Marine Mammal Scientific Support Research Programme MMSS/001/11

MR 1 & MR 2:

Report

Current state of knowledge of the effects of offshore renewable energy generation devices on marine mammals and research requirements.

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Scottish Government

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1 Executive Summary

This report is designed to provide an update to fulfil requirements MR1 and MR2 within the Marine Mammal Scientific Support Research Programme MMSS/001/11. An initial review of the current state of knowledge on the effects of offshore renewable energy generators on marine mammals was provided to the Scottish Government in August 2013 (http://www.smru.st-and.ac.uk/documents/1321.pdf). This report provides an update to the 2013 report highlighting improvements to the current state of knowledge of effects of offshore renewable energy generators on marine mammals and provides an update on progress on the prioritised list of research gaps presented in the previous report.

A total of 28 specific research gaps were identified in the previous report. Of these, 16 were at that time already under investigation to some extent with either active research projects or planned and funded future projects.

The 12 remaining projects were yet to secure funding. Of these, funding has been secured for two (AVOID and ARRY) and discussions are underway in relation to funding for a further two (TAG and MECH). The remainder remain unfunded.

Largely the research priorities remain similar, but additional priorities that were not highlighted in the original report have been identified here.

In parallel with this study an analysis of research requirements for developing models to identify Population Consequences of Disturbance (PCOD) has been carried out under the ORJIP programme. As part of this work, a number of research priorities have been identified – this has been used to extend the list of research gaps and amend the priorities of specific projects in this update.

2 Introduction

This report is designed to provide an update to fulfil requirements MR1 and MR2 within the Marine Mammal Scientific Support Research Programme MMSS/001/11. An initial review of the current state of knowledge on the effects of offshore renewable energy generators on marine mammals was provided to the Scottish Government in August 2013 (Thompson *et al.*, 2013a; http://www.scotland.gov.uk/Publications/2013/09/5811). One year on, this report provides an update, highlighting recent improvements to the current state of knowledge of effects of offshore renewable energy generators on marine mammals and provides an update on progress on the prioritised list of research gaps identified in the previous report.

2.1 Scope

The aims of this report were determined within the Marine Mammal Scientific Support Research Programme MMSS/001/11. Under this programme, the Sea Mammal Research Unit (SMRU) was commissioned to undertake a series of tasks relating to the scientific background for good environmental management of the development of the offshore renewable industry in Scotland.

This report combines an update on two of these commissioned tasks:

- MR1: Report on the current state of knowledge of effects of offshore renewable energy generators on marine mammals.
- MR2: Identify and prioritise research gaps relating to the findings of task MR1.

The details of these Task descriptions, taken from the commissioning contract, are shown in Appendix 1 of Thompson *et al*., (2013a).

2.2 Approach

The purpose of this update is to firstly review any recent progress on any of the topic areas covered in the previous report; this was done by carrying out a literature search on any new published or unpublished (grey literature) studies on the effects of renewables on marine mammals. In addition, progress on the specific research priorities identified in the previous reports was reviewed and an update provided on specific projects where they exist, and an update given on any progress towards securing funding for those projects listed as unfunded in the previous report.

A review was also carried out to determine whether the originally identified priorities were still considered priorities and if any new priorities had been identified as a result of recent research or developments in the industry.

2.3 Structure

The update follows the same structure as the previous report with updates provided on the following sections:

In Section 5 an update is given on research into the spatial and temporal overlap in marine mammal populations (and their associated parameters) and potential Offshore Renewable Energy Generation (OREG) stressors.

In Section 6 we update knowledge on potential proximate impacts.

Any new knowledge on the linkages amongst proximate, secondary and ultimate consequences for individuals is provided in Section 5.1. An update to how the effects on individuals are translated to population level consequences is provided in Section 5.2.

3 Spatial and Temporal Overlap

For a stressor to have any impact it is necessary, although not sufficient, for the stressor to overlap with the receptor, both in time and space. The previous report summarised the current state of knowledge of spatial, temporal and movement characteristics of UK marine mammal populations and the uncertainty around these. Any updates to this are provided below. It also considered the spatial distribution of OREG activity and then highlighted some locations that provide particular opportunities for answering general questions. Progress on work in these highlighted areas is given below.

3.1 Marine mammal abundance and distribution

Estimates of the abundance of marine mammals are notoriously imprecise, and that makes the detection of changes, let alone the ascription of causes, difficult.

There remain few useful population estimates for cetaceans in UK waters and for several species there is only limited information on distribution and/or occurrence. Whereas some species are well distributed throughout the areas of interest (e.g. harbour porpoise, minke whale, white beaked dolphin) others occur only sporadically or irregularly so there is uncertainty even about which species are present in sufficient numbers to be a cause for concern.

3.1.1 UK seals

3.1.1.1 Haulout counts

With the exception of the Moray Firth (e.g. Grellier *et al.,* 1996; Cordes *et al*., 2011) and Kyle Rhea (Cunningham *et al.,* 2009) there is little information on seasonal seal haul-out distribution and numbers for any of the areas of interest. Haul-out connectivity analyses are underway using telemetry data collected at areas such as the Sound of Islay to determine the extent of the area that may be affected by developments and guide the extent of individual project led impact-monitoring programmes. Combining seasonal haul-out counts with telemetry data will facilitate development of seasonal at-sea habitat usage maps to determine the periods of maximum risk and the scales at which effects may operate (Section 6). There are also plans in place for monitoring of baseline seasonal harbour seal abundance at haul-out sites in the Moray Firth, this will permit future comparison with data collected during the construction and post-construction period of offshore wind farm development in the Moray Firth and allow a test of the short term decline and subsequent recovery predicted under the Moray Firth seal assessment framework (Thompson *et al.,* 2013b).

3.1.1.2 At-sea behaviour

Some of the gaps identified in previous reviews of data (e.g. McConnell *et al.,* (in SMRU Ltd., 2011); Thompson *et al*., 2013a) have been filled; detailed analyses of the movement and dive behaviour of harbour seals in Kyle Rhea have been presented (Thompson, 2013). However similar information is yet to be provided for telemetry deployments in the Pentland Firth and the Sound of Islay. There are no available data on the behaviour of adult grey seals in high tidal energy areas and in the case of the Pentland Firth this remains an important data gap.

3.1.1.3 At-sea usage, habitat preference and at sea activity

Thompson *et al.,* (2013a) detailed the progress that had been made in producing at sea usage maps for harbour and grey seals around the UK (Jones *et al.,* 2013), highlighting that that strategic tagging of specific seal species and age classes would reduce uncertainty in at-sea usage estimates in areas sparse in telemetry data. Bailey *et al.,* (2014) have recently modelled harbour seal habitat use and preference by integrating data from a variety of tag types (VHF, Argos and GPS-GSM). The study found that harbour seals most frequently occurred in areas close to their inshore haul-out sites, but also that seals demonstrated consistent use of offshore foraging grounds, typically within 30 km of haul-out sites in waters less than 50 m deep.

Progress has also been made on the analysis of existing telemetry data to model the seasonal movements of grey seals between foraging and breeding areas (Russell *et al.*, 2013) and this work has demonstrated that although many seals breed in the same area that they forage, between 21% and 58% of female grey seals foraged in areas quite distinct from where they breed. This has implications for considering the impact of marine and offshore developments on protected areas which are designated for their breeding populations. This work also found that haul-out based population estimates are a reliable proxy for foraging population in a given area.

Grey seals tend to range more widely than harbour seals, so using telemetry to study fine scale behaviour within relatively small study areas such as tidal rapids may be less successful than for harbour seals. Telemetry studies will likely be more effective in assessing the movements and behaviour of grey seals relative to construction and operation of wind farms. Targeted deployments are planned for adult grey seals in the southern North Sea and further telemetry deployments are planned in the Moray Firth on harbour seals, but as yet, no other regions or species have been targeted.

Whilst at-sea usage maps estimate usage density, they do not indicate why individuals form these distributions. Neither do they predict the consequences of any OREG-induced environmental change. Therefore progress has been made under MR5 with additional funding from the Department for Energy and Climate Change (DECC) to model grey and harbour seal habitat preference (See Table 1 for details).

Thompson *et al*., (2013a) highlighted that the impact of overlapping OREG stressors and seals' density will be determined / moderated by the activity associated with the geographical area of overlap. The work done under MR5 in conjunction with additional work funded by DECC, led to significant progress in mapping seal activity and a paper has been submitted for publication (Section 8). Future work in this area will include the subtraction of tidal current vectors in the analysis of behaviour to allow populations in high current areas to be similarly analysed.

Work is also planned by the University of Aberdeen to obtain up to date information on the at-sea distribution and foraging patterns of harbour seals breeding at sites in the northern part of the Moray Firth. These data will allow the characterisation of foraging areas used by identified individuals and derive estimates of individual and sex-differences in the duration and range of foraging trips. These data will also be linked to existing long term studies of vital rates. In addition, these data will inform the design of additional tracking studies during offshore wind farm construction which will allow an understanding of the effects of construction noise on foraging behaviour and on individual variation in vital rates (see Sections 5 and 6).

Results of a targeted study of the responses of harbour seals to piling during wind farm construction noise and to the presence of operating wind farms are described in Section 4.1.1.1 below.

3.1.1.4 Meta-population structure

The previous report highlighted the need to take account of the structure of seal meta-populations at a finer spatial resolution than the current seal management regions would suggest. In order to identify the appropriate scales for examining the effects of developments, work is underway to understand the baseline between haul-out movements of both grey and harbour seals, with the longer term aim of developing appropriate strategies for the monitoring and management of local effects of developments (Section 6).

3.1.2 UK Cetacea

3.1.2.1 Coarse scale distribution

Thompson *et al.*, (2013a) reported that, with the exception of bottlenose dolphins, less is known about the population status and distribution of UK cetacea compared with UK seals. The primary synoptic information on cetacean abundance and distribution remains the outcomes from the two SCANS surveys conducted in 1994 and 2005 (Hammond *et al.*, 2002; Hammond *et al.*, 2013). Thompson *et al.*, (2013a) also highlighted that an assessment of the outputs of the Joint Cetacean Protocol (JCP), a collaborative project led by the Joint Nature Conservation Committee (JNCC), to collate and analyse a large range of visual and acoustic survey datasets on cetacean abundance and distribution, was underway. This review, which provides a synthesis of the advantages and drawbacks of the methodology and outputs for addressing questions of impact at the spatial scales associated with marine and offshore renewable developments, has been completed and a report has been submitted to Marine Scotland. The outputs of the third phase of the JCP analysis have not yet been made publicly available.

A short discussion paper on how best to define the range of cetacean populations is also currently in preparation and expected to be submitted in autumn 2014.

The third SCANS survey is currently being planned for summer 2016. A proposal will be submitted to the EU LIFE Nature in mid-October. Pledges of matching funding are in place from several national governments. The Commission funding decision should be known by the end of 2014. If successful, the main survey of shelf and offshore European Atlantic waters will be carried out in July 2016.

The East Coast Marine Mammal Acoustic Study (ECOMMAS), being implemented by Marine Scotland, using various passive acoustic methods, will also provide useful data on the occurrence of cetaceans in the coastal region from St Abbs to Caithness in combination with regular aerial surveys (also Marine Scotland[1]) and regional monitoring initiatives being implemented by the University of Aberdeen (in the Moray Firth) and the University of St Andrews (SAMMO) network of PAMBouys.

Researchers at the Centre for Research in Ecological and Environmental Monitoring (CREEM) at the University of St Andrews are developing methods to convert metrics from acoustic monitoring to measures of density (e.g. Marques *et al.*, 2012). This has previously been applied to TPODs (Kyhn *et al.*, 2012) and this is being applied to CPODs as part of the SAMBAH project (Static Acoustic Monitoring of the Baltic Harbour Porpoise) which completed at the end of 2014.

3.1.2.2 Fine scale distribution and behaviour

In most cases, developers continue to conduct local surveys to gain information on the density of cetaceans in the coastal waters where wave and tidal OREG developments are planned.

Thompson *et al.*, (2013a) described how at a smaller scale, presence and perhaps also local abundance of small cetaceans can be obtained by the deployment of passive acoustic detectors such as CPODs. These have been deployed in areas of OREG developments, deployed at several offshore wind farm sites and tidal and wave energy sites to collect baseline data prior to installation of devices (e.g. Thompson *et al*., 2014; Brookes *et al*., 2013; Booth, 2015) and novel methods of deployments have been developed for particular high energy environments (Wilson *et al.*, 2014).

However, there have been concerns related to methodological issues with the use of CPODs, particularly in tidal environments. The increased background noise as a result of increased flow, sediment transport, etc, can quickly fill up the CPOD buffer, resulting in a loss of monitoring time and reduced ability to detect cetaceans, there is also a requirement for retrievable flow-resistant seabed moorings (e.g. Booth, 2015; Wood, 2014; Wilson *et al.*, 2014). There are a number of additional limitations with CPODs; the algorithm for detection (the "KERNO classifier" is proprietary and not open source and therefore detections cannot be independently verified. Roberts and Read (2014) tested CPODs against digital acoustic recordings of bottlenose dolphins and found that although CPODs performed well in detecting click trains, all units consistently failed to detect some events and therefore underestimated the true occurrence of dolphins; the CPOD recorded occurrence of echolocation during 16%, 5% and 6% of recording effort at three sites, whereas the digital recording revealed the true occurrence was 31%, 7% and 34%. CPODs also cannot currently differentiate between dolphin species.

The use of drifting CPODs (Wilson *et al.*, 2014) can alleviate the requirement for moorings and provide inexpensive tool for investigating cetacean use of tidal stream habitats, yet cannot provide the same extent of temporal coverage of static devices.

