The Scottish Government
Riaghaltas na h-Alba

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

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Marine Mammal Scientific Support Research Programme MMSS/001/11

Tasks MR1 & MR2:

Current state of knowledge of effects of offshore renewable energy generation devices on marine mammals

&

research requirements

Sea Mammal Research Unit

Report to Scottish Government

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1 Executive Summary

This report is designed to fulfil requirements MR1 and MR2 within the Marine Mammal Scientific Support Research Programme MMSS/001/11. The report describes the current state of knowledge of effects of offshore renewable energy generators on marine mammals and then identifies a prioritised list of research gaps.

A total of 28 specific research gaps are identified. Of these, 16 are already under investigation to some extent with either active research projects or planned and funded future projects.

The 12 remaining projects have yet to secure funding. These are prioritised but the list of priorities has yet to be agreed with the steering group for the MMSS/001/11. A final project list with agreed priorities will be included in the next update of this report.

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 Offshore Renewable Joint Industry Programme (ORJIP). The results of that analysis will be used to extend the list of research gaps and amend the priorities of specific projects in the next update of this report.

2 Introduction

The expansion of offshore wind energy projects and the development of new technologies and devices for marine renewable energy (Wave and Tidal) generation and their imminent and potentially rapid deployment in Scottish waters mean that there is an urgent need to identify and fill certain crucial data gaps. The UK is committed to a massive increase in renewable energy generation over the next 20 years and wind, wave and tidal power will play a major role in meeting these targets. A key concern in the development of such industries is that there should be a realistic assessment of the net environmental impact of any developments. There are clear benefits in terms of low carbon energy generation and the socio-economic benefits of developing a major offshore industry. However, these must be weighed against a set of potential environmental impacts, including effects on marine mammals.

From an industry perspective, there are problems associated with planning and investment when operating in high energy marine environments. There are engineering and environmental risks that may be predicted and to some extent accounted for but there is a level of uncertainty associated with each of these risks and that uncertainty translates into increased regulatory constraint and increased cost.

From an environmental perspective, it is essential that potential effects are identified, and where possible quantified, to allow a realistic impact assessment to take place. Methods and strategies for avoiding the preventable consequences are needed, and mitigation strategies and methods are needed to minimise the impacts of residual effects.

Uncertainty about the scope and magnitude of such environmental risks means that regulators and advisors will adopt a precautionary approach. Reducing uncertainty will therefore allow more appropriate and proportional regulation of the marine renewable industry. This is to the advantage of regulators, industry and the environment.

2.1 Terminology

We use the phrase **offshore renewable energy generation** (OREG) to cover all forms and stages of offshore energy generation. For the purposes of this review, OREG will be restricted to the three main generation methods of relevance to Scotland

- Wind-OREG: Offshore turbines that harvest wind energy
- Wave-OREG: Surface or near-surface devices that harvest wave energy
- Tidal-OREG: Underwater devices that harvest tidal current energy

The latter two types can be grouped as wet-OREG. We recognise that OREG transitions through a series of stages: survey, construction, operation and decommissioning.

OREG devices may have a range of effects on their local environment such as increased noise during construction or operation, increased risk of collision and injury or barrier effects due to physical obstruction. We refer to any such effects resulting from OREG developments as **stressors**. Whilst these are usually associated with a negative effect, there may be positive effects (e.g. the reef effect). We refer to marine mammals as **receptors**. The **impact** of a stressor on an individual receptor may be physical (e.g. collision trauma), physiological (e.g. elevated hearing threshold), or behavioural (e.g. move away from stressor). The relationship between the magnitude of the stressor and the resulting impact is termed the **dose-response function.**

2.2 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 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.

2.3 Approach

Part of the purpose of this review is to identify the questions that need to be answered in order to reduce the uncertainty around interactions between species and OREG during the consenting process. Currently, the limited ability to answer some basic questions relating to the existence, likelihood and potential consequences of specific risk factors requires regulators to take a very precautionary approach when assessing proposals (i.e. the Precautionary Principle). In the medium to long term, these are the issues that will have most impact on the licensing process. Here we will deal with the potential harmful effects that have been identified in previous reviews (Wilson *et al.* 2007; Linley *et al.* 2009; Wilson & Gordon 2011). The simple aim is to identify the issues that may have an impact on marine mammal populations of interest to the Scottish Government. Targeting research resources on answering these questions, or at least reducing the uncertainty around such issues, should simplify the consenting process and reduce, or help target, the long term monitoring requirements thereby reducing unnecessary burden on developers.

2.4 Structure

This review will be broken down into the following sections.

In Section 3 we discuss the spatial and temporal overlap in marine mammal populations (and their associated parameters) and potential OREG stressors.

In Section 4 we consider potential proximate impacts. These are immediate effects on an individual. Impacts may cascade within an individual. For example, a proximate impact of displacement, caused by a stressor such as noise, may result in reduced foraging efficiency, resulting in reduced condition, then suppression of immune responses and reduced survivorship.

The linkages amongst proximate, secondary and ultimate consequences for individuals are discussed in Section 5.1. The effect of individual variability on population consequences can only be mediated though one (or more) of the three population vital rates: survivorship, fecundity and emigration. This is discussed in Section 5.2.

Within each section we highlight the most prominent gaps in knowledge. We regard data that have not been analysed and published as having the potential to fill currently existing research gaps. We also distinguish between on-going, funded work and work that has been proposed but has not yet secured funding. These research gaps are collated and prioritised in Section 6.

There is a need to coordinate OREG-relevant research to increase its efficiency and relevance. Appendix 2 contains a list of relevant UK, European and wider international working groups together with a list of Marine Renewable test centres where environmental impacts could be studied under controlled conditions and a list of recent and on-going funding programmes relevant to Scottish OREG developments.

Appendix 3 contains in depth information on the species covered in this report: harbour and grey seals; harbour porpoise; bottlenose dolphin; minke whale; white beaked dolphin; white sided dolphin; killer whale; Risso's dolphin; common dolphin; long finned pilot whales; striped dolphin; fin whale; Sei whale; humpback whale; sperm whale; Sowerby's beaked whale.

2.5 Report Review

The potential impact of OREG on marine mammals is a dynamic field, both scientifically and regulatory. Therefore, this report will be updated on an annual basis.

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. We thus first summarise the current state of knowledge of spatial, temporal and movement characteristics of UK marine mammal populations and the uncertainty around these. We follow this with a consideration of the spatial distribution of OREG activity and then highlight some locations that provide particular opportunities for answering general questions.

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. In general, the precision of estimates of abundance is higher for larger populations. Seals are also easier to count than cetaceans (Taylor *et al.* 2007). The coefficient of variation (CV) of estimates of the total size of UK seal populations are around 10-15% for large regions. The SCANS II survey of the European Atlantic and North Sea estimated harbour porpoise abundance over that area with a CV of 20%. With the exception of the intensively studied Moray Firth bottlenose dolphin populations,

other cetacean species will have higher levels of uncertainty in abundance estimates, and therefore trends.

The uncertainty around estimates of absolute abundance and trends in population size will limit the detectability of the effects of any OREG developments on population size. The detection of small localised reductions in abundance is likely to require substantial additional monitoring efforts, both before and after construction.

There are 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. Appendix 2 gives brief details of the seal and cetacean populations likely to be of interest to the OREG industry and considered in the licensing process.

3.1.1 UK seals

The Marine (Scotland) Act 2010 and Conservation of Seals Act 1970 require the Natural Environment Research Council (NERC) to provide scientific advice to Scottish and UK Ministers concerning the conservation and management of seal populations. These tasks are carried out through annual meetings of NERC's Special Committee on Seals (SCOS), using information mainly provided by SMRU. As well as examining the work directly funded by NERC for its use, the Committee also reviews other relevant projects, funded by the Scottish Government and other bodies, carried out by SMRU.

3.1.1.1 Haulout counts

Both grey and harbour seals haulout on land for periods throughout the year. Whilst the drivers and moderators of haulout behaviour (at least outside moult and breeding periods) are not well understood such counts are a useful, and readily obtained, index of local seal abundance. Harbour seal populations are surveyed using aerial photographic counts of individuals hauled out during their annual moult in August. While the intention has been to cover all locations where harbour seals haulout in a rolling five year cycle, the dramatic declines observed in many areas (Lonergan *et al.* 2007) have led to additional effort being concentrated in areas, such as the Orkney Islands, where the most rapid changes have been observed. Grey seals observed during these surveys are also recorded, and between 2007 and 2009 the surveys were extended to cover all areas where that species is known to haul out. In addition, there have been intensive studies of haulout counts at certain study sites, particularly in the Moray Firth (Mackey *et al.* 2008; Cordes *et al.* 2011).

With the exception of the Moray Firth (e.g. Grellier, Thompson & Corpe 1996) and Kyle Rhea (Cunningham *et al.* 2009) there is little information on seasonal seal haulout distribution and numbers for any of the areas of interest. Planned telemetry

work on harbour seals around Islay to examine movements into and out of tidal stream areas will help determine the extent of the area that may be affected by developments. Tailored monitoring/survey programmes for specific areas would allow development of seasonal haulout distribution maps and in conjunction with telemetry data will allow development of seasonal at sea habitat usage maps to determine the periods of maximum risk and the scales at which effects may operate (see HCON Research Gap below).

3.1.1.2 Pup counts

Grey seal pups spend their first few weeks ashore, so the main monitoring of that species around the UK is through aerial surveys of breeding colonies (SCOS 2011). Total pup production at each colony is estimated from a series of surveys and used to generate abundance estimates from statistical population models.

3.1.1.3 Population modelling

Telemetry data can be used to directly scale up haulout counts to population estimates (Lonergan *et al.* 2011; Lonergan *et al.* 2012). Alternatively, demographic models can be used to allow for components of populations underrepresented in surveys.

Grey seal abundance is estimated by using state space models to extrapolate from the pup production estimates (Newman *et al.* 2009a). These require knowledge of demographic parameters such as survival rates and fecundity and an understanding of how these change with population density. The models produced very different estimates of abundance depending on whether density dependence was considered to affect fecundity or pup survival and were not able to select between those possibilities. The 2007-9 independent grey seal abundance estimate, generated from combining data from electronic telemetry tags with observations during the summer aerial surveys, resolved that issue (Lonergan *et al.* 2011).

Attempts have been made to build similar detailed models for harbour seal populations, though these have been hampered by the much more limited information that is available on harbour seal demography. Up until the 1980's, consideration of grey seals as competitors to fishermen led to culls and lethal sampling. These provided much of the currently available demographic data. The most similar dataset for harbour seals comes from the 1988 and 2002 phocine distemper epidemics (Harkonen & Heidejorgensen 1990; Harkonen *et al.* 2007). These data are mainly from Scandinavian animals and may not be representative of UK harbour seal populations.

Detailed models have also been constructed for aspects of local population dynamics, based on long-term observational studies (Cordes *et al.* 2011a; Matthiopoulos *et al.* 2011). In most cases a major limiting factor has been the shortage of background information. The lack of relevant information forces modellers to rely on intuition and judgement about what is plausible. Those

assumptions and judgements are only testable by the collection of additional data so, in its absence, the validity of models' results remains uncertain. Attempts are being made to formalise the process of eliciting opinions from knowledgeable scientists (Lusseau *et al.* 2012), though it is hard to see how those can adequately fill gaps where there really are no data.

3.1.1.4 At-sea behaviour

Over the past 20 years, more than 200 grey and 200 harbour seals have been fitted with telemetry devices. In the past eight years, the technology has advanced from Argos satellite tags (infrequent, approximate locations) to GPS /GSM[1] tags (frequent, accurate locations plus high bandwidth channels to relay detailed behavioural data). The data holdings are summarised by (Russell *et al.* 2011)

In relation to tidal-OERG development in the north coast of Scotland and Orkney, McConnell *et al.* (in SMRU Ltd 2011) identified a number of data gaps. These included a lack of harbour seal movement and diving behavioural data in relation to high current regimes, especially in the Pentland Firth, and a lack of recent, high quality (GPS/GSM tags) adult and pup grey seal data in the same area. Since the report was completed (2011), some of these telemetry data gaps in areas of high current regimes have been filled:

date	reporting date	species	region	funder	comments
2011 ongoing	Jan 2013	harbour seals	Pentland Firth, Sound of Islay, Kyle rhea	SNH/MS/NERC	Describe movements and diving behaviour of harbour seals in relation to high tidal energy sites in PF, SoI &KR.
2013	June 2014	harbour seals	Islay and Jura	SNH/MS/NERC	Assess degree of movement into and out of the Sound of Islay to identify and if possible quantify the population at risk.
2010	2011	grey seal pups	Pentland Firth & Eday (EMEC site)	MS	Describe movements and diving behaviour of grey seals during first year. Seals tagged at sites adjacent to tidal rapids.
2009 - 2010	2011	grey seal pups	Anglesey and Ramsey (Wales)	WAG	Describe movements and diving behaviour of grey seals during first year. Seals tagged at sites adjacent to tidal rapids.

[1] Global System for Mobile communications – mobile phone technology.

