during analysis or deployment of hydrophones from a boat moving passively with the current. This final approach offers the simplest solution but suffers from two significant shortcomings. First, even with the engines off, the boat itself will generate unwanted acoustic outputs. Second, the boat will not necessarily move in the direction or speed of the water in which the hydrophone is recording and result in unwanted flow noise and strum. As a result, this approach is being tested to allow uncomplicated monitoring of tidal-stream energy sites without over-stringent constraints on the support vessels or ambient conditions.

3.1.6.3 Aims

The methodology outlined here feeds into statistical analysis that has the capacity to assess the acoustic output of tidal energy converters under test at the EMEC tidal site.

The idea behind the drifting acoustic design is to maximise the advantages of recording ambient sound from a drifting platform and minimise the disadvantages of being associated with a surface vessel. The central feature of the design is that the hydrophone, rather than any other component, is fixed relative to the body of moving water and that other constituents do not impart artificial noise into the recordings.

3.1.6.4 Data collection

To do this, the hydrophone is placed inside the bounds of a large underwater drogue (Figure 5 and Figure 6). The boat is dispensed with and replaced by a buoy and small floating case containing the ancillary electronics (batteries, recorder etc). The drogue is weighted to drift at depth and held there by the opposition of the weight and a small surface buoy. A wide diameter hawser and shock chord strop is used to negate strum and add physical separation between the sensing and surface parts of the unit. The entire unit is self-sufficient and placed into the water upstream of the area of interest. Whilst recording, the unit drifts passively in the current over the area of interest and is retrieved further downstream. The floating case includes a logging GPS, which downloads the precise path of the drifter and can be tied to the acoustic recording using a time code. This upstream-drop and downstream-retrieve approach has the dual benefit of reducing the ambient noise problem described above and it also enables recording from a swathe of locations. This latter feature provides the potential to map the sound intensity over the area of interest. Furthermore, a single support boat can simultaneously deploy multiple acoustic drifters to increase the spatial resolution of acoustic data recorded and make optimal use of brief weather or operational windows.

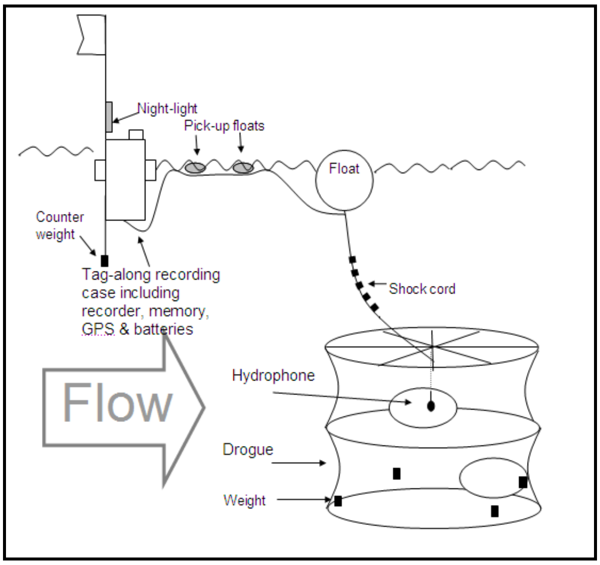

Figure 5 Schematic of components of the autonomous drifting acoustic recording equipment. Individual parts not to scale.

Figure 6 Drifting acoustic drogue set up. (Note: drogue-to-float line is looped over to fit drogue in photograph).

Whilst the concept is relatively simple, the practice of building low-noise drifters for high energy environments capable of being launched and retrieved from small boats required several development iterations. Particularly important is the isolation of noise artefacts generated by parts in the system moving against each other. Also critical is optimising the balance between the volume and mass of the drogue with the buoyancy of the floating gear. Combinations within still-water prove ineffective in the tidal-stream environment where strong lateral and vertical currents occur (often in combination). Therefore repeated tests in high energy sites are required to achieve the necessary equilibrium.

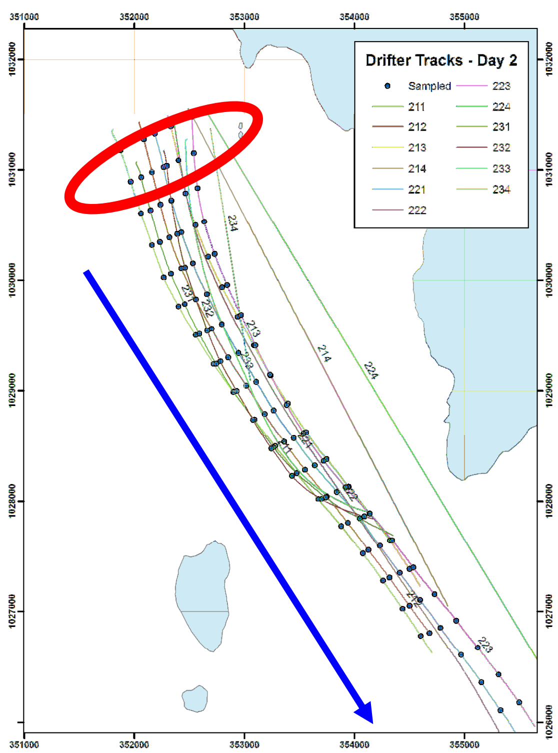

Figure 7 Plot of the tracks of drifts on the flood tide of 22nd January 2008. Red circle indicates drop off point of drifters, blue arrow general direction of flow and black circles location where sound samples taken.

The method described here is intended to be a relevant technique to measure ambient sound in typical tidal test sites. However, it is important to note that this concept is tailored to suit the EMEC Fall of Warness site which does not routinely experience significant surface waves or swells on account of the surrounding islands and limited fetch. Large waves or swells passing would lift and drop the surface float, transmitting vertical heave to the drogue and hydrophone and thereby introducing false flow noise to the recordings. Measures to add more sophisticated vertical damping to the design are feasible but have not been developed as yet.

3.1.6.5 Analysis

At the start of each drift, the boat is stationed upstream of the tidal site and the four drifters laid line abreast with the intention that they drift across the area of interest. This proves a challenge at sea because the flow over the EMEC test site is not linear although generally good spatial coverage is achieved (Figure 7). Once the drifters are deployed the boat is moved upstream of the central survey line and its engine turned off so that the boat passively drifts some way behind the recorders. The recorders are then safely retrieved at the end of the observed area.

For analysis of the sound samples, the tracks from the GPS receivers are linked to the sound recordings through time stamped records. Times are recorded on the GPS files and also recited onto the acoustic recordings prior to the launch of the drifters.

Subsequent sampling of the sound files is cued by drifter location. Because the path of each drifter is different and cannot be predetermined, precise location of sampling stations is not possible. Instead, a series of lines running NE to SW and perpendicular to the path of the tide and drifters is calculated.

From the GPS tracks it is possible to calculate when a drifter passes each of these lines and extract a sound sample from that location. The lines at the EMEC site are positioned running at 65º and spaced every quarter nautical mile (463 m). This produces 15 lines for sampling across the study site.

For the analysis at EMEC the sound characteristic at the point when each drifter passes a sampling line was analysed for sound intensity and spectral properties. The most appropriate duration for this sound segment from the recording was selected. To do this a 10 minute sound file recorded in the Fall of Warness site (Drifter 1, Run 1, 21st January 2008) was analysed five times at 1 kHz over 7 different durations (2, 10, 20, 30, 60, 90, and 120 seconds). The duration with least variance was the 60 second sound sample which appeared to be a compromise between the variability experienced in brief sound samples and the variance in longer sound samples when the drifter covered a relatively large distance. Segment durations of 60 seconds were therefore selected to be used for further analyses. Following analysis, the ambient sound in the Fall of Warness site has been found to contain energies in all parts of the spectrum up to the sampling ceiling of 48 kHz with a particular bias in frequencies below 1 kHz. The general shape of this power spectrum is similar across the study site but with variation in the absolute spectrum levels up to approximately 20dB re 1µPa. From the baseline results a number of acoustic spatial features of the site became evident and appear to be common for both flood and ebb tides at the time of sampling.

3.1.7 Overview of EMEC's Environmental Monitoring Programme

For most developers deploying at EMEC, installation at these facilities will be the first time their device has been in the open sea and grid connected. They typically will not have a track record to indicate the type and extent of any interactions between their device and the receiving environment. Therefore, whilst the central purpose of EMEC is to provide an operational test facility, there is also a key role in establishing and facilitating monitoring of devices in respect of their potential to have impacts on the receiving environment.

EMEC has been closely involved in discussions over this, largely through the licensing and consenting process which requires developers to consider environmental issues prior to testing at EMEC, and to mitigate against any potential for negative impact. To guide this EMEC has, with advice from Scottish Natural Heritage (SNH), developed an environmental monitoring programme. The aim of this programme is:

'To provide a framework that ensures that appropriate monitoring is put in place to enable critical environmental information to be collected in association with wave and tidal energy conversion devices being tested at the EMEC test sites. The findings will then be available to Industry, regulators and policy developers to inform future marine energy development decisions'.

This aims to streamline approaches to data collection in order to address stakeholder concerns and specific legislative requirements, e.g., those under the EC Directive 92/43/EEC on the Conservation of Natural Habitats and of Wild Flora and Fauna (the 'Habitats Directive').

Support and guidance for the approach taken is provided from the EMEC Monitoring Advisory Group, established in June 2008. The group is a vehicle to formally extend and coordinate the ongoing monitoring discussions between EMEC and regulators and their consultees. Advisors are asked to contribute advice on specific methods in relation to the devices deployed at EMEC, including both device-specific and generic issues, whilst taking full account of the scale of deployment at these test sites. The group also provides an ongoing feedback vehicle as monitoring is established at EMEC, and this feedback is key to the successful implementation of the environmental monitoring programme.

3.1.7.1 Programme Development

The monitoring programme has been developed by the following methodology:

1. Summarise views on the key potential impacts from marine energy converters. This is based on the output from:
    a. The EMEC/UKERC Workshop on Potential Environmental Impacts and Monitoring, held on 14th September 2005;
    b. EMEC Workshop held on the 3rd September 2008 entitled "Environmental Protection and Management for Wave and Tidal Energy Converters: best practice approaches";
    c. Ongoing consultation with regulators and key advisors.
2. Identify the key EMEC tidal and wave site sensitivities: This is based on the baseline data gathered for the test site EIAs. For the tidal site the sensitivities table has been updated to include the additional data now available from the marine wildlife observations and approved by SNH.
3. Develop an impact matrix which details the specific key areas of environmental concern and therefore need to be addressed by establishing appropriate monitoring. The matrix summarises the findings from the various information sources that have been consulted, together with expert advice and opinion that has been offered by regulators and various expert consultees in numerous discussions since the establishment of EMEC in 2003. In compiling the matrix, the specific information on receptors and the nature of the potential interaction is taken from the Workshop described in 1b) above. The matrix includes an indication of the need for the development of novel methods expressed as being relative

Table 3 EMEC Monitoring Matrix.