[1] http://www.scotland.gov.uk/Resource/0045/00458980.pdf

Until recently, fine scale behavioural studies have been more problematic. Although tagging of cetaceans using D-tags or Argos tags or equivalent has yielded useful information in other areas, no such tagging has been undertaken in the UK. However, recent OREG related and Scottish Government funded work has led to the development of drifting and fixed hydrophone arrays and associated software that can track the movement of animals based on their echolocation clicks, opening up the possibility of examining fine scale foraging and movement patterns in specific targeted areas, such as those where OREG developments are being planned. Since the previous report, much progress has been made in extending this approach to a range of sites to provide sufficient data at appropriate resolution to allow us to describe porpoise behaviour in such habitats, (Section 8).

For coastal species, in areas with suitable elevated vantage points, land-based surveys that record the position of animals (e.g. theodolite surveys) can be used to measure fine scale movement patterns which can be used to give an indication of habitat use in relation to spatial distribution – for example, Bailey & Thompson (2006) modelled fine scale bottlenose dolphin movement data to identify movement patterns and analysis indicated the presence of key foraging sites.

3.2 Possible indicator sites

Thompson *et al.*, (2013a) argued that rather than dilute resources over a large number of sites, effort should be concentrated in areas where there has previously been long-term and intensive monitoring because of the importance of baseline data for estimating impacts and changes resulting from the installation and operation of OREG devices. This view was echoed in a recent review of the post consent monitoring carried out to date at UK offshore wind farms (Marine Management Organisation, 2014).

Such a strategic regional monitoring programme has been planned for the Moray Firth, covering both harbour seal and bottlenose dolphin populations, both of which have been extensively studied (e.g. Cordes *et al.*, 2011; Cheney *et al.*, 2013). The long time series of abundance, distribution, behavioural and reproductive data from these populations makes it an obvious candidate site for continued/further investigation of demographic processes and population responses to the impending large scale wind OREG developments.

However, the Moray Firth population is not necessarily representative of the wider harbour seal population, e.g. while the population fell during the 1990s, that decline was much less than has been seen in other harbour seal populations in eastern Scotland. Therefore additional sites should be included in any programme of demographic studies of harbour seals. There remain too few harbour seals around the Firth of Tay and Eden Estuary Special Area of Conservation (SAC) for much data to be gathered there. Orkney and the Pentland Firth was identified in the previous report as an appropriate area, given the area's importance for tidal and wave developments, as although seal numbers have declined, it still contains one of the largest populations of harbour seals and therefore remains an appropriate area in which to focus efforts to understand impacts of wave and tidal developments on that species.

Bottlenose dolphins range outside the Moray Firth and it will be important to understand the impact of developments on such larger scale distribution and behaviour; therefore there is potential for developing monitoring programmes covering the whole of the east coast range of this population – the aforementioned ECOMMAS project and the long running photo ID study of this population (Cheney *et al.*, 2013) are key examples of current monitoring, however understanding fine scale movements over this whole range in response to offshore windfarm construction will require monitoring at a higher resolution than is currently implemented.

There remains clear potential for developing larger indicator sites to monitor porpoise density and seasonal movements in the Firth of Forth, Moray Firth, and west coast areas. The static acoustic monitoring that is planned for the Moray Firth along with the ECOMMAS project will cover this aim over parts of this range but currently there are no definite plans to extend

4 Potential Proximate Impacts

Three main classes of effects of OREG devices have been repeatedly identified in reviews of their potential impacts on marine mammals. These are noise (construction of offshore wind farms, construction and operation of tidal devices), risks of collision with the moving parts of tidal turbines as well as ship strikes, and changes in the availability of the animals' habitats as a result of construction, operation or presence of developments . Thompson *et al.,* (2013a) provided a review of the current status of knowledge under each of these impacts. Here, any recent findings or developments in relation to each of these impacts are described.

4.1 Noise

4.1.1 Construction

4.1.1.1 Piling

Estimates of received levels of piling noise vary widely but there is a general consensus that, in some conditions, they have the potential to cause hearing damage and behavioural disturbance to a wide range of marine mammal species over considerable areas. The use of piles in wind farm construction has been an issue since the earliest stages of the planning process (Thomsen *et al.*, 2006). As a direct consequence, the effects of pile driving noise on marine mammals is among the most intensively studied aspect of the environmental impacts of marine renewables industries. Studies in European waters have shown that pile driving during offshore windfarm construction can displace harbour porpoises out to ranges of tens of kilometres (Brandt *et al.*, 2011; Dahne *et al.*, 2013). However, predictions of future effects on marine mammals associated with construction in UK waters are reliant on extrapolations between species and populations, incorporated with modelling with a range of assumptions and uncertainties. Therefore much uncertainty remains in the process, from estimating received noise levels, to the level of response that different species may show, and the impact that might have on populations.

Hearing damage

There remain a large number of uncertainties surrounding the relationship between sound exposure from piling and hearing damage, both temporary threshold shift, (TTS), and permanent threshold shift, (PTS). Uncertainty in the relationship between the physical characteristics of the sounds produced, the levels of sound received by individual animals, and the effects on the hearing abilities of marine mammals is one of the largest sources of uncertainties surrounding the prediction of the potential impacts of offshore energy developments. Lack of information in this area has led to necessary precautionary interpretations of limited data, resulting in potentially conservative estimates of impact. A comprehensive review of the current status of knowledge in this area is outside the scope of this update, however, Houser *et al.,* (2014) recently presented a useful review of the current status and future of underwater hearing research from a workshop held on this topic, attended by many of the leading researchers in this field. This review highlighted a number of recommendations for research in this area. They included a number of high level recommendations particularly relevant to the prediction of the impact of piling noise on marine mammal hearing:

1. Increase species representation and, where feasible, increase the sample size of subjects representing a species for temporary threshold shift (TTS). Variability between individuals and variability as a function of demography are poorly understood for nearly all marine mammal species and substantially increase the likelihood of erroneous conclusions when based on a handful of subjects. The testing of additional species in laboratory studies will increase confidence in the categorisation of functional hearing groups and facilitate cross-species comparisons.
2. Increase the number of comparisons between psychophysical and electrophysiological estimates of hearing function within the same subject. Electrophysiological approaches enable many subjects to be tested over a short period of time, but psychophysical approaches permit the integrated response of an animal to be obtained. To increase the utility of the emerging

electrophysiological research methods, the information that can be obtained from such techniques needs to be assessed in conjunction with psychophysical experiments.

3. Until such time that hearing measurements are made on mysticete whales, anatomical models will be necessary for predicting mysticete hearing sensitivity. Validation of anatomical models is critical to gaining confidence in their predictive ability, but remains elusive. Effort should be placed into validating models against behavioural or electrophysiological information from available species prior to extrapolation to species for which no information exists.

In addition to these there a number of specific research gaps such as:

1. Field validation of predictions of exposure from currently used models and the extent to which such exposure leads to auditory injury in wild animals.
2. The links between TTS and PTS in marine mammals.
3. The relationship between various sound characteristics (frequency, pulse duration and interpulse interval, received SPL, received SEL) and TTS onset, growth and recovery.

However some of these questions are very difficult to answer using currently available methods, yet uncertainty around these issues currently results in uncertainty in predictions of the impact of renewable developments on marine mammal populations and leads to a necessarily precautious approach to licensing.

As part of the DECC funded telemetry study of harbour seals in the Wash (Section 6), the level of hearing damage sustained by the tagged harbour seals as a result of the estimated level of cumulative sound exposure during piling events has been estimated (Hastie *et al*., 2014) This study found that, based on published injury criteria, around half of tagged seals received sound levels from pile driving sufficient to cause auditory damage. However this was based on a number of assumptions about the relationships between piling sound characteristics and TTS growth and recovery and the relationship between TTS and PTS. The PTS onset threshold as recommended by Southall *et al.,* (2007) in their interim noise exposure criteria are intentionally conservative, and are based upon assumed relationships between the relative levels of TTS and PTS which, in turn, involves the use of proxy data from other species, as there is currently no empirical information on levels that cause PTS in marine mammals. In their report, PTS onset was estimated from TTS onset measurements and from the rate of TTS growth with increasing exposure levels above the level eliciting TTS onset. As a result, PTS was presumed to be likely if the threshold is reduced by ≥ 40 dB (i.e., 40 dB of TTS) (Southall *et al.,* 2007). However, this may be overly precautionary for harbour seals given recent work by Kastelein *et al.,* (2013) that showed despite an exposure of a high SPL signal for 1 hour that resulted in 44 dB TTS in a harbour seal, full hearing recovery occurred within 4 days.

In addition, TTS growth and recovery functions were derived from TTS measurements as a result of exposure to continuous sound (Kastak *et al.,* 2005; Kastak & Reichmuth, 2007). However, recent results suggest that this may not be an optimal model to predict TTS in harbour seals; for example Kastelein *et al.,* (2012) and Kastelein *et al.,* (2013) suggest that hearing loss induced by noise does not solely depend upon the total amount of energy, but on the interaction of several factors such as the level and duration of the exposure, rise time, the rate of repetition, and the susceptibility of the animal. Prediction of auditory damage is further complicated by results in other species that suggest that the pattern of TTS recovery following exposure to impulse noise diverges from much of the data on continuous noise exposure (Luz, 1970; Fletcher, 1970; Henderson *et al.,* 1974). It is clear therefore, that the effects of pulsed sound on the auditory system are highly complex and the prediction of auditory damage in marine mammals is a rapidly evolving field of research.

As well as the process of predicting the level of auditory damage as a result of exposure, there is also uncertainty in this process of predicting the level of exposure itself. Received levels are predicted from acoustic propagation models that are based on a number of assumptions. There are uncertainties around the extent to which animal movement, particularly vertical movement, affects the dose received during piling events. A technique that would allow the received levels of tagged animals to be directly measured would be of benefit in refining the predictions of auditory damage (and developing dose response relationships for behavioural responses). The latest version of the D-tag developed by Woods Hole Oceanographic Institute can be used to provide detailed data on the movements, behaviour (via accelerometers) and sound exposure of individual marine mammal, but only for a limited period (although up to weeks for deployments on seals). SMRU are developing an acoustic dosimeter that will provide equivalent data over longer periods.

As part of the DECC funded telemetry study of harbour seals in the Wash (Section 6) auditory evoked potential measurements were carried out on the tagged seals to estimate auditory thresholds of each individual and to compare these to seals that had not been exposed to pile driving (captive control group). The analysis of these data is now complete and a paper is currently being prepared for submission. There were some methodological issues with the technique used in this study and there is a need to further develop methodology to carry out hearing threshold measurements during capture and handling for other telemetry and sampling based studies. This would enable the extent of hearing damage in wild marine mammal populations in different regions around the UK and would provide the opportunity to link levels of hearing damage to historical levels of underwater industrial activity.

Additional Research gap				
Title	**Code**	**Details**	**Current Status**	**Reporting date**
Hearing damage and exposure to piling noise		The links between piling sound characteristics and TTS growth and recovery in key UK species: harbour seal, grey seal, bottlenose dolphin, harbour porpoise and minke whale.	No UK research groups working on these issues. Ron Kastelein carrying out studies on harbour seals and harbour porpoises in the Netherlands	
The extent of hearing damage in wild marine mammal populations		Development of standard methodology to carry out hearing threshold measurements during routine capture and handling for telemetry and other sampling based studies.	Unfunded	
Measuring sound exposure experienced be free ranging marine mammals during offshore wind farm construction		The latest version of the D-tag developed by Woods Hole Oceanographic Institute can be used to provide detailed data on the movements, behaviour (via accelerometers) and sound exposure of individual marine mammal, but only for a limited period (although up to weeks for deployments on seals). SMRU are developing an acoustic dosimeter that will provide equivalent data over periods of days or weeks. Developing on board processing software is a pressing and so far unfunded requirement. Deployments of these tags during offshore wind farm construction will allow quantification of received sound levels associated with observed behavioural responses.	Unfunded	

Masking vocalisations

Relatively few studies of the masking of biologically significant sounds by piling noise have been performed in marine mammals. Houser *et al.*, (2014) summarised presentations covering the current status of the work on this issue but to date, very little work has focused on the masking potential of piling noise, probably because the masking effects of intermittent noise is unlikely to be an issue compared to continuous signals. Masking to date has received much less attention than hearing damage or behavioural responses.

Behavioural responses by harbour porpoises

Further to the review presented in Thompson *et al.*, (2013), few new data have emerged on the behavioural responses to pile driving by harbour porpoises. The studies that have been published or presented at conferences provide similar results to those of previous studies. Monitoring carried out using CPODs by the German consultancy Bioconsult, during the construction of the Borkum West-II wind farm in the German North Sea, demonstrated that PODs exposed to piling noise levels above 140 dB (single pulse SEL) recorded significantly fewer porpoise detections as compared to the detection rate before pile driving started. Porpoise response to piling clearly followed a gradient with increasing displacement associated with increasing noise levels. Waiting times for click detections after piling ranged from 20-35 hours at the monitoring sites closest to the piling (Nehls *et al.,* in press). These results have not been published yet, although a short paper should be included in the forthcoming proceedings of The Effects of Noise on Aquatic Life meeting in Budapest in 2013. Although not related to renewable energy development, a recent study by Thompson, (2013) demonstrated that porpoises responded to the firing of a 470 cu inch airgun array over ranges of 5-10km but that animals were detected at affected sites within a few hours and that the level of response declined throughout a ten day survey. However there may be differences in how porpoises respond to seismic noise compared to piling noise and the methods used in this study cannot determine whether the displaced individuals returned to the affected area or whether the increase in detections after the activity had stopped was a result of new individuals moving into the area. The strategic, regional, static acoustic monitoring in the Moray Firth and on the East coast of Scotland by Marine Scotland, the University of Aberdeen and the University of St Andrews, has the potential to monitor the occurrence of harbour porpoises across the monitoring sites throughout periods of offshore wind farm construction. If it is continued throughout the construction phase it will potentially provide information on the responses of porpoises to consented offshore wind farm development in both the Moray Firth and in the outer Forth and Tay estuaries.