Simple descriptive summaries of the movement and dive data from grey seal pups have been presented (Thompson 2012b; Thompson 2012a). A detailed analysis of the harbour seal data has yet to be completed. Raw data from all the deployments detailed above have been incorporated in the at sea usage maps described in the next section.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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.	Not funded	NA

3.1.1.5 At-sea usage

At-sea density of individuals may be estimated from haulout counts and haulout-specific foraging patterns using methods developed by (Matthiopoulos *et al.* 2004). Usage maps at 5km grid granularity have been prepared using all data up to the end of 2012 for both harbour and grey seals (Jones *et al.* 2011). This was a deliverable of Task MR5 (Characterisations of seal populations) under the MMSS/001/11 Research Project which reported in January 2013.

The usage maps present uncertainty in the form of upper and lower 95% confidence surfaces. Uncertainty can derive from a number of sources, but can be used to identify regions that are sparse in telemetry data. Such uncertainty would be reduced by strategic tagging of specific seal species and age classes in areas relevant to OREG developments.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
Telemetry studies targeted on specific areas to improve map confidence intervals.	TAG	In light of results of current telemetry studies (3.1.1.4) and results of MR5, targeted deployments on particular species and regions will improve confidence intervals on at sea distribution maps.	Not funded	NA

3.1.1.6 At-sea habitat preference

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.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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 *et al.* 2008). Abiotic variables (e.g. depth, sediment type) will be used as candidate covariates.	Funded by MS & DECC	2014

3.1.1.7 At sea activity

The impact of overlapping OREG stressors and seals' density will be determined / moderated by the activity associated with the geographical area of overlap. Seal behaviour at sea can be conveniently divided into three main activity classes: resting, travelling and foraging. One of the metrics that discriminates foraging from travel is the speed of directed travel.

The rate of travel through an area of potential stress (rather than just the density of animals there) may affect the population level consequences of a local stressor. For example the population consequences of 10 seals each being exposed to one minute's exposure to a given level of piling noise may be less (or more) than one seal being exposed to 10 minutes of similar noise. In other words, the cumulative effect may be non-linear and dependent upon residence time.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
Map distribution and activity of UK seals	ACT	Behaviour using historical grey and harbour seal 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 based on track speed and tortuosity. 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	Funded by MS & DECC	2013

		developments 3. to identify core foraging areas. 4. modify usage maps to account for residence time		

3.1.1.8 Meta-population structure

Telemetry data on the movements of both grey and harbour seals suggest that individual animals have preferred foraging areas or regions. For harbour seals such foraging areas are usually associated with haulout sites that are used throughout the year for resting, breeding and moulting. For grey seals such foraging areas may be hundreds of kilometres away from their favoured breeding locations and many grey seals spend most of the year well away from their breeding sites. The wide ranging movements of grey seals and the more localised movements of apparently resident harbour seals means that the two species will have different meta-population structures.

The Scottish Government has divided the coast into seven seal management regions (map available at http://www.scotland.gov.uk/Resource/Doc/295194/0112738.pdf). However, developing appropriate strategies for managing the localised disturbance effects of OREG developments requires an understanding of the structure of these meta-populations at a finer spatial resolution. An OREG stressor may produce a response whereby individuals move away (emigrate) from the source. A likely, measurable response is that lower numbers of seals will haul out locally. For individuals that move long distances (e.g. grey seals) this response may be diluted geographically, to the extent that the response may not be detectable. For individuals that move less far (e.g. harbour seals) the response may be more local and more detectable. The area needing examination to investigate such effects is likely to depend on the baseline patterns of movement of the animals as well as the location of the stressor source.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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 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	Funded by MS & SNH	2013

		confidence intervals surrounding these transition probabilities.		

3.1.2 UK cetacea

Monitoring cetacean abundance is generally more difficult and expensive than it is for seals, because large areas of sea need to be surveyed to generate biologically useful estimates. Abundance estimates come from three general survey types – visual line transect surveys, acoustic surveys using passive acoustics to monitor odontocete abundance, and photo-id studies that are directed at closed populations. Electronic telemetry devices have been attached to cetaceans in other areas but not UK waters.

3.1.2.1 Coarse scale distribution

Less is known about the population status and distribution of most UK cetacea compared with UK seals. The primary synoptic information comes from the two SCANS surveys conducted in 1994 and 2005 (Hammond *et al.* 2002; SCANS-II 2008). These were large scale international collaborations that involved multiple ships and aircraft. Planning is underway for a third survey, hopefully to be carried out in 2015.

Throughout the UK, several organisations have also been conducting local surveys using acoustics, visual surveys including small scale line transect surveys and population studies using photo-id. Many or most of the visual sightings data series have been collated and standardised under the Joint Cetacean Protocol (JCP), a collaborative project lead by the Joint Nature Conservation Committee (JNCC). This project explored the potential of this information to supplement the SCANS data and examine localised effects. This project has been faced with two major constraints in its analyses: the differences in the data collection methods and formats, which require multiple assumptions and simplifications to be made, and computational complexity of fitting models to such a large and disparate dataset. The report of the third phase of the project is currently under review.

At present there has been no attempt to systematically collate or analyse acoustic data, and it seems unlikely that this will be achieved in the near future.

Photo-id studies have been conducted for only a few species, most notably for bottlenose dolphins, and here at least three UK based populations have been studied and abundance estimates have been produced (Pesante *et al.* 2008; Thompson *et al.* 2011)

The planned East Coast Surveillance Strategy currently in development by Marine Scotland, using various passive acoustic methods and aerial surveillance using high resolution cameras, will also provide useful data on the occurrence of cetaceans in the coastal region from St Abbs to Caithness.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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 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, 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.	Funded by MS	2013

3.1.2.2 Fine scale distribution and behaviour

There is limited information on the density of cetaceans in the coastal waters where wave and tidal OREG developments are planned. There are more extensive data from some wind OREG sites (but see above – JCP Research Gap is re-assessing value of JCP data) and in most cases, developers will be conducting local surveys.

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. Each of these devices contains a battery-powered hydrophone, processor and software to identify clicks produced by porpoises and dolphins. Most analyses

currently report changes in the proportion of “click-positive minutes”, which is taken as an index of relative abundance on the assumption that porpoises produce echolocation clicks most of the time. Other metrics (e.g. waiting times and detection positive hours) may be more appropriate based on nature of devices, temporal autocorrelation issues and comparison with visual data (e.g. Bailey *et al.* 2010, Thompson *et al.* 2010). CPODs are effective tools for assessing porpoise activity patterns at spatial scales of hundreds of square metres. The analysis of the resulting data remains problematic in terms of identifying the fine scale behaviour of individual porpoises since no simple way has been demonstrated to combine information from multiple devices or identify individuals.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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.	Funded by MS	2014

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 funded work has led to the development of towed 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 development are being planned. This technique has been used experimentally to track harbour porpoises in Ramsey Sound (Wales). However there is a need to extend this to other high current energy sites that may be exploited by tidal-OREG to provide sufficient data at appropriate resolution to allow us to describe porpoise behaviour in such habitats.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
Harbour porpoise behaviour in tidal rapids	PTID2	Use towed 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	2013

Whilst a large array of static hydrophones (e.g. CPODs) may be used to investigate changes in large scale distribution over ranges of kilometres (Thompson *et al.*

2010b) they are of limited use in obtaining the fine scale movement data required to assess collision risk with tidal turbine arrays.

3.2 Possible indicator sites

The importance of baseline data for estimating impacts and changes resulting from the installation and operation of OREG devices means that these will be easiest to characterise in areas where there has previously been long-term and intensive monitoring. Concentration of effort at particular sites may provide more information overall than spreading resources evenly across all areas. The existence of previous studies however, is not in itself sufficient to identify appropriate locations for focussing research effect. How well an area represents the wider population, and the range of OREG technologies and other threats present are also important. It is also necessary that there is sufficient access to areas and populations to allow research to be carried out effectively and efficiently.

Long-term intensive studies are ongoing at the North Rona and Isle of May grey seal breeding colonies. These have been following and examining the reproductive success of individual females (Twiss *et al.* 2012). Similar studies of seabirds are also being carried out at the Isle of May (e.g. Burthe *et al.* 2012).

The most intensively studied harbour seal population in Scotland is that within the Moray Firth (for example Cordes *et al.* 2011b). The long time series of behavioural and reproductive data from part of this population 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. It is therefore important that additional sites are included in any programme of demographic studies of harbour seals. There are now too few harbour seals around the Firth of Tay Special Area of Conservation (SAC) for much data to be gathered there. Orkney has seen steep reductions in harbour seal numbers, but still contains one of the largest populations and is an area where both tidal and wave OREG developments are concentrated, so that might be an appropriate area in which to focus efforts to understand impacts on that species.

Many cetacean species are very wide ranging and individuals are therefore only sporadically present in areas of interest to OREG. Of the two dozen or so species reported from UK waters, several can be reliably expected to be present in the areas currently under consideration for development. Specifically, porpoises and minke whales are likely to occur in the vicinity of any OREG developments in any marine area in Scotland, while bottlenose dolphins and white beaked dolphins could well be expected to occur fairly frequently in certain areas. Being the most abundant and widely distributed cetacean in UK waters, the harbour porpoise provides a useful ‘model cetacean’ species to study in respect of OREG developments.

Under Task MR7 of the MMSS/001/11 Research Project, fine scale harbour porpoise movement data will be collected using towed hydrophone technology. Actual and potential study sites include Orkney, Kyle Rhea, Sound of Islay and Bluemull Sound in Shetland. The Sound of Islay has been identified as a demonstrator tidal-OREG project by Scottish Government. There is 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.

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, risks of collision, and changes in the availability of the animals' habitats. These are each discussed in turn, and followed by another short section on effects due to electric fields.

4.1 Noise

All developments create noise – albeit at varying levels. Some of this is common to all technologies and stages of operation, such as that from increased shipping traffic associated with the construction, maintenance and dismantling of devices. There are also noisy activities associated with individual stages in the lifecycles of some projects. Pile-driving has been identified as being of particular concern. There is also noise resulting from the operation of both wind-OREG and tidal-OREG, though this is much quieter and studies to date suggest it may be less important (Tougaard *et al.* 2009) Each of these three are discussed in turn, after a brief introductory description of the hearing capabilities of important species.

4.1.1 Construction

Like oil and gas production platforms, current designs for OREG devices are based on prefabrication. The main noise, apart from the vessels required for installation, will be associated with the formation of foundations. Wave and some tidal devices can be tethered rather than directly sitting on their foundations, but they still require some anchoring to the seabed. Most tidal energy devices require substantial foundations. Four basic technologies are available: piling, gravity footings, anchors or drilled and grouted attachment. The noisiest of these is piling, which has been widely used for offshore wind farms in shallow parts of the North Sea. It is unlikely to be appropriate for many tidal devices because the strong currents that those devices utilise prevent the accumulation of the soft sediment into which piles are most easily driven.

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 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 mammal behaviour is probably the most intensively studied aspect of the environmental impacts of marine renewables industries. Most of the available information comes from monopole wind turbines, though the SeaGen tidal turbine in Strangford Lough was eventually fixed to the seabed with four pin-piles.

4.1.1.1.1 Noise characteristics

Thomsen *et al.* (2006) measured pile-driving noise from a jacket-pile construction in the German Bight. They reported peak sound pressure levels and sound exposure levels in 1/3 octave bands. Operation noise was also measured at a range of 110m from a 1.5MW wind turbine in Sweden. Sound levels at various distances from the source were calculated and zones of noise influences were assessed based on published data.

The broadband peak sound pressure level during pile-driving was 189 dB_{0-p} re 1 µPa (SEL = 166 dB re 1 μPa^2s) at 400 m distance, resulting in a peak broadband source level of 228 dB_{0-p} re 1 µPa at 1 m (SEL = 206 dB re 1 μPa^2s at 1 m). The 1/3 octave sound pressure level was highest at 315 Hz (peak = 218 dB_{0-p} re 1 µPa at 1 m) but as found in other studies, there was considerable sound energy at higher frequencies above 2 kHz. Source levels were estimated for larger pile-diameters by extrapolating from these results. Operational noise levels were much lower in both amplitude and frequency, with 1/3 octave sound pressure levels between < 90 and 142 dB_{Leq} re 1 µPa at 1m with most energy at 50, 160 and 200 Hz, at wind-speeds of 12 m/s.

Tougaard *et al.* (2009) reported measurements from the installation of 4 m diameter steel monopile foundations driven into hard sand in shallow water at Horns Reef, Denmark. The impulsive sounds generated had high sound pressures [source level 235 dB re 1 µPa(pp) at 1 m], and measurements at different ranges from the pile driving indicated an 18 log(R) transmission loss function. The sound profile had most of its energy at low frequencies, but they detected significant energy up to 100 kHz.

Bailey *et al.* (2010) measured pile driving sounds from installation of two 5 MW wind turbines in relatively deep water (>40 m) water off the NE coast of Scotland. Received levels were recorded at distances of 0.1km producing an estimated maximum broadband peak to peak sound level 205 dB re 1 µPa. Received levels were measured at distances up to 80 km before pile driving noise fell below background noise levels.

Nedwell *et al.* (2007a) reported the results of a substantial recording programme during pile driving operations at five wind farms North Hoyle, Scroby Sands, Kentish Flats, Barrow and Burbo Bank. Estimated source levels at the five wind farms varied

between 243 and 257 dB re 1µPa at 1m, having an average value of 250 dB re 1µPa at 1m. The transmission losses were characterised by values of geometric loss factor N of 17 to 21, and absorption factor of 0.0003 to 0.0047 dB/m. Under some conditions pile driving noise was detectable above background to ranges of between 10 and 25 km or more depending on local background noise levels.