Receptor of interaction	Nature of interaction	Priority list for method development	Tidal Site Sensitivity & Magnitude	EMEC Project	Wave Site Sensitivity & Magnitude	EMEC Project
Wildlife, particularly marine mammals and birds, but including a few other species such as basking sharks	Collision with devices, particularly tidal turbines.	High	Medium	Underwater Visualisation (in development)	Medium	Underwater Visualisation (in development)
	Alteration to wildlife behaviour. For example, reduction in access to feeding areas (mammals and birds), avoidance arising from "barrier effects" of arrays of devices in restricted waters.	High	Medium	Wildlife Observations	Medium	Wildlife Observations
	Underwater noise	Medium	Medium	Acoustic Characterisation	Medium	Acoustic Characterisation
Seabed, habitats and species	Physical disturbance of the seabed	Medium	Low	ROV Surveys	Low	ROV Analysis
	Alterations to benthic faunal communities through changes in flow or wave exposure.	Medium	Low	*No current project*	Low	*No current project*
Navigation	Surface vessels, merchant shipping, fishing vessels, naval vessels	High	Medium	Ongoing Consultation	Medium	Ongoing Consultation
	Submarine navigation	High	Low	*No current project*	Low	*No current project*
Commercial fisheries	Limitation of access of fishers to actual or potential fishing grounds	High	Low	Ongoing Local Consultation	Medium	Fisheries Project
Aesthetic impact	Visual impact of objects on or above the sea surface	Medium	Low	Ongoing Local Consultation	Medium	Local Residents Group
	Impact on marine (underwater) landscape	Medium	Low	*No current project*	Low	*No current project*

priority judgement. These have been filtered from a longer list with just the medium and high priority issues carried forward to the table. The corresponding site sensitivities listed alongside are taken from item 2.

3.1.7.2 Programme Matrix

The EMEC environmental monitoring matrix includes summary information regarding monitoring projects that have been established, or were in the course of being developed at the time of writing (Table 3).

It is intended that additional resources will be sourced in order to extend the range of projects currently underway. For further details of the projects stated in the matrix, please see www.emec.org.uk/research. In addition to the site-wide projects, EMEC developers also undertake their own device specific monitoring which is not detailed here.

The programme has been developed based on available knowledge. It is envisaged as being dynamic, and will develop as knowledge increases, subject to annual review by the EMEC Monitoring Advisory Group.

3.2 WELSH TIDAL SITES

High tidal current areas are a small and unusual part of the range of any marine mammal species. While there is a general belief that they may be important and may be preferred areas for foraging for some species, there is little information on the densities of animals in these areas, and little understanding of how they use these specialised habitats. In part, this is because the strong tidal currents and the rough sea conditions that they give rise to make these very difficult areas in which to conduct standardised surveys. In fact they would normally be avoided. A further complication is that both the occurrence and behaviour of marine mammals in these areas is likely to vary with the state of the tide. Thus any survey work or sampling strategies need to cover the areas through all stages of the tides.

In 2009 a research project was established by Welsh Assembly Government to investigate the behaviour of locally abundant marine mammals (grey seals and harbour porpoises) in areas of high tidal energy in North Wales and Pembrokeshire at locations with planned tidal turbine deployments. The project comprised two more or less independent studies, a seal component based on high resolution telemetry studies of movements and dive behaviour of naïve grey seal pups and a cetacean component that focussed on fine scale and detailed surveys of cetaceans in high tidal current areas including investigations of dive depth and underwater behaviour. The overall aim was to gain an understanding of how these animals use high tidal current systems and their significance as habitat for local populations. This type of work poses severe challenges for conventional survey methods and there are no existing agreed procedures to apply. For this reason we planned to use a number of different and complementary approaches allowing an assessment of methodologies to be made while providing the required raw data.

3.2.1 Grey seal telemetry study methods

An investigation of the scale of possible interactions with tidal turbine devices requires information on the 3D movements of marine mammals. Seals are hard to see in open water, spend >85% of their time submerged and are effectively silent and therefore cannot be accurately tracked using either visual or acoustic monitoring techniques. To study the movement and dive patterns of seals at an appropriately fine scale we used recently developed GPS/GSM Phone Tags (Figure 8).

Figure 8 GPS Phone Tag.

These tags provide GPS quality (usually better than 10m accuracy) locations at a user-controlled rate, together with complete and detailed individual dive and haul-out records. They are small, weighing 370g which is <1% of the seal pup mass. Data are relayed via a quad-band GSM mobile phone module when the animal is within GSM coverage.

They incorporate a Fastloc GPS sensor that offers the possibility of a location at every surfacing or as frequently as required. The tag also uses precision wet/dry, pressure and temperature sensors to form detailed individual dive (max depth, shape, time at depth, etc) and haul-out records along with temperature profiles and more synoptic summary records. Both location and behavioural data are then stored in memory.

For species such as grey seals that periodically come near shore – within GSM coverage – the entire set of data records stored in memory can be relayed via the GSM mobile phone system. Visits ashore may be infrequent, so up to six months of data can be stored on-board the tag and these data may also be downloaded if the tag is retrieved.

3.2.2 Analysis of movement data

Two levels of analysis are being applied to the movement and dive behaviour data. The tracks of all seals are examined in relation to locations of potential tidal turbine sites to estimate the length of time spent within specified distances and in terms of tidal energy. Dive behaviour data provides a 3D picture of space use throughout the tracking periods. At a wider population scale, space use maps can be created for juvenile grey seals for comparison with earlier adult seal space use analysis. The methods used will be similar to those employed in producing space use maps for older grey seals in 2004-05 described below.

Briefly, the space usage analysis will comprise two stages, described elsewhere ([11], [12] and [13]). The method uses telemetry data and estimates of the relative numbers of animals using haul-out sites in the areas of interest sites. Numbers of seals at haul-out sites.

Data on the number of grey seals at haul-out sites around the Irish Sea are sparse. As in the previous analysis, data will be taken from several sources:

- Scotland and Northern Ireland: data from SMRU aerial surveys in 1996-2008 [14];
- Irish Republic: data from aerial surveys and ground counts [15];
- Wales: ground count data ([16] and [17]).

Numbers of seals associated with all known haul-out sites are grouped together, based on the telemetry data, to give a single figure for each of seven haul-out regions.

3.2.2.1 Telemetry data analysis and space use modelling

Where appropriate location data are filtered to smooth the tracks and minimise the error associated with the locations before being included in the model. The high resolution GPS data provided by the current tags means that this stage can be omitted in future.

Data on seal movement (speed, trip duration, locations of haul-outs and obstacles to movement) were used to calculate the accessibility of points at sea as a function of distance from the centre of a haul-out region [11]. Maps of accessibility were used to inform estimation of space use by each seal. Estimates of uncertainty were calculated through combining estimates of usage for all tagged individuals. Usage maps were weighted for the number of seals within each haul-out region.

The main product from this analysis is a seal usage map, equivalent to a density contour plot for the estimated distribution of seal activity at sea. The usage map generated from deployment of 19 Argos satellite transmitters is shown in Figure 9 for illustration.

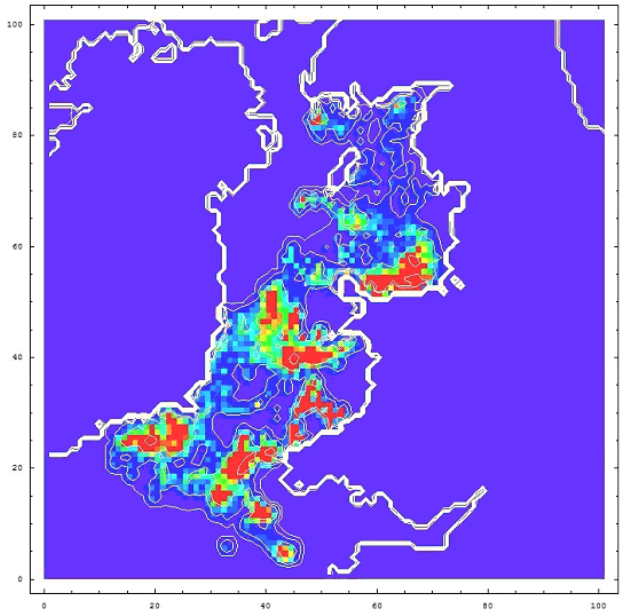

Figure 9 The modelled at-sea usage for grey seals in the Irish Sea based on data from 19 satellite transmitters attached to adult grey seals in 2004.

3.2.3 Tracking Data

An example of the type of highly detailed movement and dive behaviour records received from GPS/GSM tagged seals is presented in Figure 10.

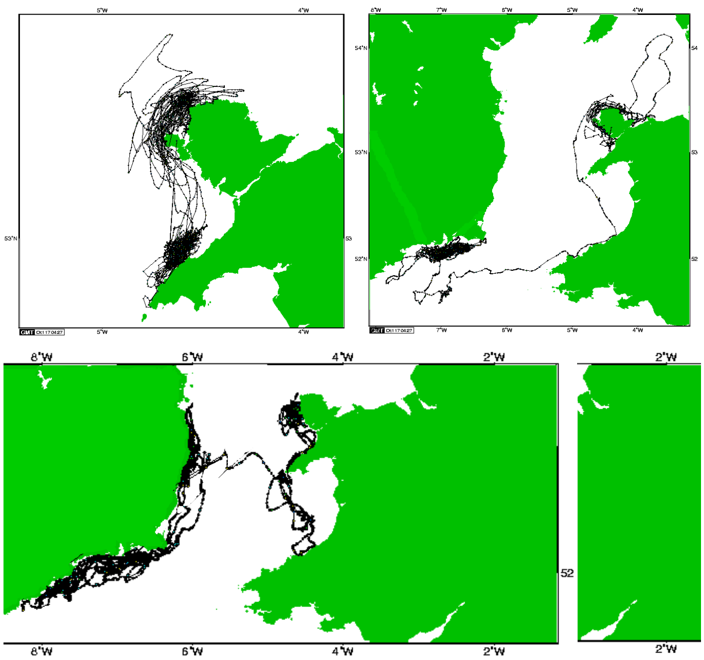

Figure 10 Example GPS tracks of three grey seal pups tagged on Skerries, Anglesey. All three seals spent an initial period foraging in the high tidal flow areas around Anglesey before moving away. One remained in the area, using a haulout site on the Llynn Peninsula for 10 weeks before moving back to the Skerries. The others moved to haul-out sites in the Saltees, Ireland.

Almost complete records of location, diving depths and durations were received from all seals. Tracking periods lasted 234, 216, 183, 63 and 14 days. In order to receive data the tagged animals must spend some time in the vicinity of a mobile phone receiver. As a result the data delivery is sporadic. However, when data transmissions occur, a large amount of stored information may be sent.

3.2.4 Dive Behaviour Data

Figure 11 shows an example of the summary data from the dive depth and haul-out sensors. The data presented are simple two hour summaries of maximum depth and time spent dry at the surface or on land. Similar data are available for all five pups for which records have been received so far. The raw dive data, i.e. detailed depth time profiles and accurate surface times are available for all animals.