As part of the international research project DEPONS (http://depons.au.dk/) porpoises are being tagged with Fastloc GPS tags that provide detailed fine scale movement information. The aim is to tag animals in area where wind farms are being constructed to monitor their movements as pile driving takes place. Animals caught and tagged outside of wind farm areas will be exposed to noise from a seismic air gun as a proxy for pile driving noise. This project should provide valuable data on individual responses of porpoises to pile driving and other pulsed noises with similar frequency spectra. These behavioural responses will be used to parameterise individual based models to predict the population consequences of exposure to noise (see Section 6). This model will be based on an extension of a previous model (Nabe-Nielson *et al.,* 2013).

Behavioural responses by other cetacean species

Little data exist on the behavioural response to pile driving of cetacean species other than harbour porpoises. Data is currently being collected, as part of a DECC funded study, in the Moray Firth on the responses of bottlenose dolphins to piling as part of harbour and port developments at Nigg and Invergordon. The acoustic monitoring project, ECOMMAS, mentioned above covers areas regularly used by the east coast bottlenose dolphin population so should yield important data on any large scale changes in occurrence or use during piling activity.

Behavioural responses by seals

The DECC funded study of tagged harbour seals in the Wash in relation to offshore wind farm construction described in the previous report is nearing completion. The data have been analysed and a number of papers have been submitted for publication. Comparisons with historical (pre-wind farm) telemetry data suggest no large scale changes in seal movements and distribution as a result of wind farm construction (DECC3; Table 8.1). Fine scale changes in behaviour and at-sea usage in relation to piling events are currently being analysed and will be reported by the end of 2014. The wind farm sites in the Wash were not typically used for foraging; the areas occupied by the wind farms were more commonly used for transit to feeding areas further offshore. There is still a need to understand the behavioural responses of seals where piling occurs in areas identified as important for foraging. Kastelein *et al.,* (2013) recently presented auditory thresholds for pile driving signals which are useful for estimating auditory ranges of piling.

Further tag deployments are planned by the SMRU and the University of Aberdeen on harbour seals in the Moray Firth during offshore wind farm construction, these deployments aim to provide dose response information for any detected behavioural response and will attempt to link individual responses to variations in vital rates of individuals tracked through time using photo ID. The time taken for individuals to return to disturbed sites after piling has ceased will also be examined using these data.

There is currently no data of this type on the behavioural response of grey seals to offshore wind farm construction. Given the current favourable conservation status of this species in the UK it is not expected that current levels of predicted impact will have a significant effect long term effect on the population as a whole or on the conservation objectives of individual SACs designated for their breeding grey seal population. Therefore this is not an immediate priority for post consent monitoring, however given the uncertainty inherent in predictions of impact (as discussed in the previous section) a degree of uncertainty still remains and consideration should be given to how SAC monitoring and long term studies of grey seals breeding on the Isle of May could be utilised to examine the potential impact of offshore wind farm construction.

Changes in local haulout counts of seals

No additional studies have been reported on any changes in hauled out seal numbers during offshore wind farm construction. Monitoring of the haul-out abundance and distribution of harbour seals on the Northern coast of the Moray Firth is planned as part of the monitoring associated with offshore wind farm development in the Moray Firth. This approach could also be extended down the rest of the east coast of Scotland and England.

Mitigation

The recent report on the first phase of ORJIP Project 4: Improvements to standard underwater noise mitigation measures during piling, (Herschel *et al.,* 2013) provides a summary of the main approaches to mitigation for the prevention of injury to marine mammals, both in the UK and across Europe. The report concludes that acoustic deterrence presents a useful way forward for preventing auditory injury during pile driving for UK species but that a number of uncertainties remain. Development and testing of deterrent methods for a range of species and environments was recommended as a second phase of Project 4. ORJIP have not yet progressed phase 2 of this work, although discussions are currently ongoing.

Marine Scotland (MS) funded research carried out under subtask MR8 of the MMSS/001/11 Research Project has carried out a series of exposure experiments with harbour seals on the west coast of Scotland (2013) and very recently (summer 2014) in the Moray Firth. The full dataset has yet to be analysed but initial analysis suggest that seals demonstrated aversive responses to Acoustic Deterrent Device (ADD) signals and playbacks of killer whale vocalisations (AcMit; Table 1).

The same monitoring at the Borkum West-II offshore wind farm in Germany, mentioned previously, demonstrated that the use of big bubble curtains (BBC) significantly reduced noise propagation during piling and acoustic monitoring reduced the extent of behavioural responses by harbour porpoises (Nehls *et al.*, in press). However this required a longer period on site, additional vessels and extra cost. More work is required to understand the costs and benefits of using such mitigation technology on the whole project environmental footprint and cost.

Vibratory pile driving (Vibropiling) is being adopted in some construction projects (e.g. construction of the Port of Ardersier) as an alternative to impact pile driving to decrease the potential for impacts from underwater noise.

4.1.2 Operation

4.1.2.1 Wind-OREG operation

Noise characteristics and effects on marine mammals

Underwater noise monitoring of operational noise has been a condition of most UK offshore wind farm licences. A recent review of the post consent monitoring carried out to date at UK offshore wind farms (Marine Management Organisation, 2014) synthesised the data collected to date at UK wind farms on operational noise. The report concludes that underwater noise from operational wind farms is not considered significant. All the measurements undertaken to-date indicate that the broadband turbine noise is generally comparable with ambient noise at distances of a few hundred metres, however, tonal components have been shown to be detectable at greater distances from the wind farm.

A recent report published by MS on the modelling of the acoustic output of operational wind turbines demonstrated that the output varied depending on the foundation structure type (jacket, monopile or gravity foundation) (Marmo *et al.*, 2013). Jacket foundations generate the lowest marine mammal impact ranges compared to monopile and gravity foundations. The report concluded that species with hearing specialised to low frequency, such as minke whales, may in certain circumstances detect the wind farm at least 18 km away and are the species most likely to be affected by noise from operational wind turbines. Harbour seals, grey seals, harbour porpoises and bottlenose dolphins are not considered to be at risk of displacement by the operational wind farm modelled.

Since the last review, there have been no empirical studies directly examining the effect of operational noise on wind farms on any marine mammals, but a study of the movements of tagged seals around operating wind farms (Russell *et al.*, 2014) has demonstrated that individual seals can show preferences for foraging around turbine foundation structures. This suggests that operational noise is not having a significant detrimental effect on seal behaviour.

4.2 Physical contact

Collisions between OREG devices (and OREG related activity) and marine mammals remain a large area of concern.

4.2.1 Tidal-OREG

The potential for injuries or fatalities resulting from direct contact with moving parts of tidal power devices remains a high priority concern. Information on the fine scale behavioural responses of marine mammals around tidal turbines remains a key knowledge gap.

Although little empirical data has been collected at operational tidal devices to inform this issue, progress has been made in the development of methodology to collect data to help address this issue. The Scottish Government has recently funded a project to develop and test methodologies to track the underwater behaviour of marine mammals around tidal turbines and this project is now underway. Monitoring methods are being developed and tested for future implementation at the Scottish Government's Demonstration Strategy tidal sites. Work packages include:

- The development and testing of a fixed array of static hydrophones to enable passive acoustic 3-D tracking of echo-locating cetaceans, building on the tracking work developed under the main Scottish Government contract.
- The development of active sonar detection, identification and tracking software.
- The integration of active and passive acoustic monitoring equipment onto suitable deployment platforms.
- Exploring the feasibility of using acoustic tags attached to seals to track seal movements in 3D around devices using passive acoustic detection of tag signals.
- Integrating with turbine mounted video monitoring.

This project is due to finish at the end of 2015 with the next phase of the project involving the deployment of the developed technology at key turbine sites and the ongoing long term monitoring of tidal turbines to inform collision risk assessments.

Other initiatives elsewhere in the UK and globally are also developing monitoring technology for deployment at tidal energy sites for monitoring interactions with marine wildlife; these include the FLOWBEC platform which incorporates a multibeam sonar for detection and tracking of birds and marine mammals (Williamson & Blondel, 2014), the development of an integrated 'Adaptable Monitoring Package' at the Northwest National Marine Renewable Energy Center at the University of Washington in the US (Polagye *et al.*, 2014) which consists of a customised, instrumented 'tool skid' built up around an inspection class ROV which can be manoeuvred into position to a 'docking station' near the tidal device to be monitored. Instrumentation can be customised but the prototype device contains a stereo-optical camera package, active sonars and passive acoustic hydrophones.

Tidal Energy Limited's DeltaStream device, which will be installed and commissioned in October 2014, is instrumented with an integrated hydrophone array to enable fine scale 3D tracking of echo-locating cetaceans around the turbine. The device is also equipment with a multibeam active sonar for detecting and tracking both seals and cetaceans around the device. Data from Ramsey Sound will provide the first empirical data on encounter rates and near field behaviour around an operational tidal turbine, anywhere in the world.

The NERC funded RESPONSE project, which has been examining the responses of wild and captive animals to playbacks of turbine noise, is nearing completion. Field and captive trials on seals have been completed and the results are currently being analysed and written up for publication. Field trials with harbour porpoises are currently under way.

4.2.1.1 Collision risk models

Since publication of the 2013 "Current State of Knowledge Report" by Thompson *et al.,* (2013a), a review of the available models for predicting collision risk has been submitted to MS and Scottish Natural Heritage (SNH) (Lonergan & Thompson 2014). The review concluded that the outputs of the available models were fairly similar despite differences in approach and that the outputs were far more sensitive to assumptions made about avoidance rate than any of the other parameters in the models. Therefore the implication is that more effort should be employed into understanding the nature of behaviour around devices and the extent of evasive and avoidance responses. It was also highlighted that estimates could be improved if models allowed the incorporation of information on the joint distribution of animal speeds, directions and orientations throughout the tidal cycle.

There is a need to update existing models to provide more realistic predictions of the probability of marine mammals and turbines occupying the same space at the same time. This will involve incorporating improvements in our understanding of the way animals use tidal areas; particularly related to the vertical and horizontal distribution of animals.

In addition, there is a need for spatially explicit and biologically informed models of individual movement and behaviour which can incorporate the residence time of individual animal with zones of risk and be used to inform simulation based approaches to assessing risk. Such an approach should be scalable and transferrable so that it may be used to assess a wide range of OREG related impacts.

This need is particularly important given that the information on avoidance behaviour hoped to be gained from the monitoring taking place as part of the demonstration strategy will not be available for another few years, while consenting decisions on further tidal energy projects are required in the next few months. However recent work has suggested that seal and porpoise behaviour can differ substantially between different tidal areas, therefore there is the possibility that a degree of site specific information for each assessment may be a requirement.

Collision models should also be updated with a variable probability that a strike will result in mortality – this can be parameterised by a combination of understanding the variation in rotor speed throughout the tidal cycle, the variation in collision force imparted by different parts of the blade and the variation in physical impact on tissue resulting from these (see Section 4.2.1.4).

4.2.1.2 Detection of collision

Developers in Scotland and Wales are in the process of assessing the effectiveness of systems of physical collision detection (accelerometers and strain gauges on turbine rotors) for detecting collisions with marine mammals. A recent presentation of preliminary results given at the Environmental Interactions of Marine Renewable Energy Technologies (EIMR) conference in Stornoway in May 2014 suggested that the signals of marine mammal collision would be impossible to detect given the noise of such systems. The ability to detect collisions through physical monitoring of the turbines remains uncertain. There is a need to publically scrutinise such data in the form of a peer-reviewed report. Discussions are underway between various research groups and the ORE Catapult about the possibility of funding a coordinated study into this issue.

In addition the Scottish Government Demonstration project is evaluating the use of video surveillance to detect collisions under conditions of good visibility (see Section 4.2.1 Tidal-OREG).

4.2.1.3 Mitigation

Marine Current Turbines' (MCT) SeaGen tidal turbine in Strangford Lough continues to operate under a shutdown mitigation rule. Although a licence has been secured from The Department of Environment Northern Ireland's Marine Division to allow a short trial of unmitigated operation, alongside associated near field monitoring of seals around the rotors, this has not yet progressed due to an extended operation and maintenance period being carried out by MCT.

It may be desirable to establish whether collision risk is a real concern for UK marine mammal populations before investing too much in the development and investigation of alternative mitigation strategies. Alerting marine mammals to help them detect and avoid structures such as tidal turbines could reduce collision risk if such a collision risk is identified. However, given the current uncertainty hampering consenting of tidal projects in the UK, it may be necessary to include mitigation measures in adaptive management approaches before information on the nature of collision risk becomes available. In addition, should it become apparent through the deploy and monitor approach, that collision risk is a real issue, a solution will need to be found rapidly in order to not risk the continuing development of the tidal energy industry, therefore it is important that mitigation solutions continue to be explored.

Permanent acoustic alarms would be undesirable but it should be possible to develop detect and deter systems incorporating the same kinds of technologies being developed for monitoring the fine scale behaviour of marine mammals around tidal devices.

Wilson & Carter (2013) concluded that sophisticated acoustic warning devices would be useful to help mitigate a collision issue should one prove to exist. They also described seven attributes that such a warning system should have. These were that: (1) the signal must elicit an appropriate response (2) emission rates must suit approach velocities (3) emission frequencies must be audible for target species (4) amplitudes must be appropriate for detection ranges and sites (5) signals must be directionally resolvable (6) the warning should be co-ordinated with the threat and (7) the location of the sound sources at a turbine or within an array must facilitate appropriate spatial responses. Given the variability of animal responses, the complexity of acoustics in tidal environments and the range of different sites and turbine technologies under consideration, the authors wish to underline the complexities of finding a system which meets all the necessary criteria.