4.1.1.1.2 Zones of audibility and potential hearing damage

Bailey *et al.* (2010) related the sound levels from installation of 5MW turbines to noise exposure criteria for marine mammals to assess possible effects. They estimated that bottlenose dolphins could suffer auditory injury but only within 100 m of the pile-driving. They also estimated that behavioural disturbance, defined as any modifications in behaviour, could have occurred up to 50 km away.

Thomsen *et al.* (2006) estimated that both harbour porpoises and harbour seals are likely to be able to hear pile driving blows at ranges of more than 80 km. They concluded that behavioural responses are possible over many kilometres, perhaps up to ranges of 20 km and that masking might occur in harbour seals at least up to 80 km. Using potential hearing damage criteria of 180 dB_{rms} re 1 µPa for cetaceans and 190 dB_{rms} re 1 µPa for seals they estimated that hearing loss might be a concern, at 1.8 km in porpoises and 400 m in seals. Thomsen *et al.* (2006) also concluded that severe injuries in the immediate vicinity of piling activities cannot be ruled out.

Nedwell *et al.* (2007a) used a metric of 90 dB above hearing threshold (referred to as dB_{ht}) to assess likely reaction and damage ranges for fish and marine mammals and predicted strong avoidance within ranges of a few kilometres by “sensitive species” such as harbour porpoise. This would suggest that phocid seals could be expected to react at significantly greater ranges. They also adapted metrics used to model the cumulative effects of noise on humans and suggested that exposure at a level of 90 dB above threshold for eight hours, or exceeding a peak level of 130 dB above threshold for 3 seconds is likely to cause hearing damage. Using the $90dB_{ht}$ L_{eq} criteria (i.e. sound exposure weighted for both hearing sensitivity and signal duration) they estimated that a harbour porpoise could be exposed to the noise during an entire pile driving operation at a typical range of 250 metres without harm. However, their results also indicated that peak levels may exceed 130 dB above threshold at larger ranges and that injury ranges indicated by the measurements using this criterion may be several hundred metres.

4.1.1.1.3 Masking vocalisations

David (2006) estimated that pile-driving sound would be capable of masking vocalisations by bottlenose dolphins within 10-15 km and weak vocalisations up to 40 km. For operational installations, Lucke *et al.* (2007) have suggested that there is potential masking of low frequency hearing. Conversely Tougaard *et al.* (2008) state that it is unlikely that the low frequency tonal noise would mask the high frequency signals of porpoises at any range. There is insufficient information on the extent to

which pile-driving or seismic pulses mask biologically significant sounds for marine mammals (Bailey *et al.* 2010). The better low frequency hearing of seals could mean that noise from operational installations would be able to mask biologically significant sounds.

4.1.1.1.4 Behavioural responses by harbour porpoises

These have been investigated during the construction of two wind farms at Horns Reef and Nysted.

4.1.1.1.4.1 Horns Reef offshore wind farm

Direct disturbance effects from piling during construction were reported at Horns Reef (Tougaard & Teilmann 2006; Tougaard, Madsen & Wahlberg 2008). Individual 4m diameter piles took approximately 70 mins to drive with source levels of 235 dB re 1 µPa (pp) at 1 m. Data from passive acoustic monitoring (T-PODs) indicated that porpoise detections fell throughout the area during piling operations. The effect was widespread, with similar declines in porpoise activity apparently out to ranges in excess of 25 km from the piling. This lack of a detectable spatial gradient in response means that it is not possible to extrapolate reactions to estimate the extent of the area affected.

Porpoise acoustic activity apparently returned to levels typical of the overall construction period within 6- 8 hours of the cessation of piling. Tougaard *et al.* (2009) suggested that although this may indicate that porpoises return to the area shortly after the disturbance, it could also indicate that there is a high natural turnover in porpoises in the area and that the recovery is due to undisturbed animals coming through. Without a method to identify and record responses of individual porpoises this cannot be resolved and the actual disturbance effects on individuals cannot be assessed.

Tougaard *et al.* (2009) estimated that during piling operations at Horns Reef, porpoises were significantly disturbed and may have been excluded from the construction area for up to 17% of the time over a 5 month period during which 80 foundations were piled. Between piling events there was no apparent decline in porpoise acoustic activity suggesting that other construction activities did not have a significant disturbing effect. Visual observations of surface behaviour of harbour porpoises was compared between days with pile-driving and days without. On days without pile-driving, the dominant behaviour was non-directional swimming (presumably associated with feeding), whereas the dominant activity on days with pile-driving was directional swimming (presumably associated with travelling) (Tougaard *et al.* 2003). Both acoustic and visual observations demonstrated significant effects at ranges up to 15 km from the construction site during pile-driving.

In a follow up study Brandt *et al.* (2011) monitored porpoise vocalisations during construction of the Horns Rev II offshore wind farm in summer 2008. Porpoise acoustic activity fell to zero for 1hr after pile driving and stayed below normal levels

for up to 72hr at a distance of 2.6 km from the construction site. A negative effect was detectable out to a mean distance of 17.8 km and within 4.7 km the recovery time exceeded the interval between pile driving bouts. The longer recovery periods meant that porpoise activity was reduced over the entire 5 month construction period.

4.1.1.1.4.2 Nysted Offshore Wind Farm

At Nysted, the main noise generating activities during construction were dredging and backfilling of gravity foundations. However some piling activity (1.5 to 10 hours per day over a 25 day period) occurred for installation of sheet piles around one turbine foundation (Carstensen, Henriksen & Teilmann 2006). Harbour porpoise acoustic activity was monitored by acoustic data loggers (T-PODs) in a structured Before-After Control Impact (BACI) experiment. A significant decrease in detection of porpoise clicks relative to the pre-exposure baseline period was seen in response to general construction noise (Henriksen, Teilmann & Carstensen 2003; Carstensen, Henriksen & Teilmann 2006; Tougaard *et al.* 2005). Mean waiting times, defined as the period between two consecutive encounters of echolocation activity, increased from 6 hr in the baseline period to three days in the wind farm area during the construction period with an apparently greater increase in waiting times (4hr to 41hr greater) during piling operations compared to general construction activities. The effect was apparently widespread although the increase within the wind farm was six times larger than changes observed in a reference area 10 km away (Carstensen, Henriksen & Teilmann 2006; Tougaard *et al.* 2005). Activity apparently returned to normal levels compared with the overall construction period some days after the pile-driving ceased.

4.1.1.1.5 Behavioural responses by seals

Tougaard & Teilmann (2006) used satellite telemetry and visual surveys to monitor harbour seal movements and behaviour during construction and operation of Nysted Offshore Wind Farm. Results suggested that the wind farm area was an important foraging site, but was not of greater importance than surrounding areas. The location accuracy of the telemetry system was not sufficient to allow estimation of the effects of construction activity. At least one seal was active inside the wind farm during operation and visual observations confirmed that seals were present. However during construction activities very few seals were observed either within or close to the construction site. Tougaard & Teilmann (2006) concluded that this was a response to pile driving noise.

Brasseur *et al.* (2010b) tagged grey seals in the Netherlands to investigate the effects of wind farm construction and operation. Their sample size at the time of pile driving activity was too small to assess the effects, but movement patterns of individual seals suggested that they may have moved towards the wind farm area after pile driving stopped.

4.1.1.1.6 Changes in local haulout counts of seals

A mixed haulout of harbour and grey seals is situated less than 2 km from the Scroby Sands wind farm (Skeate, Perrow & Gilroy 2012). Monthly surveys of the haulout showed a decline in harbour seal numbers during construction and an apparent failure to recover in the two subsequent years. During the annual moult monitoring surveys (SCOS 2011) numbers of harbour seals recorded at Scroby has increased continuously since 2003 suggesting that wind farm operation has not depressed haulout numbers. The numbers of grey seals increased year on year throughout the construction and early operational periods.

The temporary decline in harbour seal numbers seen at Scroby may indicate an effect of construction activity with some persistence in that effect. However, the Scroby counts represent approximately 5% of the East Anglian population and the observed changes may simply reflect similar changes in the harbour seal population in East Anglia (SCOS 2011).

A similar temporary reduction in numbers of seals using haulout sites close to Horns Reef and Nysted (Edren *et al.* 2010) was recorded during construction phases.

Recent piling activity in the Wash has presented an opportunity for two on-going studies: Using a combination of high resolution GPS telemetry and direct measurement of hearing sensitivity of seals using auditory evoked potential (AEP) methods SMRU are currently investigating the responses of seals to pile driving activity off the English east coast. In addition to allowing estimation of the detectability of signals from any specific piling blow for each individual seal the AEP data will also be used to assess hearing of wild seals in an area with a history of pile driving activity.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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 *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; on-going	2013

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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; on-going	2013

4.1.1.1.7 Mitigation

Pile driving is known to affect seal and porpoise distribution and behaviour. Current pile driving mitigation measures involve visual and/or passive acoustics monitoring surveys before piling starts to reduce the risk that sensitive animals are within a dangerous range of the pile when piling starts. These mitigation operations require dedicated marine mammal monitoring teams and are therefore expensive. The low probability of detecting animals at sea in a wide range of operational conditions means that current mitigation activities may not be effective in avoiding risks to marine mammals in sub-optimal conditions. Other than reducing piling noise or detecting animals and delaying operations until they move away, the only potential mitigation method seems to be some form of acoustic deterrence. Acoustic Deterrent Devices (ADDs) are widely used at fish farms to keep seals away from direct contact with fish cages. To be useful in the pile driving situation they need to also apply to cetaceans and, have the ability to move animals away over very large distances, at least several hundred metres.

Gordon *et al.* (2007) argued that aversive signals that cause animals to temporarily move away from an area where they would be at risk could underpin mitigation procedures that are both more effective in protecting wildlife and less expensive and onerous to industry. To be effective, such a method will require acoustic signals that move seals and cetaceans several hundred metres away from a sound source without contributing significant additional acoustic energy to the environment and thereby increase the risk of hearing damage. Work on ADDs at fish farms indicated that harbour porpoises may move away from, and be excluded from, large areas around ADDs (Olesiuk *et al.* 2002). Indeed, disturbance effects for harbour porpoise have been observed at ranges up to 3km. If a similar effect can be shown with seals, it may be possible to develop an effective mitigation measure for high energy

pile driving that will be cheaper to operate and potentially more reliable and effective than current observation based methods.

Development and testing of such mitigation methods have been identified as a major research requirement under the ORJIP programme and are covered by **Project 4: Improvements to standard underwater noise mitigation measures during piling**.

Wet renewables are still at a relatively early stage of development but there are concerns about the potential for collision, especially with tidal turbines (Wilson *et al.* 2007; Wilson & Gordon 2011). Alerting marine mammals to help them detect and avoid structures such as tidal turbines could reduce collision risk if a collision risk is identified. Such alerting signals would need to be more or less permanent features and would therefore need to have very different characteristics to the long range disturbance signals suggested for piling mitigation.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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.	Funded by MS	2015

4.1.1.2 Gravity footings and anchors

Both these approaches involve the lowering of suitable objects to the seabed. The difference between them is that gravity footings simply rely on their weight to maintain their position while anchors dig into or snag on the seabed. Although gravity footings may require extensive dredging to flatten the seabed the noise generated will be unlikely to approach the levels generated during pile driving operations.

4.1.1.3 Drilling

The original design for the SeaGen device in Strangford Lough was supported on a single foundation grouted into a large hole drilled into the seabed. Difficulties in obtaining a suitable barge to carry out this work led to four pin-piles eventually being used instead. Drilling noise was measured during installation of one of the footings for the SeaGen device in Strangford. Measurements indicated that at ranges between 28 m and 2130 m, the dBht (level above hearing threshold) for harbour seals varied from 59 to 30 dBht and fell below the minimum background levels at a range of 300m from the drill. Although audible to seals at close range, it seems

unlikely that the drilling of such foundations would cause substantial disturbance. Harbour porpoises have less sensitive hearing at low frequencies so that the range of detection and potential disturbance would be lower (Nedwell & Brooker 2008).

4.1.2 Operation

There will be noise associated with both the moving parts of these devices and flows over their structures. The frequencies and intensity of these noises is likely to vary between the technologies, so wind, tidal and wave devices are each considered in turn below.

4.1.2.1 Wind-OREG operation

4.1.2.1.1 Noise characteristics

The noise characteristics of operational offshore wind farms have been reviewed by Madsen *et al.* (2006). In comparison to the loud impulsive sounds of pile driving, the underwater noise from the operating turbines is generally low intensity (Madsen *et al.* 2006; Tougaard, Madsen & Wahlberg 2008; Tougaard, Henriksen & Miller 2009). Low frequency sounds generated in the turbine are transmitted through the tower to the foundations and radiated into the water column and the substrate. Sound levels from a range of turbines measured approximately 100 m from the foundations lay in the range of 100-120 dB re 1 µPa (1/3 Octave band levels) (Tougaard, Henriksen & Miller 2009).

Marine Scotland has let a contract to model underwater turbine operation noise. It is likely that this will feed into the NERC EBAO project into optimising array designs in terms of the acoustic effects of large arrays.