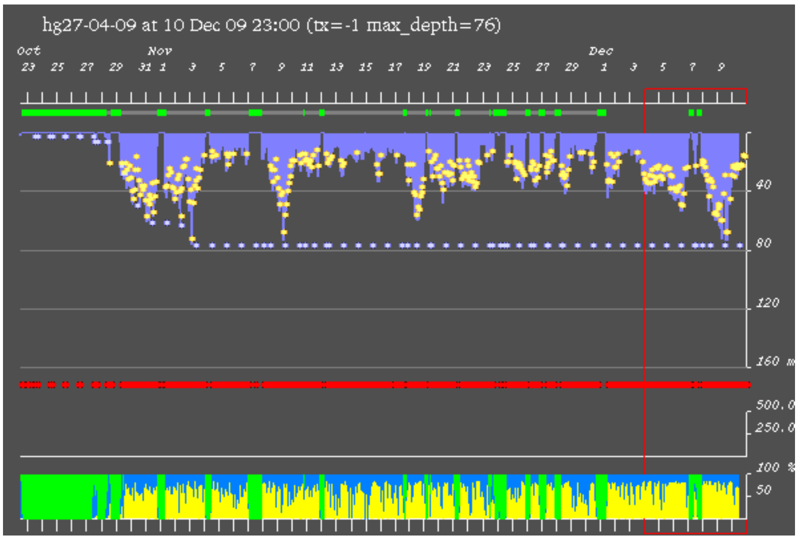

Figure 11 Example of the summary data transmitted by one of the grey seal pups tagged on the Skerries. Blue bar graph at the top represents the summary dive behaviour, showing maximum dive depth in two hr bins. Yellow dots indicate where full depth temperature profiles were recorded. Depth profiles of all individual dives are transmitted and will be used in analysis of 3D space usage.

As with all previous grey seal studies, the dives comprised a rapid descent phase followed by either a rapid ascent or a protracted bottom phase followed by a rapid ascent. While at the surface grey seals typically do not swim actively [18], simply resting at the surface for short periods to load oxygen and dump carbon dioxide before diving again. The seals therefore spent a limited amount of time in mid water depths

The rate at which seals pass through the area swept by the blades of a tidal turbine is an important parameter which sets the upper limit on the potential for direct physical interactions with the device. The GPS position fixes accurately indicate the seals' XY positions at approximately 15 minute intervals. The pressure sensor data provide a 10 point depth profile for each dive. Although these data do not provide sufficient spatial resolution to identify direct passage through a small window equivalent to a turbine, they can be used to estimate the general pattern of transits through a specified area.

As an example of the type of data available we estimated the number of times and the depths at which the tagged seals crossed an arbitrary 8km long line drawn from Carmel Head to the Skerries and extending approximately 4 km further offshore. Pairs of consecutive locations were used to estimate the seal's swimming track assuming that it swam in a straight line between the location fixes. The time at which the seal crossed the line was estimated assuming constant swimming speed between locations. Swimming depth at that point was estimated by linearly interpolating between the pair of depth estimates immediately before and after the crossing point.

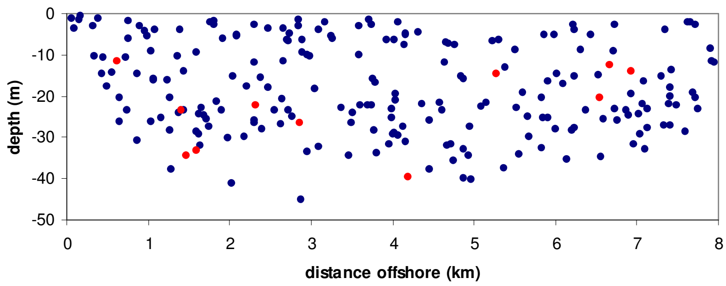

Figure 12 Depth and distance from shore of seals crossing an arbitrarily defined line stretching 8km from Carmel head passing through the Skerries.

3.2.5 *Porpoise studies*

3.2.5.1 The use of TPODs to describe aspects of harbour porpoise ecology in tidal race habitat

Data from automated, acoustic data-loggers, TPODs, was used to describe habitat use by harbour porpoises at two near-shore, tidally dynamic sites on the Welsh coast.

TPODs are self-contained acoustic monitoring devices designed and manufactured by Chelonia Ltd., UK. Each TPOD consists of a hydrophone, two battery packs and analogue circuitry housed in a robust, tubular housing. TPODs are able to operate unattended for up to 60-80 days. Data are stored on a 128 Mb memory chip. TPODs record the precise times at which ultrasonic pulses (clicks) are detected and pulse duration, both to 10 µs resolution. Click types attributable to different species or sources are identified using user-defined filter and threshold settings. Offline, TPOD software scans the data searching for regular sequences of clicks – click trains. A full description of the TPOD is available at http://www.chelonia.co.uk/index.html.

Variation in detection rates over tidal and diurnal time cycles and how these patterns and overall detection rates varied between TPOD locations were recorded. At most POD locations, both at Ramsey Sound and at the Skerries/Carmel Head, there was significantly more harbour porpoise activity at night than during the day. At several sites there were also strong patterns of porpoise occurrence that corresponded to state of tide, or the direction of prevailing tidal currents.

3.2.5.2 Vertical Array Recordings

Knowledge of the distribution of marine mammals in three dimensions is crucial to assessing and minimising collision risk. In recent years, understanding of the underwater behaviour of cetaceans has increased, mainly as a result of studies using telemetry. Telemetry studies have provided some information on their diving behaviour of porpoises. On occasion they can make very deep dives of over 200m [19]. However, few of these data come from high tidal energy areas. Because these areas are such a small part of the available habitat for porpoises it is unlikely that any randomly selected animal will spend a substantial proportion of its time in them. In addition, because these habitats are unusual, there is no basis for inferring behaviour in tidal rapids by extrapolation using data recorded elsewhere.

A method is required that has the potential for providing data on the underwater behaviour of harbour porpoises that can be taken to and operated in areas high tidal energy at times of peak current. The relative time of arrival of sounds, such as porpoise clicks, at an array of hydrophones can provide information on the location of the sound source. A linear array of hydrophones suspended vertically in the water is both relatively easy to deploy in the field and able to provide information on the range and depth of vocalising animals [20]. This technique has been used before to investigate the diving behaviour of cetaceans. There are particular challenges in applying the techniques in extreme tidal currents while maintaining a vertical alignment of the array and to making multichannel recordings and measurements at the high ultrasonic frequencies produced by harbour porpoises.

The vertical array used on this project comprised two stereo pairs of hydrophones (sub array) that could be deployed at different depths along a heavily weighted steel crane cable. Hydrophones in each sub array were separated by 25cm and each pair was mounted in a weighted rigid plastic tube suspended within a larger (200 mm diameter) free-flooding polythene pipe. This arrangement allowed each sub array to hang like a pendulum within the polythene tube. Inclinometers at the top and the bottom of the steel cable were used to measure the cable's deflection.

Signals from each sub array were amplified and filtered with a 20 kHz high pass filter before being digitised. Capturing porpoise signals from this array required digitisation of four channels at 500 kHz each.

3.2.5.3 Preliminary results

It is clear that this method can provide information on the distribution of depths at which porpoises vocalise in areas of high tidal current. The location of single clicks can be measured with a useful accuracy even when array configuration errors towards the upper end of those measured are assumed. It is likely that location accuracy can be improved if inclinometer data are used to provide better information on the location of hydrophones. It is also possible that precision can be improved by fitting tracks to sequences of clicks likely to come from the same individual animal. Animals can only be located with this method when they produce sound, thus these data really show the depths at which they vocalise rather than the probability that that they are at a particular depth. Porpoises seem to vocalise frequently during normal swimming behaviour [21]. However, some biases could result. More representative and complete data on dives might be derived by fitting a movement model to patterns of acoustically derived locations to reconstruct likely dive behaviour. The characteristics of echolocation vocalisations can provide information on other aspects of the animal's behaviour underwater. For example, rapid buzz locations are often made when animals are foraging (Kyhn et al. 2009). Putting these insights together with an ability to track the location of animals underwater should provide more detailed insights into the use porpoises are making of these areas.

3.3 STRANGFORD NARROWS STUDIES

The Marine Current Turbines' SeaGen device was the world's first operational commercial scale tidal turbine. It was installed in 2008 in Strangford Narrows, an 8 km long channel connecting Strangford Lough to the Irish Sea. The turbine has a pair of 600 kW generators powered by twin 16 m diameter rotors with a maximum tip speed of 12 m s^{-1}.

Strangford Lough holds a breeding population of harbour seals (*Phoca vitulina*) which have to pass through the Narrows to travel between the Lough and the open sea. There are also regular sightings of harbour porpoises (*Phocoena phocoena*) in the Narrows.

SeaGen therefore provided a unique opportunity to investigate the potential impacts of a tidal turbine deployment on coastal marine mammals and allow the development of methodologies for monitoring them. An adaptive management programme incorporating a series of inter-dependent or complimentary monitoring programmes was established with the aim of detecting, preventing or minimising environmental impact attributable to the turbine installation and operation. It was designed to provide an ongoing monitoring strategy to determine any immediate or emerging adverse impacts on the habitats, species and physical environment of Strangford Lough. As this is the first study of its kind it has reached a more advanced stage than any other work on marine mammal interactions with tidal turbines.

The ongoing monitoring programme for marine mammals is a combination of aerial surveys and telemetry studies of seals, and passive acoustic monitoring for porpoises as well as active sonar, visual observation and carcass surveys for all species. Biannual reports of the results of the monitoring programme are publicly available. Here we describe the telemetry study in some detail and summarise the other studies and use them to highlight important considerations for other studies.

3.3.1 Seal Telemetry Studies.

Telemetry derived movement patterns were used to test the hypothesis that the turbine does not act as a barrier to the movement of seals through the channel. Data from three deployments of GPS phone tags (see 3.2.1 above) on harbour seals in the vicinity of the Strangford Lough tidal turbine were used. These data provide the first opportunity to detect detailed behavioural change in response to an underwater turbine. Importantly, the final deployment encompassed periods of continuous operation of the tidal device interspersed with periods when it was not operating, allowing the effects of operation on the behaviour of individual seals to be investigated.

The telemetry tracking system used in the Strangford study was identical to that described above for Welsh Tidal studies. For a description of the methods and sampling rational see section 3.2.1 above. Twelve seals were fitted with tags in each year, 2006 (pre-installation), 2008 (during installation) and in 2010 (operation). In 2006 and 2008 the tags obtained a GPS location every 20 minutes. In 2010 the sampling rate was increased to one every 10 minutes. The tags also recorded detailed dive depth profiles and logged when animals were hauled out.

Seal tracks were filtered to remove occasional errors that produced un-feasible locations and then further filtered using an appropriate speed threshold (more than 3m s^{-1} greater than the speed of the current). Seals were assumed to travel in straight lines, and at constant speeds, between the GPS fixes. A line was drawn across the section of the Narrows containing SeaGen, perpendicular to the direction of the main tidal flow and the number of times each seal crossed this line during the tracking period was calculated. The points at which each track intersected this line were calculated and estimates were made of the time and distance from the turbine of each transit.