4.2.1.4 Individual consequences of collision

There remains little evidence of the likely consequences of a collision between any marine mammal species and a turbine blade. It is unlikely that all collisions will be fatal, although all management approaches currently make this assumption.

Thompson *et al*., (2013a) reported on the computer simulation, impact damage model developed to assess the likely consequences of the impact of a specific tidal turbine blade on a killer whale (US Department of Energy 2012). There are plans to extend this work, starting in October 2014, to cover a number of UK species and other turbine designs. This work is expected to report late in 2015.

Thompson *et al.*, (2013a) highlighted that research was planned using carcass experiments, to gather information on the levels of and types of injury inflicted by collisions at different rotation speeds to assess the likelihood of serious injury. The same information is required to interpret damage observed on stranded and by-caught carcasses. Trials with turbine blade tips are expected to be completed in October 2014 and reported in early 2015.

4.2.2 Shipping

Until recently ship strikes were not considered to be an important issue for phocid seals. However, recent events in UK waters suggest that seals may be killed in substantial numbers by collision with ships (Bexton *et al.*, 2012).There is a need to understand the nature of collisions and to suggest mitigation measures. This is the focus of current Unexplained Seal Deaths Tasks under the MMSS/001/11 Research Project being carried out by SMRU: Section 6. Progress has been made on this issue since Thompson *et al.*, (2013a). Research has identified ducted propellers as the mechanism by a series of investigations using scale models of seals and ducted propellers. Collisions with curved bladed propellers in a kort nozzle produced damage remarkably similar to the injuries observed in seals. Acoustic play back experiments with both wild and captive seals have so far not provided any evidence to suggest that acoustic attraction has been a factor in seals sustaining these injuries. Cases continue to be reported around Scotland and these cases continue to be monitored by SMRU in collaboration with the Scottish Marine Animal Stranding Scheme (SMASS). SMRU continues to monitor AIS data to identify the movement of vessels in areas where cases are known to occur.

Additional Research gap				
Title	**Code**	**Details**	**Current Status**	**Reporting date**
Models of Individual Movement		There is a need for spatially explicit and biologically informed models of individual movement and behaviour which can incorporate the residence time of individual animals within zones of risk and be used to inform simulation based approaches to assessing risk. Such an approach should be scalable and transferrable so that it may be used to assess a wide range of OREG related impacts.	Currently unfunded	N/A
Reassessing collision risk at a range of tidal sites using observed behaviour patterns derived from targeted telemetry tracking studies and recent population survey data		This has been carried out using data from telemetry deployments on harbour seals in the Pentland Firth study area in 2011. This work estimated the number of times that telemetry tagged seals passed through the area of the proposed turbine array, and incorporated dive depth data and population estimates to estimate the total number of times seals would have passed through the swept area of individual turbines in a hypothetical turbine array within the site. This method can be applied at a number of other sites, including the Sound of Islay.	Funded by Marine Scotland	Due to report in early 2015
Acoustic Deterrents as mitigation for collision		There is need to investigate the suitability of various deterrent s for the mitigation of collisions. A proposal has been submitted to the ORE Catapult on this topic.	Funding under consideration with the ORE Catapult.	

4.2.3 Entanglement

A review of entanglement risk to marine megafauna from marine renewable energy (MRE) developments was recently published by SNH (Benjamins *et al*., 2014). This review concluded that moorings such as those proposed for renewable energy devices will likely pose a relatively modest risk in terms of entanglement for most marine megafauna, particularly when compared to risk posed by fisheries. Nevertheless, some circumstances were identified where moorings associated with MRE devices could potentially pose a risk, particularly, 1) in cases involving large baleen whales and, 2) if derelict fishing gears become attached to the mooring, thereby posing an entanglement risk for a wide range of species (including fish and diving seabirds). Most moorings associated with renewable energy devices would likely be too strong for animals to easily break free if they became entangled. Entanglement risks among arrays will likely vary substantially based on device spacing, mooring design and array layout.

4.2.4 Exclusion and barrier effects

No new insights into the effect of device installation or operation have become available since the previous report. Analysis of the EMEC wildlife observer data in relation to device operations is still ongoing and will report in early 2016.

4.3 Electric fields

No new insights into the effect of electric fields on marine mammals have become available since the previous report. An EU funded project on the effects of vibration, electromagnetic emissions and noise (MaRVEN) led by Andrew Gill at Cranfield University which started in summer 2014 and will include a review of the environmental effects of these stressors.

5 Consequences of Impacts

Section 6.1 of the previous report considered the possible cascade of effects – from individual impacts to vital parameters. Below, in Section 6, we provide an update on research in this area.

Section 5.2 provides an update on work carried out on modelling frameworks that can use such information to predict population level consequences and highlights the defined research gaps resulting from such work.

5.1 Individual

5.1.1 Noise

5.1.1.1 Evidence for individual consequences – effects on survival and reproduction

The direct consequences of exposure to noise (mediated both through auditory injury and behavioural disturbance) on individuals in terms of their likelihood to reproduce or survive remains a key research gap. In the absence of empirical data on these key relationships, the Interim Framework for the Population Consequences of Disturbance (PCOD), recently published by MS (Harwood *et al.* 2014) used a process of formal expert elicitation to parameterise these relationships and incorporates them into a stochastic model of the population's dynamics. Experts were asked their opinions on the effects of PTS and disturbance on the survival of calves and juveniles and on the fecundity of adult females. The statistical approach used to estimate the parameters of the relationships from the expert elicitation results is described in detail in Donovan *et al.,* (in press). It is clear that for such an approach to be useful in the long term, these key parameters need to be replaced by empirical information as this becomes available. A paper outlining the model is also currently under review in Methods in Ecology and Evolution (King *et al.,* in review).

Research on captive harbour porpoises (Kastelein *et al.*, 2014) has demonstrated that TTS induced in animals exposed to low frequency (~1.5 kHz) sonar was largely at the same frequency as the fatiguing noise, there was no effect on the higher frequency hearing used for echolocation, therefore auditory injury as a result of exposure to low frequency noise may not have any effect on the foraging abilities of harbour porpoises. Similar experiments have also been carried out using piling noise, but these have yet to be published.

Nabe-Nielson *et al.,* (2013) used individual based animal movement models linked to energetics to predict the individual level consequences of disturbance and found that the effects of operational wind farms and ships are sensitive to variations in mortality resulting from bycatch and the speed at which food recovers after being depleted. This approach is being extended to explore the potential effect of North Sea offshore wind farm construction as part of the DEPONS[2] project, led by Aarhus University.

[2] http://depons.au.dk/

Similar models could be developed for UK marine mammal populations, existing data on the energetic consequences of behaviour and reproduction, food consumption, habitat preference and foraging and movement patterns could be used to simulate how responses may influence individual survival and reproduction. However there would still be reliance on data on individual responses to noise to parameterise the models.

Monitoring planned for the Moray Firth throughout and beyond the construction period of offshore wind farms may provide empirical data to address these gaps if individual harbour seal tracking studies can be linked to the survival and breeding success of known individuals. In addition long term monitoring of bottlenose dolphin fecundity and survival rates in the Moray Firth throughout and beyond periods of construction will allow comparisons to be made to baseline preconstruction values. These studies will provide valuable information on the potential for changes in demographic parameters as a result of exposure to piling noise, a key issue in the consenting process for offshore wind farm development.

As discussed in Section 4.1.1.1, if a reliable field method can be developed to routinely carry out measurements of hearing thresholds in wild seals then additional progress in this area becomes possible. As well as building up an understanding of the variability in hearing sensitivity in wild populations, and linking individual hearing ability to foraging behaviour and individual responses through tagging studies, it might be possible to link changes in hearing sensitivity to variation in condition and breeding success with properly designed longitudinal studies. It would be possible to carry out measurements at breeding colonies for both harbour seals (in the Moray Firth) and on grey seals (Isle of May) on individuals with known breeding histories. Baseline measurements could be taken now and then repeat measures of hearing abilities could be carried out longitudinally. However significant development would be required before this could happen.

5.1.2 Physical contact

Further work on collision outcomes are being carried out by SMRU with support from MS and SNH.

5.1.3 Disturbance effects

A Marine Alliance for Science and Technology for Scotland (MASTS) funded PhD study at SMRU that started in October 2013 is addressing some of the energetic issues and costs associated with disturbance in harbour seals. Captive trials aimed at understanding the energetic consequences of disturbance are ongoing and field trials have been completed in summer 2014 to understand the nature and consequences of disturbance at seal haul-out sites.

5.2 Population

5.2.1 Extrapolating to population level effects

5.2.1.1 PCOD/PCAD

The recent development of PCOD (Population Consequences of Disturbance) models or a subset of PCOD referred to as Population Consequences of Acoustic Disturbance (PCAD) dealing specifically with acoustic disturbance effects is an attempt to use whatever information is available in a formal model framework to estimate population consequences. Such models may incorporate both state-space and individual-based approaches. They also incorporate dose-response functions of potential OREG stressors.

Formal sensitivity analyses have not yet been carried out using the tool to prioritise the list of research needs provided in Harwood & King (2012), although analysis presented in the report suggests a number of key uncertainties, particularly that more precise data on individual animal movement and the spatial structure of the population would reduce uncertainty in forecasts. The list of ten critical sets of information from Harwood & King (2012) was presented in the previous report. These questions have been developed into a number of specific studies that have formed the draft scope of works for a potential ORJIP funded project. Although this list of studies have not been taken forward by the

ORJIP group, this scope attempts to identify the data and evidence that would need to be collected to enable the gradual transfer of reliance for consent decisions from qualitative expert judgements (the interim PCOD approach) to an approach that is based on more reliable, quantitative and evidence based data. The following research projects were identified:

A. **Additional analysis of data collected under the Joint Cetacean Protocol (JCP)**

A.1. Provide estimates of absolute density and abundance of cetaceans species in UK waters.

A.2. Identify areas of potential attractiveness ("hotspots") for harbour porpoise, bottlenose dolphin and minke whale around the UK.

A.3. Provide regular updates of estimates of cetacean density in UK waters.

B. Estimate the sound levels likely to result in a "significant" behavioural response from bottlenose dolphins, grey seals and harbour seals

B.1 Conduct telemetry studies of the response of bottlenose dolphins to pulsed noise.

B.2 Conduct a study of the responses of grey seals to pulsed noise using acoustic dosimeter tags.

B.3 Conduct a study of the responses of harbour seals to pulsed noise using acoustic dosimeter tags.

C. Develop mathematical models of the movement of individual marine mammals over periods of days and weeks

C1. Develop mathematical models of the movement of individual bottlenose dolphins in UK waters over periods of days and weeks.

C.2. Develop mathematical models of the movements of individual grey seals over periods of days and weeks.

C.3 Develop mathematical models of the movements of individual harbour seals over periods of days and weeks.

D. Develop mathematical models of the energetic and demographic consequences for marine mammals of the behavioural changes they may show in response to pulsed sounds

D.1 Develop a mathematical model of the energetic and demographic consequences for bottlenose dolphins of the behavioural changes that may occur in response to pulsed sounds.

D.2 Develop a model of the energetic and demographic consequences for grey seals of the behavioural changes that may occur in response to pulsed sounds.

D.3 Develop a model of the energetic and demographic consequences for harbour seals of the behavioural changes that may occur in response to pulsed sounds.

E. Development of the full PCOD framework

In addition to the requirement for specific research projects to inform the full PCOD framework, there is a need for long-term monitoring of the health of marine mammal populations that may be affected by offshore renewables developments. In the case of harbour porpoises, grey seals and harbour seals this could probably be incorporated into existing monitoring programmes that are at least part-funded by Defra, NERC, MS and SNH. However, new projects are probably required for North Sea and Irish Sea bottlenose dolphins. These are described below.

E.1 Develop and implement a research programme to monitor changes over the next decade in those population characteristics of bottlenose dolphins in the North Sea that are most likely to be affected by disturbance associated with offshore renewables development.

E.2 Develop and implement a research programme to monitor changes over the next decade in those population characteristics of bottlenose dolphins in the Irish Sea that are most likely to be affected by disturbance associated with offshore renewables development.

5.2.2 Marine mammal conservation targets

JNCC has funded SMRU to further develop the Catch Limit Algorithm for application to UK small cetacean and seal populations. The approach has its roots in the International Whaling Commission (IWC) revised management procedure (ultimately to set whale quotas) and was developed during SCANS-II to set ‘safe limits’ to bycatch. Work is being carried out to extend the approach to seals and to make the models spatially explicit to try and inform decisions on management units given the scarcity of population structure & movement data. This work is due to report in spring 2015.

6 Research Gaps - update

6.1 Marine mammals

Table 1. Explicit updates on the Research Gaps identified in the previous report.