Wahlberg & Westerberg (2005) reviewed underwater noise measurements from operating wind turbines. They reported considerable variation in the noise levels from wind turbines related to different wind speeds and recording conditions but also noted major device-specific differences in noise output and sound radiation patterns. There are nevertheless strong indications that some wind turbines make more underwater noise than others. For example, intensities reported from the Utgrunden wind farm in the Baltic Sea were approximately 10 dB higher than elsewhere (Wahlberg & Westerberg 2005).

The underwater noise produced by wind turbines is dominated by low frequency pure tone signals below 1 kHz and mostly below 750 Hz. The strongest tonal component in Ingemansson Technology's (2003) recordings was around 180 Hz at a wind speed of 13m/s. The frequency content of the signals does not seem to vary with wind speed. Early studies indicated that sound intensity is not closely related to the size of the turbine, but this contention may not be valid for large turbines of several megawatts.

Ingemansson Technology (2003) reported that sound level increased with the number of active wind turbines in a wind farm. The measured sound intensity at any

point will therefore be a composite of noise from several devices and the resulting interference patterns will create a complex sound field.

The received level will also depend on the transmission characteristics. Transmission in deep open water can be approximated by a spherical spreading model where received sound intensity will decrease by approximately 20log(r), where r is the distance in metres, (at the low frequencies generated by turbines absorption is trivial). However, sound may be channelled through reflection at the surface and bottom in shallow seas, or through refraction in stratified, water. The degree of channelling will depend on the surface conditions (wave structure) and the topography and sediment type of the sea bed. The site specific modelling of propagation or transmission loss can produce accurate estimates of received levels, but extrapolation of such models to greater ranges or to other apparently similar sites and areas may be problematic.

Tougaard et *al.* (2008) suggested that although operational noise levels are relatively low, the fact that they will be produced almost continuously for long periods means that they could significantly increase the local ambient noise level. If background noise levels are low the turbine noise may be audible to seals and odontocetes at distances of several kilometres from the turbines.

Tougaard et *al.* (2009) used recorded noise from three different operating turbines to assess the zone of influence on both harbour seals and harbour porpoises. Signals were only detectable above background levels at frequencies below 500Hz. They estimated that harbour porpoises would only be able to hear the sound at ranges of 20–70 m from the foundations. The better low frequency hearing of harbour seals meant that they would be able to detect the signals at ranges of between 60 m and 6.4 km depending on the specific measurement conditions and the choice of cylindrical or spherical spreading loss models.

In addition to spreading and absorption effects, the structure of the footings or foundations of the turbines will influence the transmission of sound and the ranges at which different effects will occur. Marine Scotland has recently funded a modelling study of operational sound propagation from wind turbines with different types of footings/foundations. The results should provide more accurate estimates of noise exposures, but are unlikely to dramatically change these conclusions.

4.1.2.1.2 Operational noise effects on small cetaceans

Harbour porpoises and bottlenose dolphins have relatively poor hearing at the low frequencies generated by wind farms. For example, the estimated received levels at 83m from a single device at Utgrunden were around 125 dB re 1µPa at around 180 Hz. and between 100 and 110 dB at frequencies up to 1 kHz. Hearing thresholds for both species are around 100dB at 500 Hz and increase rapidly for lower frequencies (Johnson 1967; Kastelein *et al.* 2002). The sound levels recorded at Utgrunden would not cause hearing damage to porpoises or bottlenose dolphins even at very

short ranges. It is also unlikely that the low frequency tonal noise would mask the high frequency signals in porpoise vocalisations at any range (Tougaard, Madsen & Wahlberg 2008) although there is potential masking of low frequency hearing (Lucke *et al.* 2007).

4.1.2.1.3 Operational noise effects on phocid seals

Phocid seals have better low frequency hearing than either porpoises or bottlenose dolphins, e.g. harbour seal hearing thresholds at around 180 Hz have been reported to be around 80 to 85 dB although Kastelein *et al.* (2008) suggest that in unmasked conditions harbour seals may be 5 to 10 dB more sensitive at these low frequencies. The recorded source levels at Utgrunden would be approximately 70dB above threshold at a range of 10 m from the source. Kastak and Southall (2005) reported temporary threshold shifts (TTS – reversible hearing loss, see section 5.1.1. for definition) of between 2.9 and 12.2 dB resulting from 20 to 50 minutes of exposure to 2.5 kHz noise at received levels 80 to 95 dB above hearing threshold in a harbour seal. All animals recovered from the exposure within 24 hr and usually much earlier. The degree of TTS was related to received level and duration. They obtained similar results from a northern elephant seal and a California sea lion, suggesting that the results may be applied across pinnipeds and therefore apply to both harbour and grey seals.

If TTS is related to sound intensity in the same way at lower frequencies, harbour seals may be susceptible to TTS only at very short ranges, less than 5 m from a turbine and only if they remained this close for several seconds. This suggests that although the turbine noise may be perceived as a loud sound it is unlikely that it would cause TTS in any realistic field conditions and is therefore unlikely to cause permanent hearing damage in phocid seals.

4.1.2.1.4 Operational noise effects on large cetacea

There is little information on the hearing capabilities of large cetaceans although their predominantly low frequency vocalisations would suggest that they have good low frequency hearing. It is likely that large cetaceans will be able to hear the noise from wind turbines at least as well as seals. Future developments of wind farms in the central and northern North Sea and other waters around Scotland mean that larger numbers of large cetaceans such as minke whales have the potential to come into contact with wind farms.

4.1.2.2 **Porpoise distribution and behaviour**

Koschinski et *al.* (2003) modified recordings of a smaller turbine to simulate a 2MW turbine and played the noise to harbour porpoises. They documented a clear reaction, with closest approach distance increasing from 120 to 182m and increasing vocalisations. This implies that harbour porpoises can detect the sounds produced by wind turbines. However the playbacks may have contained higher frequency artefacts due to the signal enhancement method used. It is not clear whether the

porpoises were responding to the turbine noise or these higher frequency components.

There are few offshore wind farms old enough to have produced useable data on marine mammal responses. Consequently there are few published reports on empirical studies. Three published reports describing the effects of wind farm operations on distribution and local abundance of harbour porpoise are available for wind farm developments.

4.1.2.2.1 Horns Reef offshore wind farm

This study entailed seven years of surveys and five years of acoustic recordings of harbour porpoises between 1999 and 2006 covering the pre-construction, construction and operation phases (Tougaard, Henriksen & Miller 2009). Acoustic activity monitoring and visual surveys were carried out at the wind farm site and a reference site.

The results showed a clear effect of pile driving. The T-POD acoustic data indicate that porpoises left the entire Horns Reef area in response to the loud impulse sound generated by the pile driving operation. After a period of 6-8 hours, activity returned to levels normal for the construction period as a whole. Overall the level of porpoise acoustic activity was not significantly lower during construction, but was lower during a period described as “semi-operation” when large amounts of boat and other maintenance activity seems to have reduced porpoise activity within the wind farm. Ship survey data indicated a reduction in porpoise activity within the farm during construction. Overall the authors considered there to have been a weak negative and local effect of the wind farm during construction.

Porpoise acoustic activity and ship based sightings surveys indicated an increase in porpoises in the area as a whole during the operational period compared to the baseline. This is consistent with the general increase in porpoise numbers in the Southern North Sea. Overall the study found no significant changes in the distribution of porpoises between wind farm and reference areas in the operational phase compared to the baseline period.

4.1.2.2.2 Egmond aan Zee wind farm

This study entailed two periods of monitoring acoustic activity at the wind farm site and at two reference sites (Scheidat *et al.* 2011). The study covered the preconstruction/baseline period (2003-2004) and an operational period (2007-2009). Porpoise acoustic activity increased during the operational period when compared to the pre-construction baseline. However, there was an overall increase in porpoise abundance in Dutch waters over the last decade. Porpoise activity was significantly higher inside the wind farm than in the reference site. The authors suggest that this apparent increase in porpoise activity within the operating wind farm may indicate an attraction effect due to increased food availability inside the wind farm (reef effect) and/or a sheltering effect with reduced levels of disturbance from vessels within the

wind farm compared to the heavy ship traffic in adjacent areas of the southern North Sea.

4.1.2.2.3 Nysted Wind Farm

Porpoise acoustic activity was monitored before, during and for two years after construction of the wind farm by deploying three T-PODs within the wind farm site and three at remote reference sites 10km away. Porpoise activity declined significantly in the wind farm during and for two years after construction. A smaller but significant decrease in activity was recorded in the reference area. This may indicate a more widespread disturbance effect due to construction activities. The levels in the reference sites had returned to pre-construction levels by the second year of operation.

4.1.2.2.4 Seal distribution and behaviour

Koschinski *et al.* (2003) modified recordings of a smaller turbine to simulate a 2MW turbine and played the noise to harbour seals. They documented reduced surface activity of harbour seals within 200m of the playback system implying that the seals could clearly hear the sounds and moved away from the source. However, as mentioned above, the playbacks may have contained higher frequency artefacts due to the signal enhancement method used. It is not clear whether the seals were responding to the turbine noise or these higher frequency components.

4.1.2.2.4.1 Nysted and Rødsand II

McConnell *et al.* (2012) used high resolution GPS telemetry tags to study movements of harbour and grey seals in southern Denmark. Seals were tagged at haul out sites within 10 km of two wind farms: Nysted and Rødsand II. The results were compared with similar data collected in 2009. Both species frequently transited from the haulout sites through the two nearby wind farms. Visually, there was no obvious interruption of travel at the wind farms' boundaries. Interactions with wind farms were assessed using residence times within wind farm zones, comparison of path speed and tortuosity inside and outside the wind farms and the proximity of individual locations to individual turbines. No significant effect of the wind farms on seal behaviour was detected. This is in accord with another local study (Edren *et al.* 2010) of haulout counts that concluded that the wind farms had no long term effect on the local seal population trends.

4.1.2.2.4.2 Egmond aan Zee

Brasseur *et al.* (2010a) used similar GPS tags and older ARGOS satellite tags to track 12 harbour seals before and 24 seals after the construction of the Egmond aan Zee wind farm in the Netherlands. The satellite telemetry data indicate that seals tended to avoid shipping activity in the major shipping routes. The large distance between the wind farm and the haul-out areas meant that there were limited data to assess interactions. Their results indicated that seals avoided the area during construction, but were observed to use the wind farm areas after construction activities ceased and seals from another study were also recorded inside the

operational wind farm (Lindeboom *et al.* 2011). The authors concluded that although seals have been observed in the wind farm, minor effects on behaviour cannot be ruled out.

4.1.2.2.4.3 Horns Reef

The movements of seals from haulout sites adjacent to Horns Reef wind farm site were studied using similar telemetry devices (Tougaard & Teilmann 2006; Tougaard, Henriksen & Miller 2009). They deployed 21 simple location only satellite transmitters. The results showed that seal foraged over a wide area that incorporated the Horns Reef wind farm area. The results did not indicate a major effect of either construction or operation but the study animals spent little time inside the wind farm site either before or after construction and the study therefore had limited power to detect effects. Tagged seals were recorded in or close to the wind farm during operational periods and concurrent visual surveys indicated reduced seal activity in the area during construction but showed that seals were present within the operating wind farm.

4.1.2.2.4.4 Scroby Sands

Monitoring surveys during the annual moult (SCOS 2011) indicate that the numbers of harbour seals recorded at Scroby have increased continuously since 2003 suggesting that wind farm operation has not depressed haulout numbers despite the disturbance associated with construction. The numbers of grey seals increased year on year throughout both the construction and early operational periods.

The Department of Energy and Climate Change (DECC) is currently funding a project run by SMRU to investigate the impact of piling activity on the distribution and behaviour of telemetry tagged harbour seals off the south east coast of England.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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; on-going	2013

4.2 Physical contact

Collisions between OREG devices and marine mammals are a cause for concern. These are most likely to occur and result in serious injuries when marine animals come into contact with parts that are moving rapidly relative to the water. This problem is likely to primarily be associated with tidal-OREG devices and shipping associated with the construction and operation of OREG devices. A related issue is

entanglement with cables tethering devices to the seabed. That is most likely to occur with some designs of wave OREG device.

4.2.1 Shipping

Ship strikes are a common cause of death for cetaceans (Laist *et al.* 2001). 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 (Thompson *et al.* 2010a; Bexton *et al.* 2012). Although the circumstances and conditions under which such fatal interactions occur are as yet unknown, it is likely that OREG activity will increase the amount of shipping activity in coastal waters close to seal haulout sites and in offshore areas that may be important foraging sites for seals and cetaceans. Therefore there is potential that any such harmful interactions could increase. This is primarily a shipping issue, and is not restricted to marine renewable developments. The risks posed by shipping may be similar to those experienced by other marine industries such as the oil and gas, transportation, fishing and fish farming. However one major incident in Norfolk in 2010 was probably linked directly to the increase in near-shore shipping activity associated with the construction of Sheringham Shoal wind-farm (report Unexplained Seal Deaths (USD) tasks 1 & 2 of Theme 2 of MMSS/001/11).

Fatal interactions between seals and ships probably occur when boats are manoeuvring slowly or maintaining position in areas of high seal density. The construction and maintenance of tidal energy devices in strong tidal flows often in constricted water ways and channels will add an additional level of complexity to interactions. The constrained channel will necessarily increase the chance of any marine mammal using the channel being involved in a close encounter with a vessel. For example, a vessel (using dynamic positioning or simply motoring) holding station in a tidal stream will effectively be moving rapidly with respect to the water but stationary with respect to the bottom. Since ship/boat strikes appear to be a relatively common cause of anthropogenic marine mammal mortality, the additional complexity of shipping operating in strong tidal currents may pose some greater risk of harmful strikes. To date there is insufficient information to be able to estimate the scale of the problem or identify when or where these problems will arise.