3.3.1.1 Uncertainty in transit locations and times

Marine mammals dive and GPS fixes are necessarily intermittent. Intermediate positions were estimated by interpolating between the GPS fixes. However, interpolation may produce erroneous swimming tracks especially where the coastline is convoluted or tracks follow narrow curving channels. The precision of the estimates of transit timings and locations was investigated using sets of location fixes, each comprising of three consecutive locations that were all within the Narrows. Error in timing was investigated by comparing the time at which the animals arrived at the 2nd location with the time of arrival that would be predicted assuming constant speed between the first and last point. Error in horizontal transit location was estimated for each triplet as the perpendicular distance of the second location from a line drawn between the first and third points.

Error in timing was related to the overall length of the triplet. The timing associated with a 20 minute track could be out by 10 minutes. The error in location increased with total distance between the end points of the triplet and turning angle. For triplets less than 1 km in length, and that turned less than 900, 95% of the estimated locations were within 160 m of the actual GPS locations.

Testing for differences between years proved difficult because of the relatively small numbers of animals tracked and the high level of individual variability in behaviour. This was further complicated by technological and methodological developments over the course of the experiments and the fact that individuals provide differing amounts of data. Finally, the different transits made by each individual cannot be treated as independent data points in comparisons of the overall behaviour of groups of animals.

The most direct method of testing for responses or changes in behaviour due to a device will be obtained from controlled exposure experiments. But, even during test deployments it is unlikely that researchers will have the freedom to start and stop the operations on the basis of the movements of animals. However, in the initial, post-installation phase turbines will be subject to a variety of engineering tests and so for certain periods will be halted or operating at reduced speed.

Using environmental data to define stationary/non-operational periods and/or using known operating schedules allows researchers to identify a series of ad-hoc behavioural response trials. In the case of the SeaGen device a low current speed operational threshold was used to determine when the device was rotating above a specific rotation speed. A binary variable (turbine on or off) was defined for each seal transit using estimates of rotor speeds.

These methods allowed differences in the mean number of transits per day and the distribution of these transits across the narrows to be compared between years, between times when the turbine was operational or non-operational, between day and night, and in relation to tide and season.

3.3.1.2 Results

This study produced over 2500 seal-days of track data and is therefore likely to be one of the most intensive telemetry based effects studies for any marine renewable deployments. The major feature of the data is that the 2010 tracks are broadly consistent with previous years. All years had a high degree of variability between seals, but a high degree of consistency within seals.

The transit rates were highly variable between individuals, but the overall mean daily transit rates were similar in the three years. The differences in the behaviour of the individual seals led to broad confidence intervals around the estimated transit rates for when the turbine was on and off in 2010. The difference between the transit rates when the turbine was operating and when it was not operating was not significant and the separately bootstrapped confidence intervals around the estimates for when the turbine was operating and not operating did not reveal a significant difference between them.

A method was devised to remove some of the effect of individual variation by calculating the ratio of the transit rates for each seal when the turbine was operating to when it was not operating. Using bootstrapping to estimate these ratios reveals evidence that the rate at which seals pass the turbine was reduced when it was operating.

Visual inspection of the distributions of transit locations suggested that they differed between years. In 2006, the majority of the transits occurred in the middle of the channel, in 2008, the peak in locations occurred on the east side of the channel whereas in 2010 there was a distinct bimodal distribution with peaks in transits at approximately 250 m either side of the turbine location. However, there was a great deal of variation between the individuals within each year, and the grouped test shows no significant difference between 2006 and 2010. Despite the high degree of individual variability there appears to be some degree of local avoidance of the turbine. This pattern was similar when the turbine was operating or not operating, suggesting that it was not a direct result of turbine noise nor necessarily related to moving turbine rotors per se. It may be simply due to the presence of the structure, or a learned “habit” of avoidance.

The GPS phone tags also provided detailed dive depth profiles but errors in transit time estimates are bigger than the mean dive duration so it is not possible to reliably estimate the actual depth when the seal makes a transit. It is still useful to examine the depth usage in the vicinity of the turbine. As in the Welsh grey seals, the majority of time is spent either at the surface or at the bottom with fairly rapid transit between them. Again, this has clear implications for the likelihood of impact with the turbine.

3.3.1.3 Conclusions

The environmental monitoring of SeaGen has produced a telemetry dataset with a very high precision and intensity of observation. It has answered a number of fundamental questions about the effects of SeaGen on the harbour seals in the vicinity. Harbour seals travel through the Narrows, and still frequently transit past the line of the turbine site. Several haulout sites occur in the Narrows and seals were still using them even after turbine installation and the start of operation. The high level of individual variation lessens our power to detect changes in the true transit rate of the local population. Nevertheless, there was clear evidence that the presence of an operating tidal turbine was not acting as a barrier to seals transiting the Narrows.

The seals which regularly transited the Narrows did appear to transit less frequently when the turbine was operating. Combining data from all three years showed that seals transited at a relatively higher rate during periods of slack tide which may reduce the probability of collision risk if seals preferentially transit during periods when the turbine does not operate. Assessing the biological significance of these responses is difficult, e.g. reduced transit rates will reduce the overall risk of collision with the turbine and the fact that tidal turbines do not operate at slack tide will always provide seals with some opportunities to move past them.

The study identified two main factors which contribute to uncertainty in the transit rates and thus reduce the ability to detect changes: interpolation error between the GPS fixes and the differences between individuals’ behaviour patterns. A method for interpolation which takes into account dive behaviour, bathymetry, and other sources of information is needed to increase the certainty in reconstructed animal tracks. This study also highlighted the necessity of obtaining frequent high quality location fixes, if possible throughout dives, for investigating small-scale or localised behaviour.

The study also highlighted the fact the intermittent operation during the initial testing phase provides an opportunity to explore the effects of turbine operation on individual animals’ behaviour.

3.3.2 Passive Acoustic Monitoring of porpoise activity (Tpods)

Levels of porpoise activity were recorded throughout the development program in the Narrows using a simple passive acoustic monitoring protocol. The vocalisation rates recorded by an array of automatic porpoise click detectors (T-PODs see section 3.2.5.1. above for description) was used to calculate the daily rate of Detection Positive Minutes (DPM) which was used as a proxy for porpoise activity levels. Ten T-PODs were deployed in Strangford Lough in 2006. Since then four have consistently been deployed in the Strangford Narrows. Over 1,900 days worth of data have been collected.

Initial calibration results indicated some variation in sensitivity between devices. To avoid biases due to device differences the PODs are rotated in sequence at each re-deployment.

Detection rates of harbour porpoise vocalisations were generally low, with higher detection rates in the inner Lough. DPM per day were lower within the Narrows during installation compared to the baseline periods (pre- and post installation). Average DPM per day recorded in the Narrows during installation and operation were lower than the average DPM from 2006 and 2007 in the equivalent months. DPM per day were apparently similar during all periods in the Inner Lough.

Changes in the recorded click rates could have several causes. It could be a result of a decrease in the number of animals using an area, animals spending less time within an area or the same number of animals echolocating less often than previously or could be due to small changes in recording operations. A detailed analysis of each individual T-POD's data shows that only those on the east side of the narrows show a decline, with the site to the west remaining constant and the site to the north showing a significant increase in detections. The T-POD's to the east of the narrows were moved from their original position and this change in location is thought to be the cause of the decline in detections;

Despite the apparent changes in porpoise detection to the east of the narrows no significant difference between detections during SeaGen operation and non-operation has been observed within the Lough, indicating that SeaGen is not causing a barrier effect. This is supported by results from the TPOD stations to the north and south of the device which show no significant difference in detection rates.

3.3.3 Active acoustic observations

Because marine mammals and large fish are submerged and not available for either visual observation or radio location fixing, some form of underwater detection would be a major advance for both studying and mitigating the potential effects of marine mammal interactions with turbines. As part of the research and mitigation programme a study of the effectiveness of active sonar for detecting marine mammals in the Narrows was included in the overall environmental study. This system fitted to the turbine pile provides real time sub-surface sonar imagery of marine mammals and other large marine animals e.g. basking sharks within 80 m of the SeaGen turbine. As a result of the adaptive management process the shut down distance has been incrementally reduced and is now set at 30m. The main objectives are to increase detection capabilities and examine the behavioural reactions of large marine animals to the turbine both in operation and while shut down.

During operations in 2009 and 2010 a total of 225 targets were recorded on the active sonar. Results were compared to the MMO's visual observations from the pile. Results indicate that small marine mammals (and other mobile targets, birds, debris etc.) can be detected in a tidally turbulent water column in real time and that their movement patterns can be determined. Targets that were likely to transit close to the turbine elicited an emergency shutdown of the turbine.

The effects of turbine activity were investigated by plotting the X-Y coordinates of tracks of all targets detected by the active sonar in relation to the device to assess the underwater proximity of targets to the device. Results suggest that turbine activity (operational vs. non-operational) did not significantly influence the track trajectories. However, it should be highlighted that sample sizes are relatively small and the method of analysis used was relatively crude.

One additional advantage of sonar over visual methods for monitoring marine mammal activity is that it is unaffected by light levels and so can function at night. Preliminary night time sonar data were collected when SeaGen was not in operation to establish the level of marine mammal activity in the vicinity of the device. Initial results suggest that marine mammal activity was lower during night time. This contradicts the telemetry results which suggested increased activity at night. However, at present the sonar is unable to accurately distinguish marine mammals from other targets such as birds and, as a result, patterns in marine mammal activity between night and day may be masked by other changes occurring between day and night, particularly the cessation of diving bird activity at night.

The sonar system is less effective in the surface 2-3 m of water, probably due to the large amount of turbulence and entrained air in that upper section of the water column. It is important to note that this portion of the water column lies above the area within which the SeaGen turbine rotates. This problem is well documented for acoustic ocean studies in general and also applied in the case of the ADCP surveys carried out for the EMP. Despite the difficult conditions in the surface layers the sonar is able to detect close to half of the sightings made by the MMOs and it is reasonable to assume that the degree of detection below the surface layers, where turbulence and entrained air are less, is considerably higher than half. Active sonar continues to be a conservative form of mitigation and the use of active sonar during night time operation of SeaGen will continue to be effective throughout potential 24 hour operation.

3.3.4 Visual Observations

3.3.4.1 Land based observations

Shore-based visual surveys were undertaken throughout the installation phase and will continue throughout the commissioning programme and beyond. Models were fitted to the data to determine both the significance and type of relationship, between the environmental variables and sightings rates for both seals and porpoises. The time of day, tidal state (phase, ingoing/outgoing), and spatial location all proved significant. There were also long-term trends evident at both a daily and monthly resolution. There was no evidence for disturbance during installation and there was no evidence for a change in underlying relative seal abundance in the area during times of lower activity. The natural variability in the system under study is high, even after accounting for the systematic changes associated with the environment under current conditions. Simulation studies suggest that the current monitoring scheme has low power to detect changes in the average abundance of porpoises. A sudden drop in average porpoise abundance of 50% would be detectable with a probability of 0.75 after 6 months of the current monitoring scheme.