Title	Code	Details	Status	Sept 2014 update – findings to date and updated reporting timeline
Determine factors affecting UK grey and harbour seal habitat preference.	HAB	Using grey and harbour seal telemetry data, habitat preference will be assessed using a case-control strategy (Aarts, MacKenzie *et al.* 2008). Abiotic variables (e.g. depth, sediment type) will be used as candidate covariates.	Funded (MS-MR5) & DECC)	**<u>Habitat analysis</u>** This work is being carried out under subtask MR5 is developing and utilising models to characterise the environments that grey and harbour seals prefer. The modelling software has been written and is at initial testing stage. It will be used to model preference using both 'all track data' (i.e. those used in the Seal Usage Maps previously published) , and also those track data classified as foraging as determined by state-space modelling above. The environmental data (e.g. depth, sediment type and tide driven current parameters) required by the model have been collated.
Map distribution and activity of UK seals.	ACT	The behaviour of historical grey and harbour seals telemetry data will be classified into three states: resting (hauled-out or at the surface), travelling and foraging. To define these states we will develop existing state-space models that are based on track speed and tortuosity (McClintock, King *et al.* 2012). The results will be used: 1. to generate usage maps distinguishing between foraging and travelling 2. to investigate changes in activity budgets resulting from at-sea developments 3. to identify core foraging areas.	Funded by MS & DECC	**<u>Modelling and mapping seal behaviour</u>** This work is also being carried out under MR5 and has attracted additional funding from the Department of Energy and Climate Change (DECC). All the grey and harbour seal track data have been classified into 'resting', 'travelling' and 'foraging' states. An analysis based on six-hour time periods has been completed and a paper is currently in review in Oikos, expected publication late 2014. Future work will entail the subtraction of tidal current vectors to allow those populations in high current areas to be similarly analysed. Initial maps showing the areas used by behaviour type have been produced. Work is ongoing to refine these maps and to make iterative improvements to the state-space modelling framework. This work will be reported on in February 2015.
Haulout connectivity of grey and harbour seals.	HCON	The network of movements between haul-out sites will be mapped using grey and harbour seal telemetry data. We will generate a transition matrix, illustrating the probability of an animal originating from	Funded (MS – MR7 & SNH)	Work funded under the MR7 subtask (**<u>quantifying the risk to marine mammal populations from renewable devices</u>**) is ongoing on this issue – part of this work has been published (Russell *et al.*, 2013) – this work demonstrated that although many female grey seals haul-out during foraging periods in the same region that they

		each haul-out moving to another haul-out or remaining at the haulout of origin. We will use telemetry data to parameterise these transition matrices. Uncertainty resulting from population size and number of animals tagged will result in confidence intervals surrounding these transition probabilities.		breed, a large number of seals transition between different regions between foraging periods and the breeding Season, This has implications for considering the impact of marine and offshore developments on protected areas which are designated for their breeding populations. This work also found that haul-out based population estimates are a reliable proxy for foraging population in a given area. Software has been developed that automates the process of determining the specific, discrete sites where seals haul-out. The rate of interchange between sites is determined using a model that incorporates both the duration of haul-outs and the inter-haul-out intervals. A transition matrix has been calculated for harbour seals in the Sound of Islay. This work will report by February 2015.
Review the utility of Joint Cetacean Protocol (JCP)	JCP	1. Monitor and report on developments under the JCP and in particular where the tools being developed under the JCP analyses to address Favourable Conservation Status at the population level, are also developed in respect of the concerns at the smaller spatial scales of marine renewable development. 2. Monitor and report on the development of methods to combine existing acoustic and sightings data to best detect population level trends. 3. Explore ways to generate probability of encounter estimates for specific OREG sites, and thus consider ways to define the "natural range" of cetacean species based on measures used for other species groups. 4. Explore ways to define optimal temporal and spatial scales at which cetacean density should best be examined in order to detect changes in density or distribution that are both statistically and biologically significant. 5. Examine existing baseline survey data,	Funded by MS MR6	Work is ongoing on this task as part of subtask MR6 – **characterising cetacean population distribution and abundance.** A synthesis of advantages and drawbacks of JCP methodology has been provided to MS. A short discussion paper on how best to define range is currently under preparation and will be available by February 2015.

		in order to assess how useful it is for determining changes in cetacean density or distribution and thereby to help refine data collection protocols to ensure that monitoring is fit for purpose.		
Estimation of harbour porpoise abundance from TPOD/CPOD click detections	PTID1	Convert TPOD/CPOD output (click-positive minutes) to an index of actual harbour porpoise density.	\unfunded but similar outcomes being developed under the SAMBAH project[3]	Abundance estimates with associated uncertainty shave been produced for the Baltic Sea Harbour porpoise population.
Harbour porpoise behaviour in tidal rapids	PTID2	Use drifting array hydrophone systems to detect and track the behaviour of vocalising harbour porpoises in the vicinity of tidal rapids associated with future tidal-OREG.	Funded by MS MR7 & NERC MREKE	This work is ongoing as part of subtask MR7. Work under this task continues to develop the tools for monitoring porpoise movements under water. Fieldwork has been carried out using a vertical hydrophone array off the coast of Islay in July 2013; measurements were carried out in the Corryvreckan/Great Race, the Sound of Jura and the Sound of Islay. Localisation accuracy of harbour porpoise clicks is sub-metre. While most detections were in the top 40 m of the water column, a number of animals were also making a significant number of very deep dives (to 150m in some cases) which were likely to the sea bed. These findings will inform collision risk and habitat use models. Visual records collected during the acoustic data collection will allow the cross referencing of behaviour to provide a greater insight into porpoise use in the tidal areas. Data has been collected in three highly tidal areas: Orkney, Sound of Islay and Corryvreckan/Great Race. Porpoise behaviours in these areas show a number of differences and similarities which makes it difficult to draw general conclusions about the use of tidal areas by porpoises. Additional data has very recently been collected in the Sound of Sleat and Kyle Rhea.

[3] http://www.sambah.org/

				This work will be report on in February 2015. Open source software has been created to make the detection, classification and localisation algorithms, including the development of real time tracking, readily available. Currently underway is the development of a method which converts discrete localisations into tracks – providing a more robust basis for analysis of depth distribution and potential collision risk. A concurrent NERC knowledge exchange grant is allowing development of a hardware package based on the technology developed under this task.
Do harbour seals exhibit auditory permanent threshold shift in the presence of piling activity?	DECC1	Audiograms for all harbour seals captured as part of DECC2 will be obtained using standard auditory evoked potential measurements during capture events (Wolski, Anderson *et al.* 2003). These will be used to: 1. Identify the hearing thresholds of individual seals to assess the sensation level at which reactions occur. 2· Assess the variability of audiograms within the sample of telemetry tagged harbour seals. 3· Identify evidence of hearing damage that may be attributable to exposure to piling noise.	Funded by DECC	Analysis is complete and is currently being prepared for submission.
Harbour seals' behavioural responses to the presence of piling activity.	DECC2	25 harbour seals will be fitted with GPS/GSM tags in the vicinity of piling operations in the Wash in February 2012. These data will permit: 1. Parameterising the dose-response of piling activity (source energy, range, received and perceived energy) to changes in behaviour (e.g. movement and dive patterns). 2. Assessment of change in at-sea usage, comparing pre- and during- pilling operations.	Funded by DECC	As part of the work, an analysis of the estimated level of cumulative sound exposure of tagged harbour seals during piling events has been carried out and the resulting levels of hearing damage estimated (Hastie, *et al.,* 2015) This study found that, based on published injury criteria, around half of tagged seals received sound levels from pile driving sufficient to cause auditory damage.

Harbour seals behavioural responses to the presence of piling activity.	DECC3	New data from tagged harbour seals in the Wash (see DECC2) and Thames will be compared with historic data and periods of non-operation within the current study to assess dose-response of movement and behaviour in relation to wind farm operation.	Funded by DECC	Comparisons suggest no large scale changes in seal movements and distribution between historical data and collected during offshore wind farm construction and operation. Analysis of the tracks of seals overlapping with operational windfarm highlighted that some seals were concentrating foraging effort around the turbines (Russell *et al*., 2014).
Acoustic deterrence for mitigation of pile driving activities	AcMit	1. Identify potential mitigation signals. 2. Conduct behavioural response trials with telemetry tagged seals. 3. Conduct behavioural response trials with harbour porpoises using 3D passive acoustic array and visual observations.	Seal trials Funded by MS MR8 Harbour porpoise trials not funded	Work has been carried out under subtask MR8 **<u>Identify and test feasible management and mitigation measures</u>**. A series of Controlled Exposure Experiments (CEE) were carried out with ten harbour seals fitted with high resolution GPS tags in Kylerhea in Summer 2013 to test the efficacy of two sound sources in deterring seals: a Lofitech Seal Scarer and playback of killer whale vocalisations. Initial analysis suggests that seals demonstrated aversive responses to the Lofitech ADD signals in all trials at initial ranges of 1km or less. Preliminary examinations of dive behaviour data suggest some difference in swimming speed which may also represent avoidance behaviour. Similar aversive responses were detected in some CEE trials with recordings of *Orca* calls. Responses were more variable, but one seal exhibited an aversive response at more than 1.2km range. Additional trials were carried out in the Moray Firth in summer 2014 but these data have not yet been analysed. This work will be reported in February 2014. Harbour porpoise exposure experiments have not yet been funded. Effort is being made to align this work with the ORJIP phase 2 project on the same subject.
Unexplained seals deaths	USD	1. Testing the hypothetical link between shipping and unexplained seal deaths through a series of controlled tests of candidate mechanisms using model testing and full scale carcass tests with candidate mechanisms. 2. Testing the hypothetical reasons for lethal interactions through a series of behavioural response trials using both captive and wild grey and harbour seals	Funded by MS USD2-5	Work continues on this issue under subtask USD 2-6. **<u>USD 2: Testing the hypothetical link between shipping and unexplained seal deaths.</u>** In collaboration with propeller engineers at VOITH Turbo different sized seal models have been tested with engineering scale models of four types of propeller. Collisions with the curved bladed propeller in a Kort nozzle produced single, helical damage that penetrated and peeled off a wax layer. Damage was similar to the injuries observed

		3. Examining the distribution of observed carcasses to identify biological and oceanographic patterns and distribution of potential causes to assess the patterns of risk associated with these unexplained seal deaths. 4. Assessing the impact of the observed and estimated levels of mortality on seal populations at a local, national and international level. 5. Identify and evaluate practical management and mitigation measures that could be developed in the short, medium and long term.		in seals exhibiting spiral injuries. Other propellers produced a range of cuts and indentations, many of which were equivalent to severe injuries, but not the typical spiral damage. A report on the scale model trials, entitled "*Testing the hypothetical link between shipping and unexplained seal deaths",* is now published on the SMRU website . **<u>USD 3 Testing the hypothetical reasons for inappropriate responses to the candidate mechanisms identified above.</u>** Work under this task has concentrated on testing whether seals are attracted to the acoustic signatures of vessels operating ducted propellers. A series of acoustic playback experiments were carried out at the captive facility at SMRU with both grey (7 juveniles) and harbour seals ((1 adult) and in the wild with harbour seals, near haul-out sites in the Sound of Sleat. Playbacks were carried out in blocks of four sounds: 1) a ducted propeller, 2) a conspecific call, 3) a sine wave, 4) no sound (2, 3 and 4 were included as controls). Each sound block lasted 20 minutes. The effectiveness of the work was severely impacted by problems with the playback system, but to date there have been no clear responses by seals to the playback signals. Work is ongoing, with a modified playback system. Captive animal trials are underway and wild animal trials have been carried out, but are yet to be analysed. USD 4: Cases of dead seals with spiral cuts continue to be reported around Scotland, with 8 grey and 7 harbour seals in 2013. SMRU continues to monitor these cases in collaboration with the Scottish Marine Animal Stranding Scheme (SMASS). The striking differences in the spatial and temporal pattern of strandings of grey and harbour seals in SE Scotland have continued. SMRU continues to monitor AIS (Automatic Identification System) data, supplemented where necessary by local radar information, to identify the movement of vessels in the area. USD 5 – A meeting is planned to take place between the Scottish Government and the Shipping and Ports industry on 13 November 2014. This meeting would provide an opportunity to present the current research findings

				and discuss the practicalities of potential mitigation measures with the aim of moving forward in addressing the issue of seal mortality in close partnership with the shipping industry.
Investigation of responses of marine mammals to playback of turbine noise	PLAY	1 .Use high resolution telemetry and active sonar to track free ranging seals and observe responses during controlled exposure to turbine noise. 2. Monitor the behavioural responses of captive seals to controlled exposure to turbine noise. 3. Use high resolution passive 3D acoustic array to track free ranging porpoises and observe responses during controlled exposure to turbine noise.	Funded by NERC RESPONSE	Playback trials with both captive and wild animals have been completed and results are currently being analysed and written up for publication. Harbour porpoise field playback experiments are currently underway at Scarba, although using CPODs instead of 3D hydrophone arrays.
Collision damage assessment	COLL	A series of collision damage assessment trials with carcasses of seals and/or other species when available using a purpose built test rig. A section of turbine blade will be dropped onto seal carcasses at a range of speeds. The seal carcasses will be positioned just below the surface of a 2.5m deep pool so that the speed of impact is known and the carcass is coupled to the water and will therefore resist the impact in the same way as a free swimming seal. Carcasses will then be examined both visually and by x-ray/ultrasound to assess damage.	Funded by SNH	Trials are currently underway and due to report at the end of 2014.
Analysis of visual observation data	VisOb	A detailed analysis of the long term data set from the EMEC visual observation programme should be carried out to assess the likelihood of being able to detect changes in distribution or fine scale habitat use in the vicinity of turbines	Part Funded by SNH	Ongoing – no update available
Effects of disturbance on hypothalamic	DIS	Repeated disturbance of animals (seals from haul-out sites for example) may have impacts on their ability to respond normally to novel stressors (through	MASTS	The energetic consequences of disturbance and field trials on the consequences of disturbance are being carried out as part of this PhD project. The role of the HPA axis in disturbance has not yet been included.

pituitary adrenal axis.		adrenal fatigue). Before that stage is reached it is important to understand how the HPA responds to disturbance. A PhD study just starting will investigate the energetic costs of disturbance and additional research into the effects on the HPA by monitoring hormone and protein markers in excreta could be included.		
UK Marine mammal conservation targets.	MMCT	Consideration of the cumulative effects of multiple impacts on neighbouring and connected populations is complicated. The IWC has a well-developed simulation framework for examining this. Work is currently being funded by JNCC to look at how similar methods could be applied to sub-populations of seals and small cetaceans within European waters.	Funded by JNCC	JNCC has funded SMRU to further develop the Catch Limit Algorithm. The approach has its roots in the IWC revised management procedure (ultimately to set whale quotas) and was developed during SCANS-II to set 'safe limits' to bycatch. Work is being carried out to extend the approach to seals and to make the models spatially explicit to try and inform decisions on management units given the scarcity of population structure & movement data. Due to report in Spring 2015.