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:

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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 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.	Funded by MS, current	2013

4.2.2 Tidal-OREG

The most obvious, and probably the most important interaction in terms of public perception, is the potential for injuries or fatalities resulting from direct contact with moving parts of tidal power devices (Linley *et al.* 2009; Wilson & Gordon 2011).

Devices and marine mammals must coincide in both space and time in order for any such effects to occur. Currently we lack any hard information on the behaviour of marine mammals during such proximate interactions so we can only estimate the potential for collisions. How animals act in terms of avoidance or attraction towards devices and their ability to evade collisions will scale the potential collision risk assessment. Understanding behavioural response to an operating tidal-OREG is a priority.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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.	Not funded	N.A.

4.2.2.1 Collision risk models

Two models have been proposed for estimating the risk of collisions between marine mammals and tidal turbines in UK waters:

a) The Scottish Natural Heritage (SNH) Collision Risk Model, also known as the Band model, was developed to estimate the number of birds that could be expected to collide with onshore wind farms (Band, Madders & Whitfield 2007). A modified version of it has been used to predict the rate of collisions between seals and the demonstrator tidal array that is planned for the Sound of Islay.

b) An alternative model (Wilson *et al.* 2007) was based on a movements and interactions model developed to investigate predation by zooplankton (Gerritsen & Strickler 1977).

Both models are based on two assumptions. The first is that any collision between a marine mammal and a marine renewable device will result in death. The second is that the patterns of movement of marine mammals will be the same in a particular place irrespective of the presence or absence of a marine renewable energy device. That is, marine mammals show neither attraction nor avoidance behaviour, and make no attempt to evade the moving parts. Under this assumption the number of marine mammals impacted can be derived from an estimate of how many will pass through the footprint of a device scaled by the likelihood of being hit by a blade based on the transit time of the animal and the rotation rate and number of the blades.

The Band model then applies a correction factor, assuming that 95% of potential collisions will be avoided, based on data on birds within terrestrial wind farms. A similar modification would also need to be applied to convert the output of the other model to estimates of actual risks to animals. Clearly, as accepted in the Band model, the assumption (not based on data) of no reaction is unlikely to be true. In addition, several factors are likely to influence both the likelihood and severity of such contacts (Wilson *et al.* 2007). To assess the probabilities of such occurrences we need information on:

- The characteristics of the device, e.g. rotation speed, blade length and number, and its position in water column.
- The short term and seasonal movement patterns of animals
- The size of the population at risk
- The dive patterns, depth usage and small scale movement patterns of individuals
- Reactions to presence of devices
    - Avoidance/ Attraction of animals to the turbines.
    - Evasion behaviour in close proximity to devices.

4.2.2.2 Data collection methods

In most cases, direct observation of collision is unlikely to be achievable, but there are available technologies that may be employed directly or modified to allow either direct (photography, sonar imagery etc.) or indirect (high resolution telemetry, acoustic localisation of natural vocalisations or attached high frequency pingers) observation of fine scale behaviour close to devices. The available methods have been reviewed and assessed under task MR3 of the Marine Mammal Scientific Support Research Programme MMSS/001/11[2]. Briefly they are:

4.2.2.2.1 Active sonar

Several active sonar systems have been developed for tracking marine mammals (Hastie 2012). In good conditions, modern acoustic imaging devices can provide reasonable quality images of marine mammals in real time. It has been proven to successfully detect and track marine mammals in the vicinity of underwater turbines at sufficient spatial and temporal scales to identify potential collisions. Such systems have been deployed as part of the research, monitoring and mitigation system at the Marine Current Turbines' Sea Gen device in Strangford Narrows (Keenan *et al.* 2011). Partly due to the safety shut-down procedures when marine mammals

[2] Task MR3: Methods for tracking fine scale underwater movements of marine mammals around marine tidal devices.

approach the turbine, there have been no recordings of close encounters in this study.

4.2.2.2.2 Passive acoustic monitoring (PAM)

PAM using an array of hydrophones that can detect (to species level) and track vocalising animals (primarily toothed whales – especially porpoises and dolphins) could be used to track fine resolution behaviour around tidal turbines. A static, accurately positioned array of hydrophones around a turbine, connected to a central processor should be capable of achieving the required level of precision. It is an unsatisfactory system for baleen whales that vocalise unpredictably. Whilst seals also do not regularly vocalise, they could be captured and fitted with individually coded acoustic 'pinger' tags. Such individuals would thus be capable of being tracked by a PAM system.

4.2.2.2.3 High resolution tracking

Here we refer to high resolution tracking using animal-borne telemetry devices. Due to the difficulties of catching small cetaceans this technique is currently limited to seals in the UK. The current best available tracking systems are based on GPS locations and detailed dive depth profiles that are sent either through the mobile phone system (the GPS/GSM tag) or through the ARGOS satellite system. These devices provide GPS quality locations for individual surfacings but positions during submergence can only be interpolated assuming some form of movement model. The accuracy of such estimates is determined by the rate at which position fixes are calculated and by the predictability of movements between fixes. Information of sufficient accuracy to determine proximity to turbine blades may be possible with the incorporation of 3D accelerometers and magnetometers to allow dead reckoning (DR) so that the 3-D underwater track can be accurately generated in between surface GPS locations. However for DR to be practically useful the local water current needs to be known to a degree of (spatial and temporal) accuracy that is not readily available.

As part of the monitoring programme at the Marine Current Turbines SeaGen site in Strangford Narrows (Keenan *et al.* 2011), GPS/GSM tags on harbour seals provided very accurate locations for a large proportion of surfacing events. Whilst the lack of usable DR precluded accurate underwater track recreation, it was possible to estimate the number of times seals passed the device as they transited through Strangford Narrows (approximately 1 km wide). Thus the method provides some information on avoidance behaviour.

4.2.2.2.4 Mechanical sensing

Turbine blades are routinely equipped with strain and accelerometry sensors to monitor mechanical performance. It has been suggested that information from such sensors could be used to detect collisions. Developers in Scotland and Wales are in the process of assessing the effectiveness of such systems for detecting collisions with marine mammals. As far as we are aware no results have been published and

there have not been any direct collision impact tests of such systems. Such a test could be conducted using animal carcasses introduced upstream of an operating turbine.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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.	Not funded	NA

4.2.2.2.5 Video surveillance

Animal-borne video cameras have been widely used to identify prey types (for example Davis, Hagey & Horning 2004). However as these all rely on retrieving the camera and the low probability of successfully recovering the device means that few samples would be obtained. Thus, although this may be an effective research tool under particular conditions, it is unlikely to be useful as a monitoring method for any UK marine mammal species.

Static video surveillance cameras can be used to monitor the local underwater activity of marine mammals (for example Simila & Ugarte 1993; Herzing 1996). In addition, direct video monitoring of a functioning underwater device has been conducted at the Open Hydro test site at the European Marine Energy Centre (EMEC)[3]. However two issues limit their ability to observe marine mammal interactions at turbines. First, underwater visibility is often limiting. Second, video surveillance would require an artificial light source at night. The responses of marine mammals to lights underwater have not been studied and they may be either attracted or repelled by artificial lights at night. In good conditions (sufficient ambient light and good visibility) video surveillance has the potential for detecting impacts and is perhaps the only method with the capacity to allow assessment of the immediate consequences of impacts.

[3] No marine mammals have been observed on the video although they are regularly recorded by the land based observers

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
Marine mammal responses to artificial lights	Light	investigate responses to different light sources to identify possible illumination for night-time video surveillance.	Not funded	N.A.

4.2.2.2.6 Stranding surveys

As part of the monitoring programme at the Marine Current Turbines SeaGen site in Strangford Narrows (Keenan *et al.* 2011) targeted standings scheme with post mortem evaluations of any stranded marine mammal carcasses was established to look for signs of turbine impact. Over a three year period of operation no such signs have been reported. At present this provides little information on the likelihood of collisions having occurred as there are no estimates of the likelihood of an injured animal or damaged carcass washing ashore and being found.

4.2.2.3 Data availability

Medium scale information about the movements of harbour seals in the vicinity of an operating tidal turbine have been obtained using GPS/GSM tags in Strangford Lough. In addition, similar information will be available in 2013 from a study of harbour seals movements close to operating turbines at the EMEC site in Orkney (NERC "RESPONSE" study). However there is still a pressing need for fine scale interaction studies for both seals and cetaceans. The potential to conduct such a study could exist at the Sound of Islay.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
Fine scale marine mammal behaviour in the vicinity of a working tidal array.	ARRY	1. Building on the recommendations of the Marine Scotland 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.	Not funded.	NA

In addition to studies at operating tidal-OREG sites there is the potential to examine the response to playback of recorded turbine noise to wild and captive seals:

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
Investigation of marine mammals' responses 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; current	2013

4.2.2.4 Effects of collision

Other than the assumption that there will be some form of trauma there is in fact little evidence of the likely consequences of a collision between any marine mammal species and a turbine blade. Analogies with ship strikes and boat propeller strikes are speculative and may be misleading because of the differences in shape and collision speeds involved. Experimental exposure of marine mammals to tidal turbines has not been attempted and to date there have been no direct tests of the effects of turbine blade impacts on marine mammal carcasses. There are therefore currently no data on the levels of damage caused by collisions. A targeted research project to examine likely damage patterns is thus required (see 4.2.2.4.2).

4.2.2.4.1 Computer simulation.

An impact damage model has been developed to assess the likely consequences of the impact of a specific tidal turbine blade on a killer whale (US Department of Energy 2012). The model was developed in response to concern about the potential severity of encounters between killer whales and an OpenHydro tidal turbine in Puget Sound. The model estimated the forces developed during a head-on collision with an adult male killer whale assuming the strike occurred on the head. The consequence of those forces on the skin and underlying tissues of whale were assessed. In the absence of data on the biomechanical properties of whale tissue the characteristics of a number of alternative natural and synthetic materials were substituted as surrogates for killer whale tissue.

Although testing the appropriateness of the surrogate tissues needs further work, the results of the finite element models suggest that the maximum forces generated in such a collision would not have been sufficient to tear killer whale skin or cause

skeletal damage. Thus it is unlikely that such a collision would kill or seriously injure an adult killer whale.

The authors point out that the results are not likely to be applicable to other species and other turbine designs, for example the hollow centred OpenHydro device is unlike most other designs being tested for deployment in UK and Scottish waters. However, a similar approach could be applied to each design and each species of potential interest.

4.2.2.4.2 Carcass field experiments.

A practical and viable model of collision effects requires information on a number of aspects of marine mammal behaviour, movements and distribution. However a major constraint on the utility of these models for management is the fact that they currently take the precautionary view that any collision will be fatal. This is unlikely to be the case and in some potential device-animal collisions there may not even be any significant injury (US Department of Energy 2012).

Blade speed increases with distance from the hub and varies, often in a nonlinear fashion, with current speed. The levels of injury sustained during a collision will therefore depend critically on where along the blade and when in the tidal cycle they occur as well as on the current velocity-blade rotation speed relationship. Information on the levels of and types of injury inflicted by collisions at different speeds is required to assess the likelihood of serious injury. The same information is required to interpret damage observed on stranded and by-caught carcasses.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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	2014

4.2.2.4.3 Fish studies.

Laboratory flume tank experiments have been carried out on live fish and these results may provide some insight into the levels of damage that may be suffered during collisions. However caution should be used extrapolating from such studies due to taxon, size, anatomy, behaviour, and turbine type differences.

Amaral *et al.* (2011) report on a study to determine behaviour, injury and survival rates. Rainbow trout (*Oncorhynchus mykiss*) and largemouth bass (*Micropterus salmoides*) juveniles were released directly upstream from two types of operating turbine (Darrieus open helical cross flow and Welka UPG axial-flow) to observe their behaviour and to record injury and survival rates from turbine impact. Two size classes of fish (100-150mm and 225-275mm) were used in flow rates of 1.5 and 2.1 m/s. Few fish passed through the area swept by the turbines, some swam upstream and others swam around the turbine. Of those assessed to have passed through the turbines over 98% survived in each case (98.4 ± 1.10), not significantly different to control groups with no turbine present, and few injuries were seen in the experimental fish other than damage due to handling.

Additional experiments with Atlantic salmon (*Salmo salar*) smolts and American shad (*Alosa sapidissima*) adults using a vertical axis Encurrent turbine produced similar results with no significant injuries observed with either species.

Fish behaviour around an array of six tidal turbines in the East River of New York was studied as part of a demonstration for the Roosevelt Island Tidal Energy (RITE)[4]. Fish movements were monitored using an array of acoustic cameras (Split Beam Transducers) and DIDSON sonar cameras. Results showed that resident and migratory fish generally avoided the areas in which the turbines were located and tended to prefer inshore, slower moving waters. Fish were not recorded in the array at flow velocities greater than 0.8 m/s. Limited observations showed fish passing by the rotating turbines, following the hydrodynamics of the system. These data indicated that fish were able to detect and successfully pass around the operating turbines.