Simulation studies suggest better power for the current monitoring scheme (and subsequent analysis) in detecting changes in the average abundance of seals. For example, a sudden drop in average seal abundance of 50% would be detectable with high probability (0.88) after 1 month of the current monitoring scheme. Drops in average seal habitat usage of <20% would only be detected with probability 0.5 after 6 months of monitoring. Following analysis of the data no statistically significant changes have been determined. However, the analysis to date covers a limited period of operation and analysis currently underway on longer dataset.

3.3.4.2 Turbine (Pile) based observations

In addition to the land based visual and active acoustic monitoring programmes during the first 16 months of SeaGen operation (June 2008 to October 2009) there was also a dedicated Marine Mammal Observer based on the device itself. These observations were instigated as part of the mitigation measures to ensure that the appropriate mitigation procedures are undertaken during the commissioning programme. Through the adaptive management process and demonstration and correlation with the active sonar system this requirement for direct visual observation from the pile was removed. In addition the observations provide data on the temporal and spatial distribution of marine mammals that transit the Narrows in proximity to the pile.

In total, pile-based marine mammal observation has been undertaken for 470 hrs (255hrs during SeaGen operation). Pile based observations began on the 8th July 2008 and ended on the 21 August 2009 (see Section 2.2.3). During this time over 400 sightings of marine mammals were made within the observation grid from SeaGen (i.e. within approximately 200 m in an upstream direction). Preliminary analysis of sightings distribution and sightings rates (total sightings per hour) indicates that seal activity in the vicinity of the devices peaks during slack water, supporting the similar observation from the telemetry data. Very low levels of porpoise visual sighting were recorded from the pile. In addition to acting as a direct input into the mitigation process the MMO observations have been used to aid interpretation of the Active sonar monitoring results (see above).

3.3.5 Aerial and Boat Based Surveys

The aim of these surveys was to determine the overall number of harbour seal adults and pups, and the location of their haulout sites, between Carlingford Lough and Belfast Lough, including Strangford Lough. The surveys provide baseline information on the number and distribution of harbour and grey seals both inside and outside Strangford Lough, complementing the monthly boat surveys carried out inside Strangford Lough by the Northern Ireland Environment Agency (NIEA) and National Trust (NT) staff.

All aerial surveys were by helicopter using a thermal imaging camera. The surveys conformed to standardised procedures for surveys of UK harbour seals: the helicopter operated at a height of 150-250 m and a distance of 300-500 m offshore to ensure that seals were not disturbed from their haulout sites. All surveys were conducted within +/- 2hrs of the local low tide times occurring between approximately 12:00 hrs and 19:00 hrs. Surveys were not carried out on rainy days as the thermal imager cannot ‘see’ through heavy rain and because seals abandon their haulout sites and return to the water in medium to heavy prolonged rain.

Seals were counted using a thermal imager (Barr and Stroud IR18) with a dual telescope (x2.5 and x9 magnification). The imager was mounted on a pan and tilt head and operated out of the helicopter window. High resolution digital photographs are also taken to confirm species i.d. and provide a back up count.

Aerial surveys are carried out during both the annual moult to provide a standard index of population size and during the pupping season (June-July) to estimate production as a proxy for current status. These data are then used in conjunction with monthly boat based surveys to track short term changes in seal haulout use and numbers.

3.3.6 Marine Mammal Carcass Surveys

A programme of shoreline surveillance, covering a pre-defined area of the Strangford Narrows and immediate coastline, is carried out throughout the year. Any marine mammal carcasses discovered within the surveillance area are subjected to a post-mortem by a Vet Pathologist. Putative cause of death is determined for each carcass to determine whether it is likely to have resulted from collision with the SeaGen turbine. To date the post mortems have shown no link with the SeaGen turbine.

3.4 WAVE ROLLER – SURGE PROJECT

The SURGE project (Simple Underwater Renewable Generation of Electricity) which if financed under the 7th framework programme (Grant agreement 239496) is a demonstration program of the near-shore WaveRoller 2 technology on the Portuguese coast near the town of Peniche. The project began in October 2009 and will run for three years with the installation of the prototype planned for the summer of 2011. Work Package 8 of the project entitled Performance and Environmental Monitoring has a Task 8.3 Environmental monitoring that aims to provide some insight into the environmental impacts that the device might have. Two aspects that are of particular interest to the WaveRoller device were selected for this research, the acoustic impact of the device and on the benthic habitats. The acoustic aspects of wave energy converters have been generally considered one of the most significant potential impacts although very few in-situ measurements have been made and the impacts are considered to be very device specific. The Benthic impacts are particularly relevant for the WaveRoller device because the entire structure is submerged, has a large surface area and footprint on the sea bed. Therefore it is important to understand how this impacts the fauna and flora surrounding the device as well as the organisms that attach to it. The campaigns were designed jointly between the Wave Energy Centre and two national experts that were subcontracted within the project, Marsensing LDA for the acoustic work and Instituto Politécnico de Leiria for the benthic campaigns. It should also be noted that the total budget for both campaigns is of 48 thousand Euros, including the acquisition of equipment, which limited the extent and reach of the campaigns.

3.4.1 Acoustic campaign

Presently there is no standardized way to carry out an acoustic monitoring campaign and consequently the methodology applied was a combination of the work done on the ongoing WEAM project (nationally funded) and the experience of the MARSensing team which has done a number of acoustic studies for other purposes. The campaign described below was the only one performed to date, on September 3rd 2010, and was the baseline campaign in which the reference condition was recorded. It is recognised that a comprehensive baseline study should attempt to have several recordings under different parameters, such as tide, season, sea state or atmospheric conditions. However, due to budget constraints, only 3 campaigns in total can be carried out. The overall plan is to obtain one baseline campaign and two monitoring campaigns with the device in operation under different sea states. The methodology is not expected to vary significantly between campaigns.

Goal: to evaluate the Sound Pressure Level (SPL) at the location of the WaveRoller deployment as well as spectral densities for comparison with measurements once the device is in operation.

Methodology: The experiment consisted in deploying several acoustic recorders at pre-defined positions over two oceanic transects departing from the position of planned deployment.

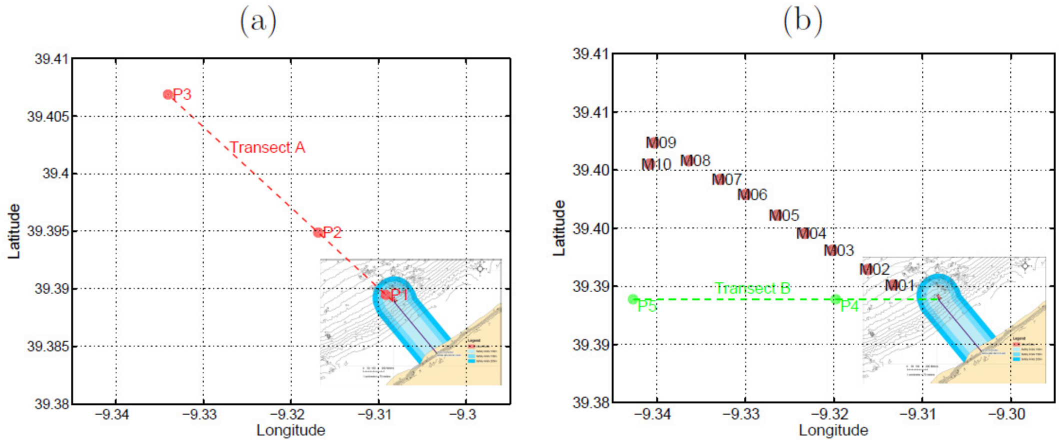

Figure 13 Transects used in the acoustic baseline campaign (a) moving offshore (b) along the shore.

Figures (a) and (b) above illustrate the two transects, one going straight offshore and another parallel to the coast. The campaign was divided into two parts. The first comprised of a series of moored autonomous acoustic recorders that were set up across transect A using the configuration which can be seen in figure (c) below. The position P1 is where the WaveRoller device is expected to be deployed and the measuring stations were placed at P1, at 1km-P2, and 3km-P3 from this point along transect A. The same was done over transect B at P4 and P5, also 1 and 3 km prom P1 respectively. The hydrophones were programmed to operate by making 5 minute recordings followed by 5 minutes of standby over the course of 2 hours at each station. The hydrophone was placed at mid water column depth which ranged from 6m at P1, 12m at P2, 17m at P3 and 10m at P4 and P5.

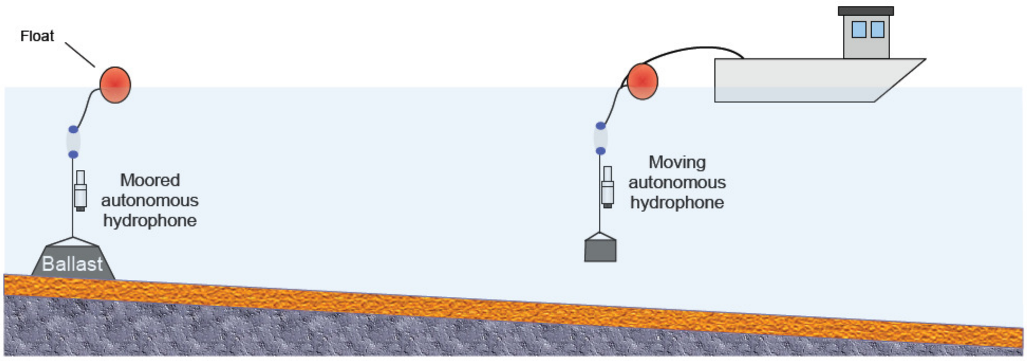

Figure 14 Configuration of the acoustic set up for fixed measurements on the left and boat towed measurement on the right.

The second part of the campaign consisted of, as the transect B moored recordings were occurring, the boat took several 5 minute measurements off the side of the ship, as illustrated in Figure 13a above, and took stations at the M points shown on Figure 13b. The distance from P1 ranged from 0.43 km at M1 to 3.07 km at M10. The hydrophone was again placed at mid water column depth. The goal of these measurements was to use the third hydrophone, which was available as transect B only had two fixed positions, to obtain a higher spatial resolution across transect A to complement the data which had been gathered previously.

3.4.2 Benthic campaign

Instituto Politécnico de Leiria, which has a campus in Peniche and has done extensive environmental work in the area was sub-contracted to carry out the benthic work which was particularly limited by the budget available of 20k €. It was agreed that the study would focus on two aspects.

3.4.2.1 Goals

Determine the composition of the benthic communities within the vicinity of the WaveRoller device and any change occurring during the duration of the project. Describe the first stages of colonization of the structure by biofouling organisms and attempt to predict what effects might be expected in long term exposure.