Table 2. Table showing unfunded/partially funded research gaps.

Unfunded/partially funded Research gaps				
Title	**Code**	**Details**	**Priority**	
Telemetry studies targeted on specific areas to improve map confidence intervals.	TAG	In light of results of current telemetry studies (4.1.1.4) and results of MR5, targeted deployments on particular species and regions will improve confidence intervals on at sea distribution maps.	MEDIUM	A funding application is being developed to carry out further tag deployments on grey seals in southern North Sea in relation to offshore wind farm development.
Behaviour of grey seal adults in relation to high current regimes in the Pentland Firth.	HCR	There will be significant tidal-OREG development in the Pentland Firth. There is a lack of adult grey seal movement and dive behaviour data in this region – especially in relation to areas of high current flows. GPS/GSM tags will be deployed in this region to address this data gap.	MEDIUM	No Progress
Fine scale marine mammal behaviour in the vicinity of a working tidal array.	ARRY	1. Building on the recommendations of the MS project, Hastie (2009) and Hastie (2012), suggest active sonar systems that would be appropriate for trialling at the Sound of Islay. 2. Consider the capability of developing Passive Acoustic Monitoring (PAM) systems to track vocalising cetaceans around tidal turbines. Develop and test systems for possible trials in the Sound of Islay, taking account of the use of acoustic tags for seals. 3. Evaluate the ability of the above, or other, technologies to monitor potential actual impact detection. 4. Trial the feasibility of these technologies for direct observation of marine mammal movements at the Sound of Islay.	HIGH	The Scottish Government has recently funded a project to develop and trial methods for the fine scale detection and tracking of marine mammals around tidal energy devices. This project started in June 2014 and runs until the end of 2015. The aim is for the methods developed under this funding will be deployed as part of the monitoring strategy for the first operating commercial turbines in Scottish Waters. Funding is likely to be available as part of a further contract to SMRU to enable this deployment and allow analysis of the resulting data. Tidal Energy Ltd are about to deploy their DeltaStream turbine in Ramsey Sound in Wales. Fine scale behaviour of seals and echolocating cetaceans will be closely monitored during operation with a combination of passive and

				active acoustic monitoring. In addition TEL will be collecting data to assess whether physical strikes are likely to be detectable using sensing mechanisms built into the turbine blades. Research into the physical detection of collision remains unfunded although discussions are underway between various research groups and the ORE Catapult for a project addressing this issue.
Avoidance and evasion behaviour by marine mammals in close proximity to tidal turbines.	AVOID	1 Using high resolution telemetry to observe the behaviour of seals in close proximity to marine renewable devices, concentrating on tidal turbines. 2 Using high resolution 3D hydrophone arrays to monitor porpoise behaviour in close proximity to marine renewable devices, concentrating on tidal turbines. 3 Using high resolution 3D hydrophone arrays and ultra-sonic pinger tags to monitor seal behaviour in close proximity to tidal turbines.	HIGH	The above Scottish Government funded project and developer led studies will also address this issue.
Assessment of mechanical sensing of impact with tidal turbine blades.	MECH	In cooperation with the Operator a turbine device will be instrumentation with appropriate strain and accelerometer sensors. A series of carcasses (resembling the size and mass of a seal or porpoise) will be presented to the rotating blades to determine whether the turbine sensors provide sufficient data to enable automated strike detection.	MEDIUM	Research into the physical detection of collision remains unfunded although discussions are underway between various research groups and the ORE Catapult for a project addressing this issue.
Marine mammal responses to artificial lights	LIGHT	Investigate responses to different light sources to identify possible illumination for night-time video surveillance.	LOW	This priority has been downgraded to LOW - no progress or update available
Fine scale habitat use by porpoises in tidal rapids	EDDIE	Combinations of drifting arrays and static 3D arrays may be used to monitor fine scale movements of porpoises within tidal rapids to investigate their use of small scale and/or transient eddies.	HIGH	This objective has been partly addressed through the work involved in the development of the technology to enable data collection (under PTID2, above). Further funding is required to fully analyse the data collected and collect data at a range of sites.

Electrical sensitivity of small cetaceans	ELECT	A series of carefully controlled tests of sensitivity of small cetaceans (porpoises and bottlenose dolphins in the first instance) to electric fields similar to those generated by OREG devices and export cables. These will necessarily be carried out in captive animal facilities. As there are no captive cetaceans in the UK such studies will require an international collaboration.	MEDIUM	No trials have been carried out to our knowledge.
Auditory brain stem responses in pups of females exposed to OREG construction and operation noise	ABRPuP	There is some evidence from studies in mice, sheep and humans that foetuses exposed to noise during gestation might be at risk of some hearing loss. This effect could be investigated in seal pups (using ABR response measures) from females exposed to OREG noise.	MEDIUM	Remains unfunded
Ototoxic effects of PCB exposure in seals	PCB	Previous studies have shown that harbour seals in some areas have high levels of PCBs in their blubber. PCBs have the potential to cause cochlear damage during development. Further work on hearing loss in these animals in relation to their age and PCB exposure levels would determine if they have pre-existing damage caused by these pollutants.	LOW	Remains unfunded
Hormone and protein markers in marine mammals in relation to noise exposure	HORM	Establishment of hormone and protein markers and noise associated dose-response relationships for the key marine mammal species found in Scottish waters. Captive studies in harbour and grey seals could determine the variability in a range of potential markers in blood, faeces, urine and skin samples taken from animals exposed to various sound sources and levels.	MEDIUM	Remains unfunded

6.2 Co-ordination of monitoring at marine renewables sites

To date there has been very little coordination of the pre-consenting studies made at different marine renewable sites. Each site developer has a responsibility to produce evidence to support their application for permitting and their licence conditions usually include some form of pre and post deployment monitoring. The link between the monitoring requirement and the methods employed may not always be clear and in some circumstances the likelihood of the resulting data being useful for detecting even quite major effects may be low. To some extent this restriction can be alleviated and statistical power can be increased by combining data from a number of sites, covering larger areas and longer time periods. Unfortunately the methods used even in adjacent sites can differ significantly making it difficult to combine data sets. MS commissioned a review of the Marine Monitoring Network in Scottish waters, which was completed in 2012. The Marine Management Organisation (Marine Management Organisation, 2014) commissioned a strategic review of offshore wind farm monitoring data associated with Food and Environment Protection Act (FEPA) licence conditions with the aim of summarising the monitoring undertaken at each site. They compared the monitoring and licence conditions between sites to distinguish between generic and site specific issues, and assessed the comparability of datasets. The eventual goal was to determine which conditions could potentially be removed or amended and to determine whether such data could be used to forecast implications of identified effects for future offshore wind farm development.

The study reviewed all natural environmental aspects of the monitoring reports including benthos, fisheries, sediment processes, noise, birds and marine mammals. There were very few examples of post consent marine mammal monitoring at UK Round 1 and Round 2 wind farms. The review suggested that EIA predictions made based on noise modelling, should be validated by on-site noise measurements during construction. Behavioural displacement can to some extent be predicted beforehand and then validated during monitoring before, during and after construction if uncertainty remains about the potential for disturbance, this has only currently been measured directly in harbour porpoise at several European offshore wind farms and at Robin Rigg Offshore Wind Farm in the UK, and in a sample of tagged harbour seals in association with piling at the Lincs windfarm. The practical investigation of the population consequences of these impacts are not likely to be within the scope of individual development Post Consent Monitoring (PCM) programmes. Given the large spatial scales over which marine mammal populations generally range, the report concluded that there are limits to what can be achieved through post consent monitoring programmes on a site-specific basis. Marine mammal density and abundance is likely to be highly variable over baseline conditions over the scale of a monitoring area that includes the wind farm site plus zone of potential impact and the power to detect change and attribute it to activities associated with the development will almost certainly be too low. The ability to link cause and effect to detect change using ‘traditional’ monthly visual methods (whether air or boat based) may then be too low. The report also concluded that it will be virtually impossible to determine population level changes as a result of activities on a particular site (even on large sites), or to determine cumulative effects of neighbouring sites. In those cases, a more regional and co-operative approach to monitoring across a number of sites may be the most appropriate approach. Monitoring is likely to focus on linking individual responses to demographic parameters.

The authors identified some general recommendations across the sector for future monitoring and concluded that clearer objectives within licence conditions are essential to ensure clear and realistic links between required work programmes and specific questions. They also highlighted the importance of combining datasets to utilise all available data and identified a need to develop an appropriate analytical framework. The study recommended that regional monitoring programmes should be encouraged wherever possible, particularly where several wind farms are being developed in close proximity. It was acknowledged that there were difficulties inherent in this approach surrounding fair splitting of costs, timing of monitoring to align with varying project timescales and competitiveness between developers. These issues may prevent the successful co-operation of wind farm developers. These difficulties need to be recognised at the outset of planning monitoring programmes such that problems that might affect the success of programmes are minimised.

All recent wind farm licences issued in Scotland require that developers work together in regional groups to facilitate this approach to monitoring and reducing uncertainty in impacts.

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8 Appendices - Related OREG working and other groups

A number of national and international bodies are involved in setting research priorities and directing funding for environmental aspects of marine renewable energy developments. In addition, there are research working groups and research consortia at both national and international levels. The roles and membership of these bodies tend to overlap substantially. The following list is divided into three sections, first organisations with a remit to investigate and/or provide management advice on interactions between marine mammals and OREG developments; second a list of OREG test centres with potential for investigating some aspects of marine mammal interactions and finally a list of recent and on-going funding programmes incorporating some aspect of the environmental aspects of OREG developments.

8.1 Working groups

8.1.1 UK

8.1.1.1 *The Scottish Marine Renewables Research Group (SMRRG)*

SMMRG was formed in response to a Strategic Environmental Assessment (SEA) for wet renewables which examined marine zones with potential to tidal and wave energy development to the north and west of Scotland. The group consists of Scottish Government (MS and SG Energy), Regulators/ Agencies (SNH and the Crown Estate), Local Government (Highland, Western Isles and Orkney Islands Councils), the Enterprise network (Scottish Enterprise and Highlands and Islands Enterprise) and industry partners (Scottish Renewables Forum). It established an Environmental Research Sub Group (ERSG) which concentrated on issues relating to new technology deployments and gaps in understanding of environmental interactions.

Details of the SMMRG structure and responsibilities can be downloaded at www.scotland.gov.uk/Resource/Doc/295194/0099734.pdf

The Scottish Marine Renewables Research Group (SMRRG) is being replaced by the Scottish Offshore Renewables Research Framework. The aim of the framework is to provide a mechanism for collaborative and co-ordinated research to facilitate the sustainable development of the whole Offshore Renewable sector (Wind, Wave and Tidal) in Scotland. The work on the framework is now progressing with the view to establishing specialist scientific working groups and overarching strategic group by the end of the year and holding an initial workshop on developing evidence maps early next year. It is expected that a marine mammal specialist scientific working group will be established.

8.1.1.2 *NERC Marine Renewable Energy knowledge exchange programme*

The UK's commitment to marine renewable energy brings with it significant environmental challenges. The marine renewable energy sector needs to better understand the potential impact of wave and tidal devices on the ecology and hydrodynamics of the marine environment and the long-term impact of wind farms, particularly in deep-water settings.

To meet the challenges presented by these potential impacts, the programme is working to catalyse the development of stronger partnerships between the academic, public and private sectors. It:

- Provides the private and public sectors with access to potential suppliers of the most up-to-date academic research in this field.
- Facilitates public, private and academic sectors in integrating policy, business and research needs.
- Supports the private and public sectors in delivering a sustainable future for marine renewable energy.
- The latest information about the programme, including news and events, is available on the interactive knowledge exchange portal.

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- The portal contains information on research, technologies and policy for the sector, and provides access to relevant data and literature.
- Is a useful hub for connecting with others in the sector.
- Provides up to date information on relevant funding opportunities.

8.1.1.3 Welsh Government: Marine Renewable Energy Strategic Framework

Welsh Assembly Government (the WAG) developed a Marine Renewable Energy Strategic Framework (MRESF) to investigate the potential marine renewable energy resource of Welsh Territorial Waters (TWs) and to consider potential scenarios for the sustainable development of that resource. The final report is available at (http://mresf.rpsgroup.com/)

The project was undertaken in three stages, starting in 2007:

- Stage 1, literature reviews, data gathering, stakeholder engagement and GIS mapping,
- Stage 2 a number of discrete reports, each aimed at increasing the knowledge base for a number of key data gaps in Welsh TWs identified as part of Stage 1,
- Stage 3 has drawn on the findings of Stages 1 and 2 to develop the Framework. The MRESF project team is comprised of RPS staff, with the project Steering Group including invited members from the following: The Welsh Assembly Government; Ministry of Defence; The Crown Estate; Countryside Council for Wales; Department of Energy and Climate Change; The Marine Management Organisation and Cefas.

8.1.1.4 UKERC UK Energy Research Centre:

UKERC was created in 2004 on the recommendation of the Chief Scientific Advisor's Energy Research Review Group. It is a research consortium led by Imperial College London, University of Oxford, Cardiff University, Plymouth Marine Laboratory, University College London and the Rutherford Appleton Laboratory. The UK Energy Research Centre carries out research into sustainable future energy systems. UKERC has a core research programme and also administers a competitive UKERC Research Fund. UKERC represents UK interests on the European Energy Research Alliance (EERA).