Observations of fish were recorded around a barge mounted tidal turbine in Cobscook Bay, Maine, USA (http://www.orpc.co). An Ocean Renewable Power demonstration turbine was mounted on a barge that allowed the turbine to be lowered into the water for testing. Two acoustic (DIDSON) cameras were mounted in front of and behind the turbine, and data were collected over a 24 hour period. The study indicated that fish did not entirely avoid, and regularly approached, the turbine and barge. More fish interacted with the turbine when it was still than when it was rotating. The majority of the fish detected by the cameras were already located above or below the turbine when they entered the field of view, which may indicate that they were able to detect the turbine at greater distances than could be

[4] http://www.theriteproject.com/Documents.html

monitored (> 2.5 m upstream) by the DIDSON cameras. Results of day night behaviour comparisons suggested that vision was an important component of turbine detection.

Operating turbines at the EMEC site in Orkney were monitored using ambient light video monitoring. When turbidity conditions allowed, concentrations of fish were observed on the downstream side of the device when the turbine blades were stationary. However, during strong flows they were absent and no fish were seen to pass through the rotors.

4.2.3 Entanglement

Marine mammals are known to become entangled or entrapped in a wide variety of man-made structures especially fishing gear (Read, Drinker & Northridge 2006). In terms of marine renewables, most/all tidal-OREG devices will be fixed directly to the seabed or held in place by robust tethers that will be unlikely to pose an entanglement risk. Because of the severe drag on cables in high tidal flows it is also unlikely that there will be any freely hanging cables associated with tidal turbines.

Most perceived entanglement issues are related to wave-OREG devices. Very little is currently known about the risk of entanglement to whales and other marine wildlife in such devices. In general any rope or cable in the sea can pose a finite risk of entanglement or collision to whale or other cetacean. The facts that sperm whales have been reported caught in undersea telegraph cables and dolphins get caught in crab pot lines make it clear that such animals are vulnerable. Most work on baleen whale entanglement has previously been focused on interactions with fishing gear since most ropes and cables in the oceans are put there by fishery related activities. In Scottish waters it is generally assumed that most baleen whale carcasses that are recovered with evidence of rope marks have been the result of entanglement in lobster creel lines. Previous work has estimated that there may be over 7000 km or rope deployed in the sea around Scotland at any one time, and indeed it is therefore likely that this single source poses the greatest risk (Northridge *et al.* 2010). A fin whale that was stranded at Stoer in the Highlands in October 2007 was diagnosed as having died due to entanglement, where the marks on the animal's body were consistent with a thick cable rather than a creel line. Whale entanglements have also been reported in aquaculture mooring lines in Australia and Iceland - which are likely to be much thicker and more taught than the loosely set polypropylene line used for creel fishing. Sometimes cetaceans will actively rub against taught cables and can then get entangled.

The advent of moored structures such as wave machines on a large scale could potentially open up a new area of concern for wildlife entanglement. The issue has been addressed in at least one workshop in the US, where the risk of entanglement was identified but not quantified. Mitigation measures to minimise whale interactions are already being deployed around at least one wave power development site in Oregon.

We assume that slack lines will pose a greater risk of entanglement to large cetaceans than taut cables, but it is difficult to predict how cables will behave during operation and how whales will react to them. However, small the risk of entanglement posed by mooring lines, the greater their number, the greater the probability of entanglement.

4.3 Exclusion and barrier effects

If habitat exclusion and/or barrier effects do occur it is highly likely that the disturbance would be due to marine mammals responding to the acoustic signatures of devices or arrays.

To date the only study to have addressed the issue of barrier effects or habitat exclusion has been the environmental impact study of the single SeaGen turbine in Strangford Narrows. A combination of GPS/GSM tag telemetry studies of harbour seals and visual and passive acoustic monitoring (TPODs) of porpoises showed that both species continued to swim past the SeaGen device and moved into and out of Strangford Lough while the turbine was operating. There was some indication that harbour seals avoided the centre of the channel when the turbine was operating. It was also noted that during the operational phase the rates of transit past the device were lower when the turbine was active compared to periods when it was stationary. The TPOD data did not allow precise estimation of locations so it was not possible to assess fine scale avoidance. There was a reduction in porpoise activity during construction, but this was temporary and porpoise acoustic activity returned to baseline after construction was complete.

Porpoise activity has also been monitored in the vicinity of an OpenHydro tidal turbine device in the Minas Passage in the Bay of Fundy (Tollit *et al.* 2011). Long term data were collected from two C-PODs placed at 150m and 700m from the turbine. Harbour porpoise presence was detected on most days (93%), but usage of the site was typically low. Activity was significantly higher at night. There was no significant difference in porpoise activity levels between the turbine (11%) and control (12%) site although there appeared to be a difference in click train structure. However, the study reported that the device was not operational during the study so the porpoise activity relates simply to the presence and absence of devices and not the noise associated with operation (Tollit *et al.* 2011).

Long term data from an on-going wildlife observer programme at the EMEC site in Orkney has been collected before and during operation of several wave devices (that effectively form a small, ad hoc array of tidal devices). To date there are no published analyses of the effects of device operations on the observations and it is not clear that the data are sufficient to allow an assessment of effects on marine mammals at either site. An analysis of the entire dataset is currently underway.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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	2014

4.3.1 Wave-OREG operation

Most of the wave generators in a relatively advanced stage of development are floating platforms of some sort and also have minimal contact with the seabed. Even bottom mounted systems such as Oyster[5] are unlikely to reduce overall foraging habitat availability. Although wave generators will have mooring and or anchor systems they are unlikely to have a major impact on the available habitat in comparison with the scale of foraging area used by marine mammals.

4.3.2 Tidal-OREG operation

Individual tidal turbines are relatively small and many designs have only minimal structures in contact with the sea bed.

There may be some downstream changes in sedimentation or benthic communities as a result of disruption of tidal flow patterns and there may be changes in shorelines due to changes in wave patterns, but again, on the scale of marine mammal foraging ranges these would not be expected to significantly reduce foraging habitat availability and would, at most, have a small effect on several animals or a larger effect on a small number.

Changes to local oceanographic features such as tidal eddies may also alter foraging habitat quality. To date we have little information on foraging behaviour for any species at the fine spatial and temporal scales needed to identify such effects. Recent studies of harbour porpoise activity suggest that they may exploit eddies in tidal rapids (Gordon *et al.* 2011) but it is not clear if this is an important habitat requirement at an individual or population level. Nor is it clear how the changes in tide streams would alter foraging behaviour and/or alter foraging habitat quality.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
Fine scale habitat use by porpoises in tidal rapids	EDDIE	Combinations of towed 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.	Not Funded	

[5]http://www.aquamarinepower.com/

Any large stable structure, either floating or fixed to the sea bed, is likely to attract prey species. Several offshore fisheries exploit this by deploying Fish Aggregating Devices (FADs) (Buckley, Itano & Buckley 1989). It is likely that large arrays of any marine renewable device will have some sort of reef effect. The magnitude of any such effect, however, is likely to be linked to the size of the structure and is likely to be strongly dependent on the site characteristics and the device architecture.

This could potentially provide enhanced foraging habitat and improved foraging success for marine mammals in the vicinity of the devices/arrays. Conversely it may attract marine mammals to the vicinity of devices and increase the potential for direct potentially harmful interactions with devices. To date there have been no studies of marine mammal foraging behaviour in the vicinity of multiple tide or wave devices. Studies in Netherlands may indicate increased use of wind farm sites by harbour porpoises and possibly also harbour seals, after initial disturbance during construction. This has been speculatively associated with either reef effects or reduced boat traffic.

4.4 Electric fields

Recent reports of tests of electric fields as seal deterrents appear to show that both phocid and otariid seals are extremely and unexpectedly sensitive to electric fields. This is being exploited as a means of deterring seals from predating on fish in freshwater systems. Forrest *et al.* (2009) showed that seals were deterred from swimming though a 200 microsecond pulse electrical field with gradient of between 0.1 - 0.32 V/cm. These levels did not seem to affect the behaviour of salmonid fish and catch rates of salmon were higher at nets protected by an electric field.

Recent trials using a similar system in sea water, Milne *et al.* (2012) demonstrated similar deterrence effects but also showed that the electric field intensities eliciting responses in seals are similar to those eliciting similar voluntary and involuntary responses in humans and dogs. They conclude that there is no evidence for higher sensitivity in seals than in large terrestrial mammals. This is consistent with the fact that seals do not appear to have specially adapted electrically sensitive organs.

Wilson & Gordon (2011) point out that the seal exclusion trials used short pulse length electrical fields and that seal sensitivity increased as pulses lengthened. However, Milne *et al.* (2012) show that this response asymptotes at pulse duration around 1 ms, indicating that seals are unlikely to be more sensitive to a continuous electrical field.

Estimates of the electrical fields that will be generated in seawater from buried power cables from offshore renewable energy devices are around 4 orders of magnitude lower. The maximum electrical field in the sea for buried power cables was estimated to be 0.9μV/cm and even lower, between 0.015-0.025 μ V/m in a later study (Gill *et al.* 2005). It is therefore unlikely that seals would be able to detect these signals and extremely unlikely that any avoidance behaviour would result from such exposures.

There have been no attempts to assess the sensitivity to electrical fields in any cetacean species found in UK waters, it has been shown that at least one dolphin species, the Guiana dolphin (*Sotalia guianensis*), has specialised electro receptor sense organs. These modified vibrissae appear to be sensitive to voltage gradients several orders of magnitude higher than the apparent sensitivity of seals (Czech-Damal *et al.* 2012).

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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.	Not Funded	

4.5 Changes in distribution

In this section we only consider the effects of operating wind farms and ignore the effects of piling noise and other construction disturbance.

4.5.1 Porpoises

The underwater noise levels from operational wind farms are considered to be too low to pose any realistic risk of physical damage to porpoises. The frequency range of the underwater noise from wind turbines also makes it unlikely that there are any masking effects.

A summary of information on displacement of marine mammals around operational wind farms is available from Scottish Government at http://www.scotland.gov.uk/Resource/0040/00404921.pdf. Controlled exposure experiments indicate that porpoises may be able to detect wind turbine noise at ranges of tens to hundreds of metres. However, based on the results of acoustic and visual monitoring of porpoises at operational wind farms, there is no clear evidence of significant displacement of animals from the wind farm sites due to turbine noise. Studies at Nysted and Horns Reef suggest that construction effects may be detectable tens of kilometres from the wind farm sites. At Nysted the observations suggested that the decrease in activity due to construction carried over into the two subsequent years although there were reportedly indications that the effect was decreasing. Activity levels in the reference area were depressed during construction but had returned to normal by the second year. It therefore seems that the underwater noise generated by operational wind farms is unlikely to cause significant disturbance to harbour porpoises within the wind farm area. If there are

no significant local effects it seems highly unlikely that there are significant wider scale effects.

We are not aware of any reports of studies of other cetaceans around wind farms. Other small cetaceans likely to occur in UK waters will have similar hearing capacities to harbour porpoises at the low frequencies produced by tidal turbines. Some may be several dB more sensitive, but the same arguments about lack of damage risk and lack of masking effects will apply.

As there have been no reported studies of reactions of other species to wind farms it is not possible to predict their responses to wind turbine noise. However Marine Scotland have a contract to model underwater turbine noise and make a judgement on likely effects on various species (these include bottlenose dolphins, minke whales, harbour porpoises and harbour seals). The report will be available in September at http://www.scotland.gov.uk/Publications/2013/09/3362/downloads.

4.5.2 Seals

The underwater noise levels from operational wind farms are probably too low to pose any realistic risk of physical damage to seals at ranges of more than 10m. Even within this range, seals would need to remain within the sound field for considerable periods before suffering any TTS effects. It therefore seems unlikely that seals will suffer hearing damage from wind turbine noise.

Seals are more sensitive to low frequency sound than are small cetaceans. If they use this low frequency band for passive prey detection or predator detection, it is possible that wind farm noise may cause some masking of biologically significant sounds. If such effects occur and are biologically meaningful they will probably be restricted to the close vicinity of turbines.

The only study of seal movements with sufficient power to detect effects of an operating wind farm was McConnell *et al.* (2012). They found no effect on any of the movement and distribution metrics that they could test. In addition, other studies with lower power are broadly in agreement.

A study of haulout behaviour at Scroby Sands within 2km of the wind farm indicated that counts of both harbour and grey seals have continued to increase during the 6 years of operation after a possible temporary effect of construction activity on harbour seals (Skeate, Perrow & Gilroy 2012).

There is at present only a limited amount of information, but these preliminary results do not indicate a major change in distribution of either grey or harbour seals as a result of current wind farm operations. It is also therefore unlikely that there have been larger scale redistributions as a result of wind farm operations

5 Consequences of Impacts

In Section 5.1 we consider the possible cascade of effects – from individual impacts to population vital parameters. In Section 5.2 we consider modelling frameworks that can use such information to predict population level consequences.

5.1 Individual

The potential proximate impacts outlined in Section 4 can have various consequences for individual animals within a population depending on different factors at the time of exposure. These include species, sex, condition, age, sociality, behaviour and season. Impacts considered at the individual level may be manifest at the population level if responses are sufficient to produce effects on any of the vital rates (namely reproduction or survival, two major drivers of population trajectories and abundance) or on permanent emigration rates. Assessing such impacts at the individual level will therefore be considered in the context of the ultimate effects on the population in the short, medium or long term, recognising that there may also be transient effects and welfare issues for individual animals.