3.4.2.2 Methodology

For the first goal of determining the species composition in the area, one possibly two, baseline campaigns will be undertaken followed by two, possibly three monitoring campaigns during the project. The number of campaigns will be dependent on the timing of the installation of the device within the project timeframe. Seven sampling stations, shown in Figure 15, within 300m of the WaveRoller device were selected to be sampled with a Ponar type grab which has 248 cm² collecting area and is deployed from a RIB boat. Six samples are collected at each station, one for the physical assessment of the substratum (grain size analysis, dry weight, organic weight) and five for the identification of the invertebrate macrobenthic community. The biological samples are processed through a 1mm mesh sieve and placed in 10% formol to be sorted and identified under a microscope. The colonization of the WaveRoller device will be done by resorting to divers who will collect photographic and video images of the device in order to have some qualitative and quantitative (quadrat coverage) assessment of the colonization which will be coupled with organic samples to be scraped off the surface of the WaveRoller wings and base.

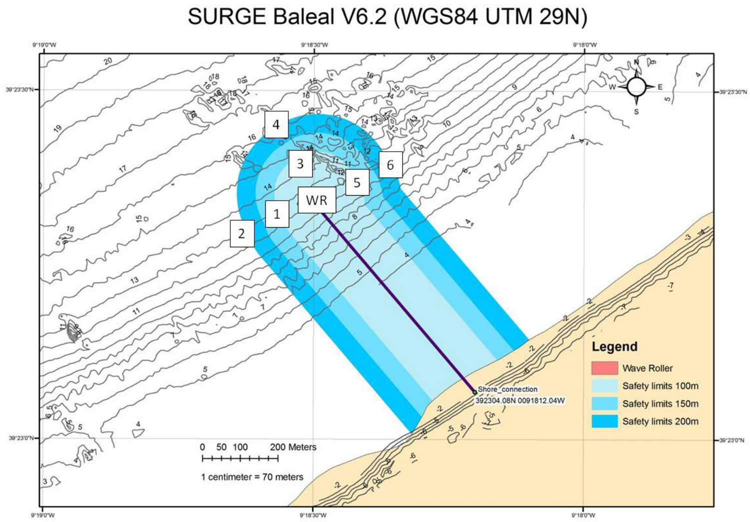

Figure 15 Location of benthic survey stations of the baseline campaign

These samples will be analysed for dry weight per measure of area scraped to attempt to estimate the total organic weight on the device at several stages as well as what organisms are having more success attaching to the structure.

3.5 COLLISION RISK MODELS

In an effort to understand the processes that lead to a risk of collision between animals the moving parts of marine energy converters and identify gaps in knowledge that require further investigation encounter and evasion models have been used. Encounter models have been used extensively in ecology to estimate predator-prey interactions of marine animals and to assess risk of predation mortality. Such models can also be used to predict rates of encounter of animals with renewable energy devices. A three dimensional encounter model has been used to assess the relationship between animal size and encounter rate with tidal turbines as well as the risk for individual species. Our model showed that encounter rate increases with body size, indicating greater risk to larger animals such as marine mammals (Figure 16). This is because bigger animals take up more space and also swim faster. Their population sizes and densities are also smaller and hence the risk is greater in terms of the proportion of the population that may be affected. Using the model, we estimate that if, for example, 100 turbines, each with 2 blades and a radius of 8 m, were deployed on the west coast of Scotland, between 3.6% and 10.7% of the harbour porpoise population and 2% of the herring population may encounter some part of a turbine blade every year.

Marine vertebrates will of course have the ability to avoid the area round a device, providing that they perceive it as a hazard, and may also be able to take evasive action when about to collide. The encounter model has, therefore, highlighted the need for more information on the abundance of animals at risk close to sites that are being considered for development as well as the sensory information that is available to allow detection, avoidance or evasion.

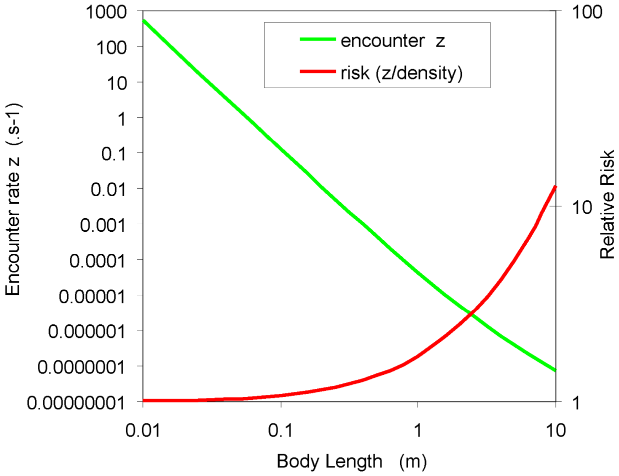

Figure 16 Encounter rate and relative risk for marine vertebrates of increasing body size.

Detailed studies of predator evasion by fish have shown how they respond to looming images, a predator lunging toward them, and have allowed us to model their evasion capabilities. An evasion model based on visual responses to looming objects and locomotor performance indicates that, for fish, the probability of evasion increases with fish size, as maximum swimming speed increases but is also critically dependent on blade thickness. Thin blades present a smaller looming target that will only exceed the animal's looming response threshold at too close a range allowing insufficient time for evasion. The relative velocity of the blade to the water is also critical. Below 6 m s^{-1} the probability of evasion is near to 1 but declines rapidly above that velocity (Figure 17).

It is essential, therefore, that we obtain a better understanding of animals' use of tidal stream environments above this velocity. Animals can respond when they detect the rapidly increasing pressure resulting from a predator rushing towards them, allowing evasion when visual cues are not available. A transient sound stimulus evoked evasion model, based upon the pressure fields around turbine blades (predicted using Computational Fluid Dynamics), is also being developed. Preliminary results indicate similar or better evasion response distances and therefore evasion probability to the visual looming stimulus model. The challenges that remain are to extend this modelling effort both to marine mammal behaviour and to predicting the potential for evasive responses of animals to the sound pressures emitted by turbine blades. This will be a useful tool to estimate the probability of evasion for fish and may be extended to include mammals and birds. Ultimately there is a hope that monitoring effort can then be better targeted, can test the predictions and then refine future assessment of environmental impact.

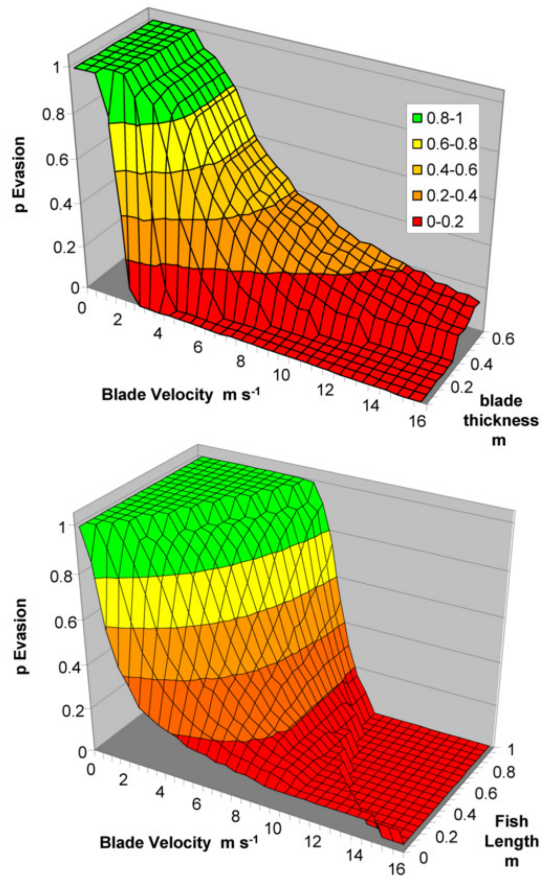

Figure 17 Fish collision with turbine blades: the probability of collision evasion.

3.6 Influence of Flow Direction on the Propagation of Sound in a Tidal Stream

An experiment to test whether flow direction (ebb or flood) and velocity have any impact on the sound level received from a point source was conducted in a tidal stream: the Falls of Lora, Scotland. It is expected that sound will travel through the water in all directions and will not be affected by tidal flow direction, velocity and turbulence. This has not been previously tested. This experiment is part of a wider study on background noise, noise generated by turbines and the potential for this acoustic signal to provide a cue for avoidance responses by marine vertebrates and marine mammals in particular. Water velocity is slow (less than 5m s^{-1}) compared to the velocity of sound in water (1500 m s^{-1}). A tidal stream site adjacent to the falls of Lora, near Oban, Scotland was chosen as the study site. The experiment was conducted on 10th February 2011.

a)

b)

Figure 18 a) Fall of Lora study location from Google Earth with speaker position marked. b) Speaker was suspended below the moored workboat (Photo by Jim Elliot).

A 0.5 second pulse of sound at 1 kHz was used for the test. For this purpose a sound file generated in Cool Edit (ramped up and down) with 9.5 seconds silence played back on a Panasonic Toughbook CF-19 portable computer running Cubase LE4, through an amplifier and transformer to a Lubell LL916C (Pro) underwater speaker with 15.24m cable. The speaker was suspended at a nominal depth 5m, but with flow this depth was slightly reduced, beneath a small boat moored in the tidal stream (Figure 18b). Separate tests showed that at the frequency used output the Lubell speaker was omnidirectional and would not be affected by movement and change of orientation in the flow.

Sound received by a B&K hydrophone type 8104, amplified by a Nexus conditioning amplifier type 2692 was recorded in .WAV files on a Sound devices 744T digital recorder. The recordings were made from a second boat, a 6m rib 'Usige'. The rib was motored in to position such that, after switching off the engines, it would drift with the tide towards or away from the speaker location and the Falls. When in position at the start of the drift, the engines and all electronics were switched off and the hydrophone was deployed at a depth of approximately 5m. A recording was made for the duration of the drift and this process was repeated on both the flood and ebb tides. The drift tracks were recorded using a handheld GPS receiver. Speed of drift (and tidal flow) was calculated from the GPS tracks. 60 second samples from the sound recordings were analysed at three stations at increasing distances from the speaker (Figure 19).