The research is divided into themes, one of which covers Energy & Environment and is led by Plymouth Marine Laboratory. The theme aims to develop strategies for marine and land-based energy production and greenhouse gas (GHG) mitigation technologies which limit environmental impacts while safeguarding or even restoring the ecosystem.

There are three main activities:

- Development of analytical tools applicable to all energy technologies in a common framework to assess their contribution to GHG emissions reductions.
- Development and application of modelling and valuation methods for assessing environmental and socio-economic impact of offshore energy production technologies.
- Development and testing of methods for assessing environmental and socio-economic impacts of developing bioenergy resources.

8.1.2 Europe

8.1.2.1 EUROPEAN ENERGY RESEARCH ALLIANCE

www.eera-set.eu

EERA is an alliance of energy research organisations across Europe. Its stated primary The primary focus of EERA is to accelerate the development of energy technologies to the point where they can be embedded in industry-driven research. In order to achieve this goal, EERA streamlines and coordinates national and European energy R&D programmes under the EERA Joint Programmes.

The EERA Joint Programmes constitute strategic, permanent collaborations between major research organisations and institutes forming a virtual centre of excellence. In response to the **EU's SET-PLAN**, the Joint Programmes implement the need for better coordination among Member States, maximising synergies and identifying priorities for future funding.

In 2011 an Ocean Energy JP was launched. It comprises six themes including Environmental Impact. An initial workshop was held in late 2011. The report is available at: http://www.eera-set.eu/index.php?index=29.

8.1.2.2 SOWFIA Streamlining of Ocean Wave Farms Impact Assessment

www.sowfia.eu

The aim of SOWFIA was to facilitate the development of European wide coordinated, unified and streamlined Environmental and Socio-economic Impact Assessment (IA) tools for offshore wave energy developments. The SOWFIA project has been completed and the final deliverables can be found here: http://sowfia.eu/index.php?id=22

SOWFIA produced a series of guidance documents on specific aspects of environmental and social impact assessment for developers and regulators, based on scientific evidence from across Europe, supplemented by the expertise of wave energy developers to date.

8.1.2.3 Marine Renewables Infrastructure Network (MARINET

www.fp7-marinet.eu

MARINET (Marine Renewables Infrastructure Network) is an EU-funded infrastructure initiative comprising a network of research centres and organisations involved in Marine Renewables technologies. The initiative aims to streamline and facilitate testing by offering periods of free-of-charge access to world-class test facilities and by developing joint approaches to testing standards, research and industry networking & training.

The €11m network initiative is majority-funded through the EC's Seventh Framework Programme (FP7) and runs for four years until 2015. The network of 29 partners with 42 specialist marine research facilities is spread across 11 EU countries and 1 FP7 partner-country, Brazil.

Companies and research groups can avail of periods of free-of-charge access to cross-border facilities ("Transnational Access" - TA) to test devices at any scale in areas such as wave energy, tidal energy, offshore-wind energy and environmental data or to conduct tests in cross-cutting common areas such as power take-off systems, grid integration, materials or moorings. In total, over 700 weeks of access is available to an estimated 300 projects and 800 external users, with at least four calls for access applications over the 4-year initiative.

In parallel to offering free-of-charge access, MARINET partners are working together to:

- Implement common standards for testing across the network in order to streamline the development process.
- Conduct coordinated research to improve testing capabilities across the network.
- Facilitate industry networking & training in the form of user workshops, staff exchange and free-of-charge training courses in order to provide opportunities for collaboration, joint ventures and expertise development.

Access is open to research groups and companies of any size who wish to avail of these facilities. The two main conditions are that the majority of the applicant group must work in Europe or a country associated to the European FP7 programme, and the proposed facility must be outside the applicant's home state.

8.1.2.4 I.C.E.S. Working Group on Marine Mammal Ecology (WGMME)

In 2010, 2011 and 2012 the ICES WGMME held workshops to discuss aspects of marine renewable developments of interest to marine mammal management. These were essentially discussion groups with no formal remit to design or define research priorities. The latest workshop report is available at: http://www.ices.dk/community/groups/Pages/WGMME.aspx

Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas is a regional agreement set up under the UNEP Convention on Migratory Species, or Bonn Convention, in September 1991. In 2009 ASCOBANS held a series of workshops addressing the issue of marine renewable effects on small cetaceans and provided comment and advice on questions related to marine mammals and renewable energy developments. The workshop reports and comments (*MOP6_5-06, AC16_42; MOP6_2009-2)* are available at *www.**ascobans**.org*.

8.1.3 United States of America

8.1.3.1 The Bureau of Ocean Energy Management (BOEM)

The Bureau of Ocean Energy Management (BOEM) manages the exploration and development of the nation's offshore resources. It seeks to appropriately balance economic development, energy independence, and environmental protection through oil and gas leases, renewable energy development and environmental reviews and studies.

Key functions of BOEM include:

BOEM is responsible for offshore Renewable Energy Programs. The Renewable Energy Program grants leases, easements, and rights-of-way for orderly, safe, and environmentally responsible renewable energy development activities.

BOEM's **Office of Environmental Programs** conducts environmental reviews, including *National Environmental Policy Act* (NEPA) analyses and compliance documents for each major stage of energy development planning. These analyses inform the bureau's decisions on the Five Year Program, and conventional and renewable energy leasing and development activities. Additionally, BOEM's scientists conduct and oversee environmental studies to inform policy decisions relating to the management of energy and marine mineral resources on the OCS.

BOEM regional offices manage oil and gas resource evaluations, environmental studies and assessments, leasing activities including the review of **Exploration Plans and Development Operations and Coordination Documents,** fair market value determinations, and geological and geophysical permitting.

The **Office of Strategic Resources** oversees assessments of the oil, gas and other mineral resource potential of the Outer Continental Shelf, and BOEM handles the actual **Oil and Gas Lease Sales**, along with **Sand and Gravel** negotiated agreements and official maps and GIS data.

In addition, the United States Department of Energy has established three National Marine Renewable Energy Centers; the Northwest National Marine Renewable Energy Center (NNMREC), the Hawaii National Marine Renewable Energy Center(HINMREC) and the Southeast National Marine Renewable Energy Center(SNMREC).

The NNMREC is a partnership between Oregon State University (OSU) and the University of Washington (UW). OSU focuses on wave energy. UW focuses on tidal energy. NNMREC has a full range of capabilities to support wave and tidal energy development and serves as an integrated, standardized test centre for U.S. and international developers of wave and tidal energy. They are in the process of commissioning a re-locatable offshore OREG testing platform due to be operational in late 2012.

The HINMREC was established to facilitate commercialization of Wave Energy Conversion (WEC) devices and to accelerate development and testing of Ocean Thermal Energy Conversion (OTEC) technologies

SNMRECat Florida Atlantic University seeks to advance the science and technology of recovering energy from the oceans' renewable resources, with special emphasis on those resources available to the south-eastern US: initially focusing on ocean currents and offshore thermal resources.

8.1.4 Canada

8.1.4.1 *Fundy Energy Research Network (FERN)*

http://fern.acadiau.ca/

FERN is an independent non-profit organization initiated by academic and government researchers as a forum to:

- *Coordinate and foster research collaborations, capacity building and information exchange to advance knowledge, understanding and technical solutions related to the environmental, engineering & socio-economic factors associated with tidal energy development in the Bay of Fundy;*
- To identify and provide objective guidance on emerging and priority issues related to tidal energy proposals and developments;
- To facilitate research collaboration and information sharing among government scientists, academia and tidal energy developers to address environmental, socio-economic and engineering issues and challenges associated with tidal energy developments in the Bay of Fundy;
- To enable creation of research teams capable of obtaining funding to support collaborative research and training of the next generation of highly qualified people;
- To enhance communication and cooperation among those involved in tidal energy research and development;
- To develop and maintain productive relationships with regional, national and international groups involved in tidal energy research;
- To communicate information and research progress through meetings, seminars, conferences, reports, FERN website, and/or other forms of public presentation.

8.1.5 International

8.1.5.1 International Energy Agency: Ocean Energy Systems (IEA:OES)

The Ocean Energy Systems Implementing Agreement (OES) is an intergovernmental collaboration between countries, which operates under framework established by the International Energy Agency in Paris.

The Ocean Energy Systems Implementing Agreement (OES) was launched in 2001. The need for technology cooperation was identified in response to increased activity in the development of ocean wave and tidal current energy in the latter part of the 1990's and the beginning of this decade, primarily in Denmark, Portugal and the United Kingdom. These three countries were the inaugural signatories to the OES.

The OES brings together countries to advance research, development and demonstration of conversion technologies to harness energy from all forms of ocean renewable resources, such as tides, waves, currents, temperature gradient (ocean thermal energy conversion and submarine geothermal energy) and salinity gradient for electricity generation, as well as for other uses, such as desalination, through international cooperation and information exchange.

OES has 19 member countries (as of Nov. 2011). Participants in the OES are specialists from government departments, national energy agencies, research or scientific bodies and academia, nominated by the Contracting Parties.

8.1.5.2 International Whaling Commission (IWC) Scientific Committee

The IWC has recently started to consider marine renewable energy developments noting that baseline data on the impact of interactions with cetaceans are lacking. In response to this perceived lack of knowledge a workshop aimed at identifying research needs and formulating recommendations for research, monitoring, conservation and management was held in 2012. A copy of the report "Workshop on interactions between marine renewable projects and cetaceans Worldwide" (SC/64/Rep6 Rev1) is available at www.iwcoffice.org.

The workshop considered in particular the current state of development of marine renewable energy in waters off Germany, the United Kingdom, Belgium and the United States.

8.2 Operational open sea OREG test centres

Centres with potential for testing interactions with marine mammals

8.2.1 UK

8.2.1.1 The European Marine Energy Centre (EMEC)

EMEC Ltd was established in 2003 as the first and only centre of its kind in the world to provide developers of both wave and tidal energy converters with purpose-built, accredited open-sea testing facilities.

With 14 full-scale grid-connected test berths and two scale test sites where smaller scale devices can gain real sea experience in less challenging conditions than those experienced at the full-scale wave and tidal test sites.

Operations are spread over five sites across Orkney:

1. Billia Croo wave energy test site, Stromness, Mainland Orkney
2. Fall of Warness tidal energy test site, off the island of Eday
3. Nursery wave test site at Scapa Flow, off St Mary's Bay
4. Nursery tidal test site at Shapinsay Sound, off Head of Holland

8.2.1.2 WAVE HUB

Wave Hub off the north coast of Cornwall in South West England provides shared offshore infrastructure for the demonstration and proving of arrays of wave energy generation devices over a sustained period of time. It consists of an electrical hub on the seabed 16 kilometres offshore to which wave energy devices can be connected. The hub is linked to the UK's grid network via a 25km subsea cable operating at 11kV.

The project holds a 25-year lease for eight square kilometres of sea with an excellent wave climate. Wave Hub has the necessary consents and permits for up to 20MW of wave energy generation and offers a clearly defined and fully monitored site for marine energy production. Four separate berths are available to lease, each with a capacity of 4-5MW. Wave Hub can readily be upgraded for up to 50MW of generating capacity in the future once suitable components for operating the cable at 33kV have been developed.

Wave Hub is complemented by the Peninsula Research Institute for Marine Renewable Energy, a centre of excellence delivering research, facilities and technology transfer in marine energy, excellent port infrastructure and an established supply chain in South West England.

Wave Hub has been funded by the South West RDA, the European Regional Development Fund Convergence Programme for Cornwall and the Isles of Scilly and the UK government.

WaveHub incorporates the FaBTest site in Falmouth Harbour, a nursery site with three berths for the testing of marine energy technologies, components, moorings and deployment procedures. The site offers water depths of 20m-50m and seabed types of rock, gravel and sand.

8.2.1.3 Perpetuus Tidal Energy Centre (previously Solent Ocean Energy Centre)

A planned tidal turbine array test site and commercial energy generation facility at the Isle of Wight. Currently in the planning stages with planning application expected in late 2014.

8.2.1.4 National Renewable Energy Centre (NAREC)

Narec is an open access test and research facility operated by the Offshore Renewable Energy (ORE) Catapult. Narec has invested over £150 million of UK Government, private sector and European Regional Development Funding (ERDF) Projects cover a variety of Narec operations in the offshore and onshore wind, wave and tidal and electrical network sectors and primarily focus on capital investment, training provision, sector support and research and development activities.

Projects are usually developed in consultation with a range of external agencies and have included the European Union, Department of Energy and Climate Change (DECC), Department of Business Innovation and Skills (BIS), Technology Strategy Board (TSB) and the Energy Technologies Institute (ETI).

Current projects include:

- Innovation Facilities Infrastructure
- Marine Testing Facility
- Narec Site Infrastructure
- National blade testing facility
- National wind development centre
- Offshore wind test site
- Renewable energy technology accelerator
- Social housing energy management

The focus is largely engineering and little environmental testing has been included in projects to date.

8.2.1.5 Renewable Energy Test and Education Centre (RETEC), Cumbria

The Renewable Energy Test & Education Centre (RETEC) is hosted by the University of Cumbria and aims to support research into innovative, low-carbon energy technologies. It provides a focal point for renewable energy research and development, testing and educational programmes.

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The project has received £150,000 funding from Britain's Energy Coast in partnership with the Nuclear Decommissioning Authority.

The aims are:

- To establish a renewable energy research and test capability on the west coast of Cumbria,
- To help the University of Cumbria develop an international industry-led research capability based on low-carbon energy production and reduction,
- To provide seed-corn funding to local business for prototype manufacture and test of low carbon technologies,
- To begin the development of an educational outreach facility to inspire local students to take up HE education in the renewable energy sector.