The pathways that the three main proximate impacts, namely noise, physical contact and habitat alteration may take to potentially affect either survival or reproduction or both are shown in Figure 1. The key points within each are discussed below.

5.1.1 Noise

5.1.1.1 Direct effects on survival and reproduction

Although there are no specific studies on the effects of noise on marine mammal vital rates, particularly reproduction, much attention has focused on the direct effects of noise on the auditory system (Southall *et al.* 2007), particularly following the mass strandings of beaked whales in the Bahamas, Canary Islands and Mediterranean, that, in some cases, have clearly been associated with the use of midrange tactical military sonar (Wartzok *et al.* 2005; D'Amico *et al.* 2009; Filadelfo *et al.* 2009). Follow-up studies have also considered the non-auditory physiological effects of sound. These include resonance effects in which air spaces and gas-filled tissues could be theoretically driven into resonance by acoustic energy, (Finneran 2012) and rectified diffusion in which microscopic bubble nuclei are formed in the presence of high-intensity sound (Crum *et al.* 2005). Such direct physical effects, generally resulting from very loud impulse sounds in specific frequency ranges have the potential to be individually fatal (Nedwell *et al.* 2007b). Extremely loud noises exceeding 220 dBre 1 µPa are likely to occur only at close range during piling activity.

Studies on sheep and mice have reported hearing damage in the foetus of pregnant females exposed to noise during gestation (Griffiths *et al.* 1994; Pierson 1996) although the strongest responses were reported in the studies which exposed the ewes to intense broadband noise (120 dB sound pressure level for 16 h). In

humans, a study on the effects of noise exposure to the foetus of mothers that worked while pregnant, in noise conditions ranging from 65 to 95 dBA-8h (Lalande, Hetu & Lambert 1986) found a three-fold increase in the risk of having a high-frequency hearing loss in the children whose mothers were exposed to noise in the range of 85 to 95 dB Leq, and a significant increase in the risk of hearing loss at a frequency of 4000 Hz when these exposures involved a strong component of low-frequency noise. Although it is difficult to directly compare these studies with the exposure levels to underwater sound that are likely to occur as a result of OREG activity the results of these and other studies on noise-induced hearing loss in the foetus (Pierson 1996) suggest this is a potential direct effect risk. Further studies on auditory brainstem responses (ABR) in seal pups of females potentially exposed to OREG construction and operation noise are warranted. Noise attenuation differences between species may mean that the received levels between mice, sheep and marine mammals are different and that higher exposures are required before the same effect is seen but permanent threshold shifts (PTS) in pups and juveniles could have consequences for their longevity, survival and reproduction as they may be unable to forage well or reproduce successfully due to impairment in hearing abilities necessary to navigate and mate.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
Auditory brain stem responses in seal 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.	Not funded	NA

Ear infections are known to cause hearing damage in harbour seals (Ketten *et al.* 2011). An additional pre-existing impact to consider, particularly relevant to marine mammals in some regions, is the impact of exposure to polychlorinated biphenyls (PCBs) on hearing (direct ototoxicity). Crofton and colleagues (Crofton & Rice 1999; Crofton *et al.* 2000; Lasky *et al.* 2002) demonstrated the ability of PCBs to disrupt the development of the cochlea in rats, by disrupting thyroid function. A relationship between thyroid hormone disruption and PCBs in seals has been well established in a number of studies (Brouwer, Reijnders & Koeman 1989; Tabuchi *et al.* 2006) and harbour seals in some regions in Scotland (particularly on those on the southwest coast such as Islay and Jura where OREG developments are planned) have high levels of PCBs in their blubber (Hall & Thomas 2007). However, no studies on the ototoxic effects of PCBs in seals prior to OREG developments have been carried out. Further studies on ABR responses in seals in relation to PCB exposure and age

are needed to investigate this, particularly to establish any existing negative impacts prior to OREG construction and to determine the potential for exacerbating effects.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
Ototoxic effects of PCB exposure in seals	PCB	Previous studies have shown that harbour seals in particular captured on Islay and Jura have very 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.	Not funded	NA

5.1.1.2 Indirect effects on survival and reproduction

If noise exposure is below some critical energy flux density limit, there will be a temporary loss of hearing known as a temporary threshold shift (TTS) in hearing sensitivity (Wartzok *et al.* 2005). This is because the hair cells in the ear will eventually return to their normal shape. However, if the sound exceeds a higher limit the hair cells in the cochlea become damaged and die. This is known as the permanent threshold shift (PTS). Threshold limits for these effects vary among species and individuals so need to be characterized statistically.

Wind-OREG construction noise is probably the most widely recognised potential impact with particular emphasis on piling noise. Pile driving produces high sound source levels and the potential impacts are of most concern (Dolman & Simmonds 2010). In addition, there is some evidence that other non-auditory effects of noise exposure may need to be considered as loud noise exposure may directly affect reproduction in mammals, largely mediated through the neuroendocrine system (Figure 1).

The hypothalamic pituitary axis (HPA) is the integral part of the endocrine system responsible for maintaining homeostasis. The neural core consists of the hypothalamus which contains neurosecretory neurons that synthesise hormones such as dopamine and corticotropin-releasing hormone and the pituitary gland that produced adrenocorticotropin. The adrenal gland makes up the third arm which secretes catecholamines (epinephrine and norepinephrine, also known as adrenalin) and steroid hormones such as cortisol, corticosterone and aldosterone (the corticosteroids). Production of these proteins increases after a wide variety of stressful stimulus to allow the animal to respond quickly, the so-called ‘fight or flight’ response. The physiological changes are collectively known as the ‘stress’

response. The ability of an animal to return to and maintain a balanced state is central to the impact of noise on individual reproduction and survival.

The connections between the physiological, cellular, and genetic processes involved in individual responses to noise and their effects on behaviour and fitness suggests an integrative framework is necessary when assessing how and why animals are affected (Kight & Swaddle 2011). Given the cascade of interlinked effects of stressful noise in a receptor like a marine mammal it's not possible to find a single hormone or protein response marker. To address this issue a number of corticosteroid, other hormone and protein markers to assess stress need to be developed validated and dose-response curves in relation to noise established (Wartzok *et al.* 2005). Wartzok *et al.* (2005) also recommend the "development of a sampling package that could take blood samples on a controlled basis and stabilize hormones for later analysis or process samples "on-board" for corticosteroids at various stages of a controlled exposure experiment would be invaluable for determining the stress that the sound is producing". SMRU and scientists from the University of Tokyo in conjunction with a company called Little Leonardo in Japan are currently in the process of developing a remote blood sampling device for phocid seals and early results from the studies on the captive animals at SMRU are very promising (Takei and Hall pers. comm.).

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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.	Not funded	NA

There are a number of studies which suggest that noise stress is particularly damaging to females, probably due to their size, hormone expression and the costs of reproductive investment (Kight & Swaddle 2011). Rasmussen *et al.* (2009) found that mice exposed to construction noise produced a significantly higher number of stillborn mice compared to the control group when exposure occurred early in gestation. In particular the average litter size of the mice exposed to 70-90 dBA (1 h daily exposure to a 6 min continuous loop of concrete saw cutting with a dominant energy between 2 and 8 kHz) during the peri-implantation period was significantly smaller ($p=0.005$) than that of controls (5.8 mean litter size in exposed compared to 10.2 mean litter size in unexposed). Zakem & Alliston (1974) exposed mice to 83

and 95 dBA of noise intermittently during gestation also reported increased preimplantation mortality, decreased litter size, embryo size and weight among the exposed offspring. Kimmel, Cook &Staples (1976) exposed pregnant mice to 100 dB of noise on various days during the first two weeks of gestation and reported significantly increased resorption rates and decreased numbers of live foetuses per litter in each of the treated groups of animals. Meyer, Aldrich & Easterly (1989) reviewed these and a number of other studies on rats and mice (Nawrot, Cook & Staples 1980; Nawrot, Cook & Hamm 1981; Cook, Nawrot & Hamm 1982) finding that embryotoxic studies of noise supported an exposure effect although the data were quite inconsistent among the various exposure conditions. However, many did report statistically significant effects that included intrauterine growth retardation, foetal mortality, increased litter resorptions and teratogenesis (malformations in the embryo). Although the specific mechanisms for these effects were often unreported some studies have suggested that it is likely that increased catecholamines in blood cause a reduction in blood flow to the uterus and ovaries resulting in foetal death (Esquivel, Castro-Vazquez & Rosner 1974). Other studies suggest an immune-endocrine disequilibrium as a result of increased glucocorticoids, resulting in an unsustained pregnancy (Arck *et al.* 1995).

However, although mice have a similar hearing range and audiogram to those of pinnipeds and odontocetes, particularly at the high frequencies (mouse range 4 kHz to 45 kHz at 70 dB sound pressure level (SPL), odontocetes have best frequency hearing at between 10 and 100 kHz at better than 70 dB re 1 µPa, for pinnipeds between 1 and 30 kHz at better than 70 dB re 1 µPa) it is difficult to determine how comparable the data from these model species would be for pinnipeds and odontocete cetaceans. Comparing the levels of noise to some reference, such as the noise required to produce a TTS might be a useful benchmark. The noise exposure in the reproductive effects experiments were often at or around the level causing TTS in mice. Studies of bottlenose dolphin using pure tones and octave band noise ranging from 1 s for pure tones up to 54 min for octave band noise at frequencies between 3 and 75 kHz found the observed minimum intensity at which TTS was observed to range from 160 to 194 dB re 1 µPa. This reference level may then provide some guidance for the magnitude of reproductive effects taking into account the difference between SPL sensitivities in air and in water. However, we would guard against using this as some reference threshold, given the difference in species sensitivities, reproductive strategies (single births compared to litters of offspring) etc. it is not clear how relevant or transferrable the results of the studies on laboratory animal models are for assessing the direct risks of underwater noise exposure to marine mammal reproduction. In addition the laboratory animals were unable to escape the noise. Although the most likely response to loud impulsive noises such as pile driving would be for the marine mammals to move out of the area when the noise becomes intolerable, effects may occur at levels within the zone of toleration. Animals may tolerate chronic the noise, perhaps because of productive foraging habitat, with potential consequences for future reproductive success.

5.1.1.3 Displacement, avoidance and permanent emigration.

There is a significant body of data showing that whales avoid underwater sounds starting at 110-120 dB re 1 µPa. Beluga whales for example fled icebreaker noise at received levels of 94-105 dB rms re 1 µPa returning in 1-2 days to the area where the received noise was 120 dB re 1 µPa (Finley *et al.* 1990). Kastelein *et al.* (1997) reported captive harbour porpoise avoided exposure to high frequency pingers with a source level of 103-117 dB re 1 µPa at 1 m and received levels of 78-90 dB rms re 1 µPa. In captive bottlenose dolphins Finneran & Schlundt (2004) found that the probability of adverse reactions to noise increased with increasing received levels from 160 to 200 dB rms re 1 µPa at 1 m. Seals have a lower maximum hearing frequency and sensitivity than odontocete cetaceans with a high frequency cut off between 30 and 60 kHz. However, there is a paucity of information and data on the response of phocid seals to known levels of noise such as piling. Some data exists on the startle response (Gotz & Janik 2011) and on the effect of seismic air guns (Gordon *et al.* 2003). This Research Gap (DECC2) is considered in section 5.1.1.1.6, (Nedwell *et al.* 2007b) suggest that animals will show strong avoidance to levels of 90 dB_{ht} and above and slight reactions at around 75 dB_{ht}.

Any avoidance behaviour or displacement of marine mammals by OREG noise could have cascade effects on reproduction and survival (as shown in Figure 1), again largely mediated through the hypothalamic-pituitary axis and the stress response. The two primary responses that could affect vital rates are changes in the ability of animals to forage or their ability to find mates. In addition once displaced, they may not return to their original habitat, resulting in increases in permanent emigration and effects on meta-population. At what level the different species of marine mammal receptors are likely to move away will depend on their foraging and communication methods, cetaceans may be more sensitive to impacts using echolocation to find prey than phocid seals that rely on other senses, particularly their vibrissae for detecting prey (Dehnhardt *et al.* 2001).

Alternative terminology for the stress response, within the context of effects of noise on the life cycle of an animal, has been proposed by McEwen & Wingfield (McEwen & Wingfield 2003; McEwen & Wingfield 2010) where various levels of allostatic state (equivalent to the 'health' concept with the PCOD framework) are used to categorise individuals. Allostasis refers to the physiological and behavioural mechanisms used to support the stability of the physiological systems that sustain life. This structure is used in the NRC Report on Marine Mammals and Ocean Noise (Wartzok *et al.* 2005) to investigate impacts of noise on energy requirements. This translates into a useful framework for modelling an individual's energy balance were an animal's allostatic load results from its need to obtain enough energy for normal activities on a seasonal basis such as moulting, mating and lactating. Animals can adapt to extra demands on this within limits, however if resources in the environment are insufficient, or other challenges such as disease increase the allostatic load the

animal may be unable to cope and will develop a physiological dysfunctions that may lead to death.