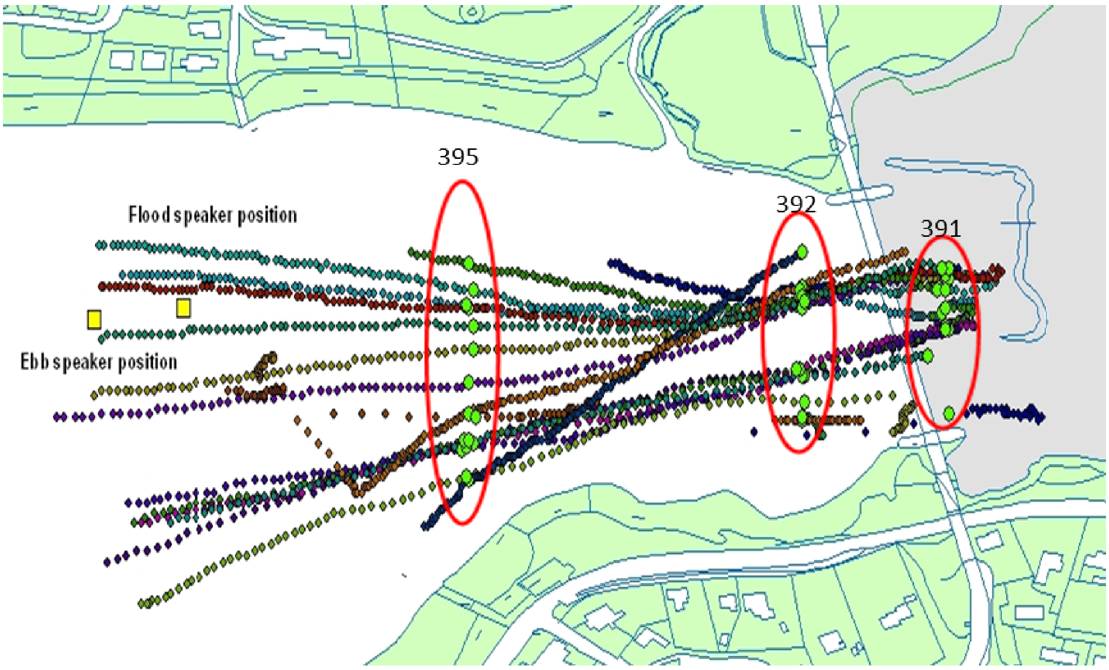

Figure 19 GIS map of flood and ebb survey tracks with sample points highlighted.

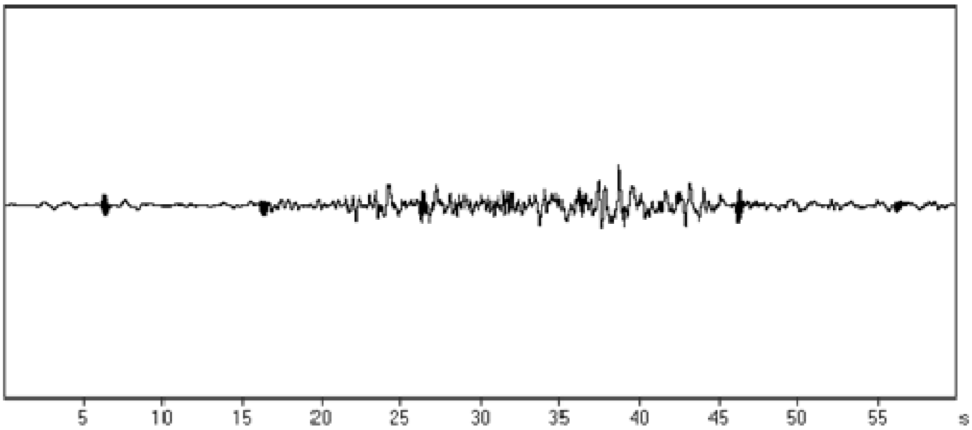

Figure 20 Example 60 second time series segment with the 1 kHz pulses circled. Also illustrating an area, in the middle of the recording, of increased intensity of sound.

Sound level decreased with increasing distance between the source and the receiver (Figure 21d) but neither tidal flow nor velocity had any significant effect on propagation. A General Linear Model fixed factors of tidal state (ebb or flood) and station (391, 392, and 395) fitted to the data resulted in p values of 0.456 for tidal direction (ebb, flood) and 0.008 for station. This suggests that the direction of flow has no effect on sound levels received from a point source. There are still likely to be differences in background noise level between ebb and flood that will be unique to a particular site and may affect the range at which turbine noise will be above background noise. Individual sites should be investigated using the technique described in section 3.1.6 above.

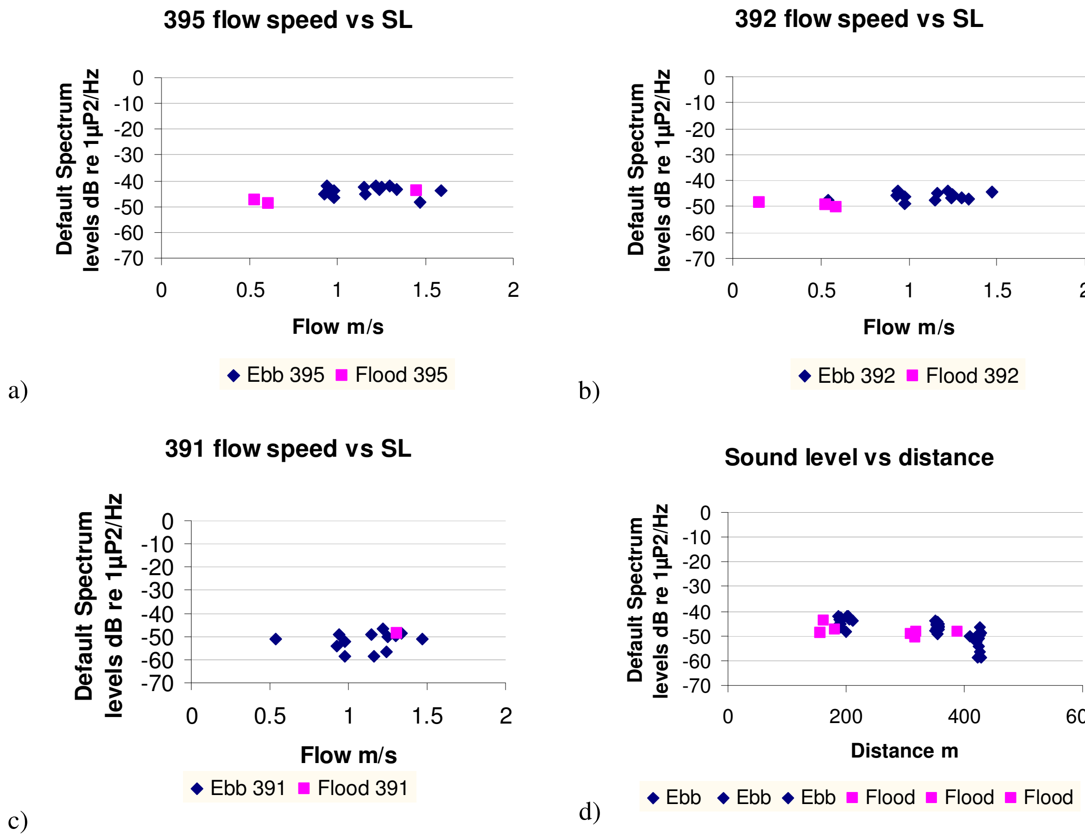

Figure 21 Sound levels measured relative to flow speed (a, b and c) and sound levels relative to the distance away from the speaker (d).

4 USEFUL TOOLS

4.1 ANALYTICAL AND PREDICTIVE TOOLS

4.1.1 Modelling approaches

Models, both mathematical and conceptual, may be of value for predicting and assessing the environmental impact of ocean energy devices and schemes. Geospatial models, such as that developed by CEFAS in the UK [22] can be used to quantify the cumulative impact of ocean energy. Ecological modelling is used extensively to predict the wider scale effects of marine protected areas on both commercial species and the ecosystem. These models should also be applied to understanding the impact of ocean energy via the displacement of both key species and of fisheries. Mathematical models are being used in recent, on-going, work [23] to investigate the interaction between fisheries and marine renewable energy. The spatial overlap between fisheries and tidal or wave resources can be modelled to investigate the sensitivity of individual species of both fish and invertebrates. Further spatial fishery models can be used to investigate the potential impact (both positive and negative) of marine energy developments as fishery exclusion zones affecting fishery yield and spawning potential.

The risk of collision between marine animals (mammals, fish and diving birds in particular) is difficult to predict and to monitor. In an effort to understand the processes that lead to a risk of collision between animals and the moving parts of marine energy converters and identify gaps in knowledge that require further investigation, encounter and evasion models are being developed and used. Three-dimensional encounter models (used extensively to understand predator-prey interactions of marine animals (e.g. [24], have been modified and used to assess the encounter rate with tidal turbines as well as the risk for individual species [25]. This model showed that encounter rate increases with body size, indicating greater risk to larger animals such as marine mammals. Collisions will result from failure to avoid encounter or to evade a close encounter; thus highlighting the need for more detailed information on spatial and temporal distribution of the species at risk.

Evasion models are also being developed as tools to predict the probability of evasion by fish and marine mammals in response to visual and acoustic stimuli. These models estimate the probability of collision evasion during what can be described as near-field, close encounters between marine animals and tidal stream turbine blades. Such models are based on the extensive literature on the behaviour and locomotion of fish in predator-prey interactions (see review by [26]). So far, a model has been constructed for fish responding to the visual looming stimulus of an approaching turbine blade [27]. By combining computational fluid dynamic models (verified by tank testing) with behavioural models it will be possible to construct models to predict evasion probability in response to transient sound pressure pulses resulting from the "bow-wave" of an approaching turbine blade. A further challenge will be to extend this approach to cover other marine vertebrates. This may, however, require further behavioural and physiological experiments. Collision evasion models have the potential to assist with the assessment and comparison of relative risks posed by different device types and to inform mitigation measures; for example improving visual and auditory cues to evoke animal evasive responses.

Considering the possibility of reducing collision by behavioural responses at greater distance, an acoustic avoidance model [28] has been developed to predict the range at which marine mammals may detect the sound emitted by tidal turbines over the ambient noise and be able to avoid encounter. This type of model has to be used in conjunction with ambient noise survey data.

Physical models that predict tidal and wave resources (see other Equimar documents) can also be adapted and used to indicate likely areas that will be impacted by reductions in energy input or in some cases increases in tidal energy due to displacement resulting from the drag induced by tidal stream arrays [29].

4.1.2 Geographic Information Systems

A Geographic Information System (GIS) can be defined as the computer hardware, software and technical expertise that inputs, stores, maintains, manipulates, analyzes and outputs geographically referenced data. A GIS combines the power of spatial database management with high resolution graphic display to effectively present information. GIS outputs can include statistical reports, tables, charts, on-screen displays and high quality maps available in digital format that can be quickly and easily distributed ([30] and [31]). GIS has been widely used in the EIA process (Figure 22).

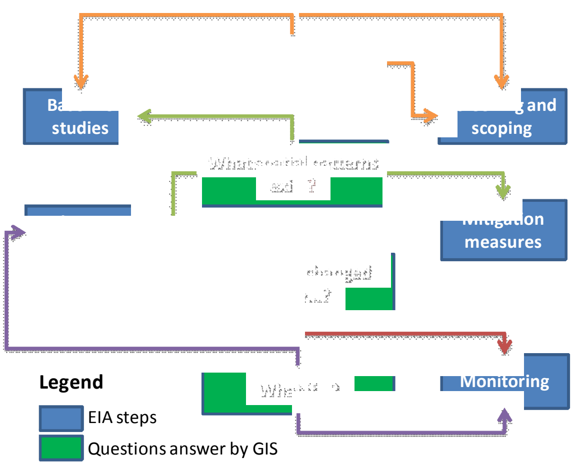

Figure 22 Central questions answered by a GIS during an Environmental Impact Assessment process [38].