8.2.2 EUROPE

8.2.2.1 SEAI_OEDU - Wave Energy Test Site

Belmullet, Co. Mayo Ireland

The project was intended to be fully operational by 2013/2014 depending on the readiness of full scale wave energy converters. The information given below is therefore based on the current proposed design of the test site

- Full scale wave energy test site with 10MW export capability,
- Two separate off-shore test areas, 1x 50m Water depth, 1x 100m water depth,
- Two 10KV cables with integrated fibre optic to each test area,
- Each separate test area is capable of containing individual devices or arrays,
- The project will be focused primarily on providing open sea test facilities for full scale pre-commercial devices – Provides for one of the best wave resources in the world,
- Grid connection - 10MW export capability,
- Wave and current resource data relevant to the site,
- Meteorological data for the area.

Ongoing environmental and acoustic monitoring

AMETS is a test site orientated towards testing of pre-commercial devices. With its extreme wave resource available it is suited as a final stage test facility. While grid connected for wave energy converters, AMETS will accommodate other ocean energy related project, such as acoustic monitoring etc.

A consent application was submitted in December 2011 and a decision on this is expected sometime in 2014. The decision has been delayed due to inclusion of a portion of the area of interest in a proposed new Special Area of Conservation (SAC) for bottle-nose dolphins. This occurred some considerable time after the lease application had been submitted and meant that the AMETS team has had to commission an Appropriate Assessment report on the potential impact of test site activities on the new SAC. The final decision on the lease application will take this assessment into account. - See more at: http://www.seai.ie/Renewables/Ocean_Energy/Belmullet_Wave_Energy_Test_Site/#sthash.vJxo2cSi.dpuf

8.2.2.2 SEAI_OEDU & SmartBay - Wave Energy Test Site, Galway Bay

The Galway Bay test site is a quarter scale test site for floating wave energy devices. This site is located on the west coast of Ireland in Galway Bay off the Spiddal coast. Analysis of wave data since 2005 data has shown that for quarter scale devices the site can be highly energetic and comparable to the Atlantic Ocean off the west coast of Ireland.

Test area 37 Hectares, mean water depth of 23m and a tidal range of 4m.

Two device berths within test area.

A non-directional wave recording buoy.

The site is not grid connected.

A network of data buoy sensors provides information on the resource and meteorological conditions at the test facilities.

The site incorporates SmartBay Ireland which is run by the Marine Institute. This is a national research infrastructure project for oceanographic monitoring.

Typical projects/examples:

Testing of ¼ scale prototype devices.

Testing of products and services for the marine sector

8.2.2.3 EVE - Biscay Marine Energy Platform- bimep

The Biscay Marine Energy Platform (bimep) is an open sea test infrastructure for research and demonstration of offshore Wave Energy Converters (WEC). The facility will (apparently scheduled to open in 2013) offer the opportunity for testing full-scale prototype devices as single devices or arrays in order to assess and monitor performance.

Main characteristics of the infrastructure:

- high energy potential (21 kW/m).
- Water depth between 50-90m.
- Closest point to the land: 1km.
- A rectangle area (4 x 2 km, including a safety area) has been defined to hold the WECs.
- 4 grid connected test berths or power connection units of 13 kV and 5 MW. Overall power:20 MW.

The infrastructure is still apparently under construction.

8.2.2.4 AAU - Nissum Bredning Test Site

Helligsø, Denmark

Infrastructure Specification:

- Single wave device testing berth.
- Grid connection.
- Mooring pile.
- Water depth 4-6 m in the test area.
- Access to wind and wave measurements.
- Statistics on wind and waves in the area.
- Typical Projects/Examples:
- 30 Wave energy devices have been tested in scale 1:10 to 1:4.

8.2.3 CANADA

8.2.3.1 Fundy Ocean Research Center for Energy (FORCE)

http://fundyforce.ca/

FORCE is a test center for in-stream tidal energy technology in the Bay of Fundy in eastern Canada. FORCE provides a shared observation facility, submarine cables, grid connection, and environmental monitoring at its pre-approved test site. FORCE receives funding support from the Government of Canada, the Province of Nova Scotia, Encana Corporation, and participating developers.

FORCE’s test site is in the Minas Passage area of the Bay of Fundy, Nova Scotia. Minas Passage is 5 km wide and has the world’s highest tides. At mid-tide, the current in Minas Passage is about 4 cubic kilometres per hour, the same as the estimated combined flow of all the rivers and streams on Earth combined. Features of the site include: water depths up to 45 and currents up to 5 metres per second on ebb and flood. The land-based facility is now complete and open to the public.

Nova Scotia Power tested a 1 megawatt OpenHydro turbine at this site between November 2009 and December 2010. Black Rock Tidal Power (in partnership with Schottel), OpenHydro, Minas Energy (in partnership with Bluewater and Siemens) currently hold berths at the site. The first devices are expected to be in place in 2015.

A subsea cable was installed in December 2013 and work is currently ongoing to install a subsea monitoring platform. The platform is part of FORCE's Fundy Advanced Sensor Technology (FAST) program. The FAST program is designed to monitor and characterize the FORCE site with a recoverable platform that uses a variety of onboard sensing equipment.

8.2.4 USA

8.2.4.1 Northwest National Marine Renewable Energy Center (NNMREC)

NNMREC is funded by the U.S. Department of Energy to facilitate the development of marine renewable energy technologies -- primarily wave and tidal -- via research, education, and outreach. Established in 2008, NNMREC is a partnership between Oregon State University (OSU) and the University of Washington (UW). In 2011 NNMREC's research agenda expanded to include offshore wind energy technology as well.

The Pacific Marine Energy Center (PMEC) is the name of NNMREC's marine energy converter testing facilities located around the Pacific Northwest region. Much of PMEC is still in the early planning stages. Ultimately PMEC will facilitate testing of a broad range of technologies being produced by the marine energy industry. For intermediate scale wave energy devices, UW supports open water testing in Puget Sound and in Lake Washington. For a full scale wave energy resource, the North Energy Test Site (NETS) can accommodate devices up to 100kW connected to the Ocean Sentinel, and larger devices if no grid emulation or connection is required. The grid-connected site currently under development (initially referred to as "PMEC") will be referred to as the South Energy Test Site (SETS). SETS will serve as the utility-scale wave energy test facility for the US, and is expected to be available for device testing in 2016.

8.3 UK funded research programmes

Current and recent UK funded research programmes (excluding Scottish Government funded programmes) involving environmental aspects of marine renewable developments

8.3.1 SuperGen Marine (Phase 1)

Funded by EPSRC

Generic research to reduce risk and uncertainty for marine energy development. A consortium of 5 core universities: Edinburgh, Heriot Watt, Robert Gordon, Lancaster and Strathclyde.

£2.6 million 2003 - 2007

8.3.2 SuperGen Marine (Phase 2)

Funded by EPSRC

Generic research towards increasing understanding of the device-sea interactions of energy converters from model-scale in the laboratory to full size in the open sea. A consortium of 5 core universities: Edinburgh, Heriot Watt, Lancaster, Strathclyde and Queen's University Belfast. £5.5 million 2007 - 2011

8.3.3 SuperGen UK Centre for Marine Energy Research (UKCMER)

Funded by EPSRC

Current state of knowledge of the effects of offshore renewable energy generation devices on marine mammals and research requirements

A consortium with core universities: Edinburgh, Strathclyde, Exeter and Queen's University Belfast. Research towards array planning, turbulence, power take off development, reliability, mooring and foundations, and environmental impact. 2.75 million 2011 - 2016

8.3.4 UK Energy Research Centre (UKERC)

Funded by NERC

The UK Energy Research Centre carries out world-class research into sustainable future energy systems. Coordinators of the National Research network and developers of roadmap documents for renewable energy. A roadmap for marine energy was produced in 2008 and is available on the UKERC website. £170k for marine (phase 1) Approx. £150k for phase 2 2004 - 2009 (phase 1) 2009 - 2014 (phase 2)

8.3.5 EPSRC Grand Challenge (SuperGen Marine Challenge 1)

Funded by EPSRC

Proposals were invited for collaborative research proposals for fundamental research that will overcome barriers to Marine energy deployment. The remit of this call is regarding those aspects of marine energy generation technologies, the environmental impacts of the technologies and the socioeconomic aspects of marine energy (including policy) that are holding back the deployment of marine energy. £3 million 2011 - 2014

8.3.6 EPSRC Grand Challenge (SuperGen Marine Challenge 2)

Funded by EPSRC

Proposals were invited for fundamental research that will investigate novel concepts for marine energy deployment on 2050 timescales. The remit of this call is all aspects of marine energy generation technologies, the environmental impacts of the technologies and the socioeconomic aspects of marine energy (including policy). £3 million 2012-

8.3.7 Marine Renewable Energy Research Programme

Funded by NERC/Defra

The overall aim of the research programme is to understand the environmental benefits and risks of up-scaling marine renewable energy schemes on the quality of marine bioresources (including biodiversity) and biophysical dynamics of open coasts. £2.4 million 2012-2015

8.3.8 The Research Councils UK Energy Programme

Funded by EPSRC, BBSRC, ESRC, NERC, STFC

The Research Councils UK Energy Programme aims to position the UK to meet its energy and environmental targets, and policy goals through world-class research and training. The Energy Programme is a collaboration of research councils and is investing more than £530 million in research and skills to pioneer a low carbon future. This builds on an investment of £360 million over the past 5 years. The Energy Programme funds some marine research.

£7.7 million into marine renewables (including SuperGen)

8.3.9 Developing The Offshore Wind Supply Chain

Funded by TSB and DECC

The Department of Energy and Climate Change (DECC) and the Technology Strategy Board (TSB) are investing up to £11.2m in technical feasibility studies; development and demonstration of component technologies; and knowledge transfer partnerships (KTP) to stimulate innovation in the UK offshore wind sector and to strengthen the supply chain.

Current state of knowledge of the effects of offshore renewable energy generation devices on marine mammals and research requirements

Up to £7m is available for the third round of DECC and the Technology Strategy Board's offshore wind component technologies development and demonstration scheme. Applications are invited from single businesses or consortia, including those not currently established in the UK or those seeking to expand into the offshore wind sector. Successful projects are expected to attract between about 25% and 60% public funding, and may receive up to £4m funding per project. This competition opened in November 2012 and the deadline for applications is 16 January 2013

Up to £3m is also being provided for technical feasibility studies lasting up to a year and applications should be made to the Technology Strategy Board. Projects must be led by a UK business and may be developed by a single company or be collaborative. They will attract up to 75% public funding of up to £100k for pre- industrial research, with total project sizes expected to be between £100k and £150k.

8.3.10 Developing the offshore renewable energy supply chain: Knowledge Transfer Partnerships

Funded by the TSB and NERC

TSB & NERC are to invest up to £1.2m to establish new Knowledge Transfer Partnerships (KTPs) in the field of offshore renewable energy to stimulate and support innovation in the offshore renewable energy supply chain.

The aim is to establish a group of KTPs that will run together as a cohort, supported by a programme of networking between the partners. This call is currently open with a deadline for applications of24 April 2013.

8.3.11 Marine energy: Supporting array technologies

Funded by NERC, TSB and Scottish Enterprise.

The TSB, Scottish Enterprise and NERC are investing £10.5m in collaborative research and development to support successful deployment and operation of the first series of wave and tidal energy arrays.

The competition, aims to encourage innovation that can address key common challenges to de-risk deployment of early arrays by removing technical barriers and reduce the cost of energy produced..

Proposals had to be collaborative and business-led. The competition opened in spring 2012. Successful projects required 50% industry funding to match 50% public funding. Project funding ranged between £500k and £1.5m per project.

8.3.12 In-Stream Tidal Energy: Advancing environmental monitoring, sensing and instrumentation technologies for high flow marine environments

The OERA and TSB are investing collectively approximately $1.4 million CAD (approximately £755,000) in funding for the initial Call.

The initial call competition under the MoU shall be environmental monitoring, sensing and instrumentation technologies for application and deployment in high flow marine environments. Project teams or consortia shall be collaborative and business-led, comprising both Canadian and UK expertise. The aim of this competition is to fund innovative industrial research to address current and compelling knowledge gaps related to sensing and monitoring technologies that will lead to improvements to the quality and quantity of data available to the industry. Ultimately, improved data will contribute to resolving challenges, and reduce risk and costs associated with tidal development. Additionally, the planned research or investigative testing is expected to generate new knowledge and skills for developing and commercializing new products, processes or services, or for bringing about significant improvements in same; to provide support to environmental permitting requirements; and contribute to building social license and acceptance within the sector.

Funding levels vary by jurisdiction and according to the type of partner organisation in a consortium; large organisations could attract up to 50% of project costs from the call fund, small and medium sized enterprises (SMEs) up to 60%, and research technology organisations (RTOs) and not-for-profit organisations up to 100%. Partners are expected to leverage the remaining portion of the project costs through 'match-funding' or contributions in-kind. Funding from OERA/TSB should not be relied on to cover the total project costs. Total project costs are anticipated to be in the range of $500,000 CAD (approximately £275,000), though not to the exclusion of projects of other sizes.

This is a two stage competition, namely stage one Expression of Interest (EOI) and stage two invited proposals. The EOI competition opened for applicants in October 2014 (precise date TBA) with a deadline date for EOIs due in late November 2014. The OERA and TSB plan to host information sessions for potential applicants in their respective countries.

8.3.13 The Offshore Renewable Energy CATAPULT.

A technology innovation and knowledge centre established by the Technology Strategy Board for the identification, development and rapid commercialisation of innovative technology to deliver affordable, offshore renewable energy. The CATAPULT will work in collaboration with policy makers, industry large and small, utilities, owners and the UK's research organisations.

The ORE catapult is in the process of establishing an environmental programme and is currently in discussion and consultation with NERC, Scottish and UK governments and other stakeholders.