Regarding renewable energy, one of the biggest issues facing its exploitation is the selection of suitable sites [32]. One of the most widely used techniques to help on this task is the Multi-Criteria Decision Analysis (MCDA) within the framework of GIS which allows multi competing site selection objectives to be taken into account at once by renewable energy developers. This technique has grown significantly in recent years and several articles have been published in refereed journals since

1990 [33].

As regards ocean energy, this technique has also been used in site selection of wave farms in e.g. UK [34] and Portugal [35]. It considers a wide variety of environmental and administrative factors (water depth, distance to shore, distance to the electric grid in land, geology and environmental impacts) and assign corresponding weights, which returns a numerical result in a given scale – suitability value – to be obtained for each location [35].

The criteria definition has two different supporting factors in the multi-criteria analysis: restrictions and weighted factors. Restrictions (e.g. existing underwater cables, marine protected areas, military exercise areas) are used to define exclusion areas that should be eliminated from the analysis; weighted factors (e.g. ocean depth, bottom type, distance to ports, distance to shoreline and to power grid, wave climate characterized by significant wave height, period and power) are evaluated through the relevance or significance of their impact(s) [35]. A GIS method has also been developed to optimise the cable route between a wave farm and the electricity network, in order to keep the underwater cable infrastructure costs to a minimum [36].

Bibliographic reviews show that the most common GIS applications are by far environmental issues including EIA. Although the use of GIS is limited by the availability of data with a good spatial coverage, its application on EIA process can help answering central questions. Examples of GIS applications on several steps of the EIA process (e.g. for ocean energy schemes) are presented in Table 4. GIS have been applied in several environmental assessments of wave energy projects e.g. WaveRoller in the coastal zone of Peniche - Portugal (AW-Energy Oy) and Wave Dragon in Milford Haven Coast, South West Wales (Wave Dragon Wales Lda).

Table 4 GIS and Environmental Impact Assessment steps (adapted from [38]).

EIA steps	Objectives of the GIS use	GIS application examples
Screening	Deciding whether a project requires EIA	- Maps of the project area can be generated automatically - Using GIS to overlay a map of the project and a map of the relevant sensitive areas (in which case an Environmental Impact Statement can be required) - In some cases EIA is required if a project is within a certain distance from a certain type of feature (e.g. road, residence area); GIS can be used to create a buffer zone around the project and clip a map containing all the relevant features
Scoping	Identifying impact themes which require further investigation; helping to clarify the spatial scope of the study (In this step GIS can be used in ways not too different from those applicable to screening)	- To inform a scoping decision regarding archaeology, creating a 500 buffer around a proposed project and then combine a map of known archaeological sites; the query can be structured to identify areas of archaeological interest falling within the buffer zone that have been submerged following sea-level rise - Identification of areas or receptor locations which will require detailed consideration in the assessment of a particular impact
Baseline studies	Building on the spatial information generated as part of the scoping process GIS is ideally suited to organizing and storing multi-disciplinary monitoring data sets to be analyzed, queried and displayed interactively;	- GIS can be a powerful tool for displaying and visualizing trends and patterns in spatial data sets: ▪ Point-type data relate to specific sample location ▪ Spatially continuous data (e.g. noise) can be used to produce a contour (isoline) map ▪ Linear data describing features ▪ Area data which relate to discrete spatial units (e.g. census data, designated sites and habitat patches)
Impact prediction	Spatial identification of impact magnitude and dimensions	- GIS is most suited to deal with the spatial dimension of impacts, and at the simplest level of analysis it can be used to make quantitative estimates of aspects such as: ▪ "Land take" caused by the development ▪ Length of zones which passes through designated land or seascape areas ▪ The number / importance of features (e.g. archaeological finds) that would be lost to the development
Impact mitigation	Identification and evaluation of alternative locations for a development project Exploitation of visualizing and displaying impact spatial distribution to identify and target possible mitigation measures (through impact significance)	- The maps produced for the baseline and impact assessment stages in an ecological assessment could be used to investigate: ▪ The potential to minimise impacts on nature conservation sites or habitat patches by project design modifications ▪ The potential for species translocation or habitat creation including e.g. corridor habitats between fragmented habitats ▪ The optimum locations and dimensions of buffer zones to protect sensitive habitats
Monitoring	Integrative tool to store, analyze, and display monitoring data to identify patterns in the data and examine change over time	

GIS may be of particular value for identifying submerged sites that may retain archaeological remains, for example around Orkney [37] and in the North Sea. Layers showing submerged sites combined with identification of features likely to have human activity and current tidal and wave energy maps can indicate areas where remains are likely to be preserved. For tidal stream developments, therefore, is not likely that artefacts will remain at such high energy sites but cables to shore may be laid across them.

4.2 DATA COLLECTING TOOLS

4.2.1 Telemetry

Telemetry techniques can be divided into two large classes: acoustic and radio. Each has a set of advantages and disadvantages with respect to monitoring marine animal movements and behaviour. Features of both technique classes are presented in Table 5. There are several different radio telemetry options with a wide choice of frequencies, information encoding, duty cycle, placement, antenna design and receiving strategies. These can be grouped into two classes of radio system, terrestrial and satellite and the set of advantages and disadvantages are presented in Table 6. There are certain fundamental constraints on any form of telemetry systems that can effectively be summarised as:

- Energy storage limits (i.e. constraints of weight and volume of battery); these can be addressed to some extent by sophisticated bit delivery strategies and maximised receiver "sensitivity";
- Transmission inefficiencies e.g. lack of knowledge that Tx was received, little message flexibility, bandwidth constraints, animal behaviour.

Table 5 Advantages and disadvantages of telemetry technique classes.

Acoustic	Radio
- Travels through water	- Blocked by sea water
- Relatively short range	- Potentially long range
- Continuous monitoring	- Temporary storage needed for continuous coverage
- Signal corruption along Tx path	- Line of sight
- Relatively low band width	- High band width
- Blocked by air bubbles and other obstacles	- Frequencies and power regulated by bureaucrats
- Choice of frequency limited by animal's perception	

Many of these limitations and problems can be overcome with the use of intelligent loggers and transmitters which can perform some or all of the following functions through onboard processing: organising data into behavioural events, on-board data processing, data compaction and scheduling communications. In addition to intelligent transmitters, the receiving system can be optimised by including some or all of the following features: notification that a message is received, maximum possible message flexibility, error checking and reporting and minimised transmission power requirements.

Table 6 Advantages and disadvantages of radio system telemetry classes.

Land based VHF & Cell phone	Satellite
- Limited geographical coverage	- Provide global but intermittent coverage
- Developments	- Rapidly developing new platforms
- Automated recording systems that collect data and/or produce directions	- Polar orbiting satellite, LEOs, new geostationary platforms
- Possibly GPS location part of data stream	- Some platforms locate, others will not
- Cell phones	- All will require careful power management and data collection strategies

There are again clear advantages and disadvantages to all telemetry systems. Unless a bespoke telemetry system is being designed for a particular study it is essential that all known aspects of the study animals' behaviour patterns and the aims and requirements of the particular study are taken into account before a particular system is chosen.

A specific example of telemetry system for use on marine mammals is the Argos satellite tags (Satellite Relay Data Logger or SRDL) and the more recent SMRU GSM/GPS phone tag. The Argos tags relay data via the Argos satellite system. However the data flow bottleneck of the satellite system results in only a sample of all data stored for transmission being successfully relayed. Of relevance here is the fact that not all haul-out records or dive records are relayed. Also, Argos locations may have errors from tens of metres to tens of kilometres. The more recent development of SMRU's GSM/GPS phone tag allows the collection of GPS quality locations (up to c. 50 per day, cf only c. 6 per day with Argos). These, and complete sets of high quality dive and haul-out records, are stored and relayed through the mobile phone system. Haul-out records are derived from the wet/dry sensors on the tag and are important in helping define the standard unit of subsequent analysis – the trip.

Other simpler, location only, types of Argos tag have been used for specific studies. Whilst they do not relay detailed individual dive and haul-out information, they are cheaper and thus a greater number of seals can be tagged e.g. the Wildlife Computers

Argos Spot tag produces track data, but only rudimentary haul-out information, while the Wildlife Computers Argos Flipper tag produces more detailed haul-out information, but, because they are attached to the flipper, seldom provide locations at sea.

4.2.2 Passive and Active Acoustic detection

Acoustic monitoring for marine mammals relies on either passive acoustics – referred to as PAM (Passive Acoustic Monitoring) or active acoustics usually known as Sonar. Passive methods record the acoustic signals produced by the animals. Acoustic survey techniques are popular because they are less labour-intensive and are not as limited by weather conditions as visual techniques. However, only vocalising animals will be detected and these methods are of no use in surveying silent species such as seals or basking sharks.

Passive acoustic methods have the advantage of not being weather dependant, and can be used to collect reliable data at relatively high wind and sea states. Passive acoustics can also allow extended survey duration when visual surveys are not possible e.g. at night. There are currently two systems in use for carrying our passive acoustic monitoring of cetaceans: towed hydrophone arrays and static autonomous acoustic data loggers (e.g. TPODs).

4.2.2.1 Towed hydrophone array

A hydrophone array can be towed behind a research vessel to detect vocalisations of cetaceans in the area. Sounds detected by the hydrophones are digitised and cetacean sounds detected by automated click and whistle detection software. This can be monitored in real time by a trained observer but usually also requires detailed offline analysis. These methods are particularly useful for monitoring odontocetes and have been particularly useful for studies of harbour porpoise which can be reliably detected at ranges of several hundreds of metres. Current PAM systems have some species identification capabilities, e.g. harbour porpoises and sperm whales can be identified with existing automated detection algorithms, software for other odontocete species is under development.

4.2.2.2 Autonomous acoustic data loggers

Pop-Up data recorders developed by Cornell acoustics laboratory records raw acoustic data on hard disk for data storage. They can be deployed on the seabed at depths of 6000m. Data is retrieved by retrieving the device. The Pop-Up mooring incorporates an acoustic release system and the device "pops up" to the surface for retrieval.

A similar system known as the Ecological Acoustic Recorder (EAR) is another acoustic data logger which monitors sound at sea for extended periods at depths up to 500m. It too incorporates an acoustic release device to separate it from its mooring when commanded. The EAR is a microprocessor-based autonomous recorder that periodically samples the ambient sound field and also includes automatic signal detection capabilities.

The POD is an autonomous device incorporating a hydrophone and a hardware data-logger, which detects cetacean echolocation clicks. Dedicated software processes these detections and filters out noise from other sources. Recent version of the POD, the C-POD, can detect odontocete vocalisations in the 20-160 kHz range. They are suitable for long term monitoring, and can log continuously for up to 4 months. They are a useful tool for looking at behaviour of animals in response to marine activities and have been used extensively to monitor the impact of wind farms on harbour porpoises in Denmark, Germany and Holland. PODs need to be anchored, either to the seabed or an existing buoy, and the hydrophone floats upright in the water column. PODs provide a relatively low cost method of long term acoustic data collection.

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