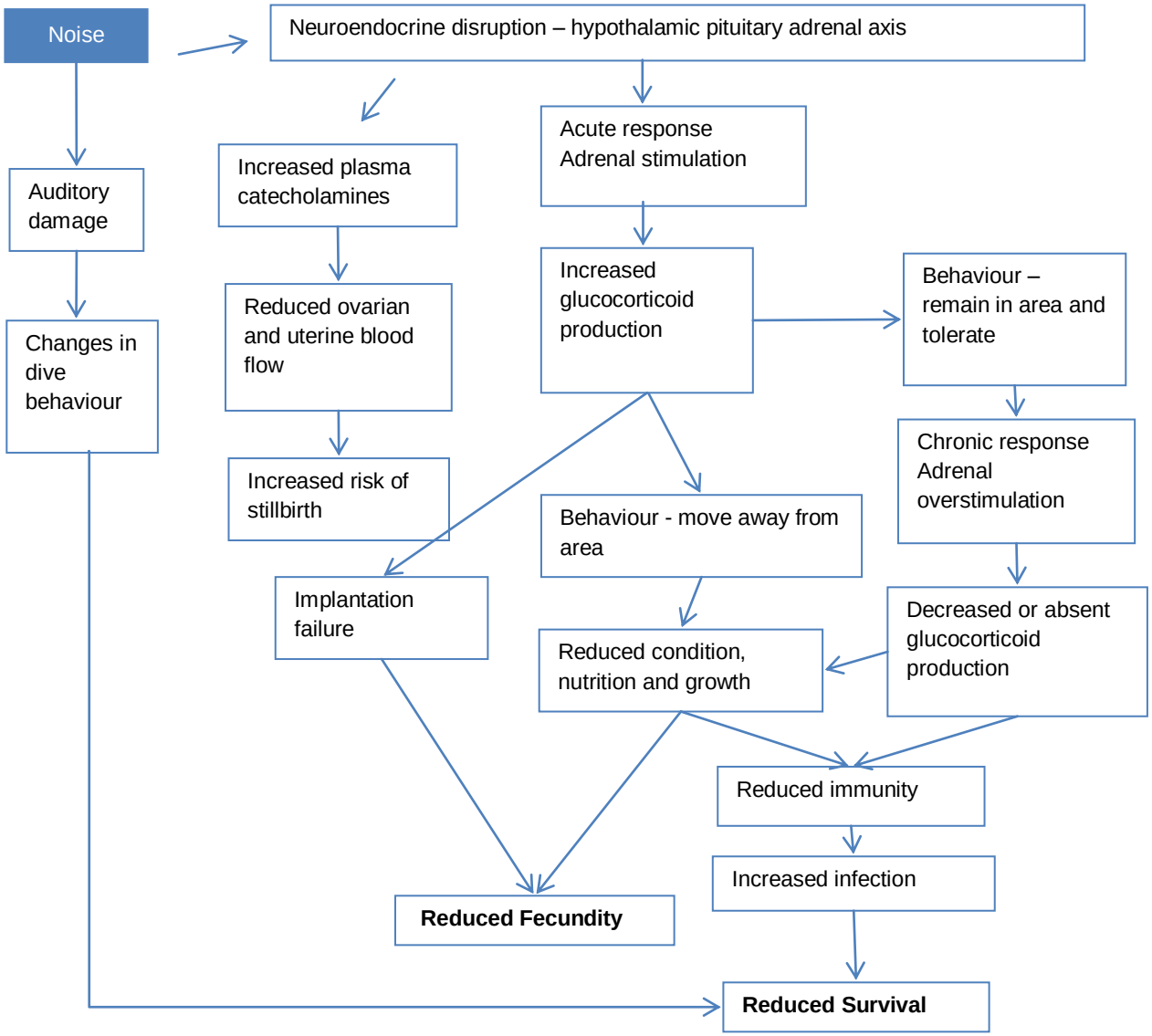


Figure 1. Potential pathways to effects on vital rates

Studies are also being funded by the Strategic Environment Defense Program (SERDP) and the Office of Naval Research (ONR) in the US to determine the effect of noise on behaviour and condition in cetaceans and then how condition relates to reproductive state. One study (entitled “Behavioural Ecology of Cetaceans: The Relationship of Body Condition with Behaviour and Reproductive Status”) is being carried out by SMRU and it addresses the issue of how noise (killer whale playbacks) affect condition and ultimately reproductive state in beaked whales and humpback whales.

Thus if the habitat noise is above a tolerance threshold that produces an aversion response animals are likely to move away and may be unable to find good alternative foraging, breeding, moulting or resting areas. This will have knock-on effects on their nutritional state, body condition, immune function and reproductive ability (Barber, Crooks & Fristrup 2010). Determining at what level this is likely to occur and the number of receptors in the populations whose reproductive output or survival probability is reduced is likely to be difficult.

However, it is now recognised that since (particularly when conducting appropriate assessments within the context of impacts on SACs) risk assessments are a requirement for consent, a pragmatic approach to this uncertainty should be taken. It is thus important to determine the most appropriate individual displacement or permanent emigration dose-response relationships to use for the various potentially impacted marine mammal receptors.

One example of a pragmatic approach that has been taken is a recent framework for assessing the effects of pile-driving noise from wind-OREG construction on a harbour seal populations (Thompson *et al.* in prep) where the effect of PTS on vital rates was modelled. The noise distribution from the piling activities and the seals' behaviour were used to estimate received noise levels. They then used a combination of dose response for TTS and PTS (Nedwell *et al.* 2007b; Southall *et al.* 2007) and information on response of harbour porpoise to piling noise (Brandt *et al.*, 2011) in the absence of data for seals, to estimate the total sound exposure, likelihood of hearing damage and level of displacement. They also assumed that individuals experiencing PTS would be subjected to an additional mortality risk and that the consequences of behavioural displacement would be that a proportion of pregnant females would not be able to sustain their pregnancy due to poor foraging, energy imbalance and allostasis overload, resulting in stillbirth, abortion or reduced pre or post weaning survival of pups. Each of these stages had associated uncertainty and this was reflected in the final model used to estimate the potential effect on the population (see Section 5.2).

Noise induced hearing loss, TTS or PTS may have an impact on survival as individuals may be unable to detect and thus avoid predators. Studies suggest that a decrease in hearing sensitivity could increase the risk of predation for harbour seals (Deecke, Slater & Ford 2002) in areas where killer whales are likely seal predators (such as Shetland and Orkney).

5.1.2 Physical contact

Clearly it is important that individual marine mammals are not in direct contact with, for example tidal OREG devices that could result in their death. Furthermore, non-fatal collisions that result in major trauma could subsequently become infected and lead to death through septicaemia. More minor injury may affect immune function where their immune system is activated and up-regulated, a process that can be energetically costly (Lochmiller & Deerenberg 2000). This again may lead to

allostatic overload and may temporarily impair the reproductive capacity, depending on age and life history stage of the injured animal.

Collision risk models are being evaluated as part of the MSS/001/11 Research Project (see Section 4.2.2.1.) and further work on collision outcomes are being carried out by SMRU with support from Marine Scotland and SNH. Entanglement may also be an issue for an individual that could result in death directly or indirectly through injury and infection. Continued collaboration with the Scottish Marine Animal Stranding Scheme (SMASS) will assist in determining the likelihood of these effects being important at either the individual or population level.

5.1.3 Disturbance effects

Disturbance over a prolonged period, either for seals at haulout sites or for all marine mammals during foraging at sea, could result in a chronic stress response. Whilst continual elevated circulating corticosteroid levels are not beneficial to the animal, in the short term they are the appropriate physiological response to a perceived stressor. If the stressor is of short duration and magnitude this is clearly how the animal copes in order to eventually return to a homeostatic state. Disturbance effects may be considered analogous to anti-predator responses. Mammals and birds have evolved to cope with repeated and often intense threat from predation. Occasional or sporadic disturbance may be within the scope of marine mammals' abilities to deal with the existing challenges these populations face in their natural environment. However, in chronic stress such as may be induced by continual disturbance (or indeed perhaps continual low level noise) animals may begin to exhibit adrenal hypertrophy and hyperplasia (Reber *et al.* 2007). Rats exposed to chronic stress often exhibit adrenal enlargement and increased basal plasma corticosteroid levels, despite normal plasma adrenocorticotropic hormone levels, suggesting that chronic stress also affects the peripheral limb of the HPA axis as ACTH is produced in the pituitary (Ulrich-Lai *et al.* 2006; Reber *et al.* 2007). However, additional studies of chronic or prolonged stress (particularly in chronic fatigue syndrome in humans) have found the opposite, that the adrenal gland may become dampened with low levels of cortisol (hypocortisolism) being produced, possibly causes by preceding long periods of high HPA axis activity (Fries *et al.* 2005). This may have knock-on physiological effects on individual animal health and reproductive capacity. The role of cortisol in the stress response is only one of many downstream physiological actions it has. It is important in immune function (Costa-Pinto & Palermo-Neto 2010) and reproduction (Jensen Pena, Monk & Champagne 2012) and phocid seals have some of the highest circulating levels of cortisol of any mammal possibility related to their diving physiology, although this is only speculation. However, it is clear that decreased cortisol production by the adrenals following chronic stress may have other unforeseen consequences for an individual's physiology and allostatic state.

A MASTS (Marine Alliance for Science and Technology for Scotland) funded PhD study at SMRU starting in October will be addressing some of the energetic issues

and costs associated with disturbance in harbour seals. However, this will also provide an opportunity to further our understanding of the HPA axis and its response to disturbance with the confines of the captive situation.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
Effects of disturbance on the hypothalamic pituitary adrenal axis.	DIS	Repeated disturbance of animals (seals from haulout sites for example) may have impacts on their ability to respond normally to novel stressors (through 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.	Funded by MASTS	2016

5.2 Population

Effects on individuals will be transmitted through to affect the sizes of populations by altering overall fecundity and the survival probabilities of particular groups of animals. Displacement of animals may, temporarily or permanently change the local population that they belong to and the connectedness of different sub-populations.

The primary population scale effects are likely to be changes in abundance, which could lead to, local or widespread, extinctions. Long-term displacement away from areas, or reductions in abundance, could reduce the connections between local populations. In turn, that could reduce gene flow, increase the vulnerability to localised events and make it more difficult for the subsequent re-colonisation of areas.

The remainder of this section will consider focus on four issues:

- the scaling up from estimates of individual effects to changes in abundance;
- how conservation targets are currently set for marine mammals;
- the balancing of different environmental goals; and
- the specific problem of the implications of working within an area where abundance is already declining.

5.2.1 Extrapolating to population level effects

If the baseline population dynamics of a species are well understood, and the size and distribution of effects of an OREG development on individuals can be estimated (see Section 5.1), then computer simulation should be able to estimate likely

consequences for a development. Three approaches to investigating existing or anticipated changes are shown in the box below:

Regression Analysis simply takes the numbers of individuals observed and looks for trends or patterns through time. It is straightforward to do, and does not attempt to investigate detailed processes within the population or changes in its structure. It can therefore work with small datasets, but is limited in what it can discover about causes. This method was used to demonstrate that the reductions in numbers of harbour seals counted in eastern Scotland were not merely due to measurement error but indicated real declines (Lonergan *et al.* 2007). The impact of simple effects, such as across the board reductions in survival, can be considered by comparing them to estimates of current trends in abundance.

State-space models divide the population into classes, age or stage groups, and model the process of animals moving between them as well as how observations are made. The grey seal population model (Newman *et al.* 2009b) is an example of this. A similar approach is taken in a Moray Firth harbour seal model (SCOS 2010). Once a model is fitted to historical data, the implications of particular changes in vital rates can be investigated by simulation. The two limitations on this approach are the amounts of data required to estimate the connections between the various groups of animals and the computational complexity of the model fitting.

Instead of considering classes of animals as behaving in the same way, **Individual-based models** keep track of each individual separately. If enough information is available, that should allow the models to capture the effects of individual variation. However, for marine mammal populations, sufficient information is seldom available to take advantage of this potential. In practice these, even more than state space models, need to make sweeping generalisations to cover gaps in knowledge.

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.

PCOD is a simple population model where assumptions are made about the relationships between observed behavioural responses and vital rates of individuals. Such a modelling framework does not avoid the requirement for information on particular demographic parameters or on the types of dose-response relationships that allow us to link behavioural responses and population processes. At best such a system can be seen as a sensitivity analysis tool to allow us to assess the potential effects of different environmental disturbances. At the very least it provides a method to identify the most critical data gaps. A description of the PCOD methodology, data requirements and methods for dealing with data deficiencies are presented in Lusseau *et al* (2012). Clearly for any such model the data requirements will be determined by the particular species of interest and the specific device/interaction that is under consideration. Lusseau *et al*. (2012) describe a PCOD framework for modelling the population consequences of disturbance developed by the US Office of Naval Research working group on PCAD (Anon 2012). This combines all aspects of the internal state of an individual that might affect its fitness into a single term denoted as “Health”. This is a catchall for such factors as energetic state or resistance to disease, etc. The effects of the health of the animal on its vital rates are then calculated, where “Vital rates” refers to all the components of individual fitness (probability of survival, fecundity, growth rate etc. as well as secondary factors such as offspring survival).

The data requirements for such studies are extensive. As a minimum, there needs to be some form of estimate of the initial structure of the population of interest, its vital rates and information on the important components of the “health” state of the population. In addition, for any particular disturbance factor, the model requires a set of parameterised dose-response models that ultimately predict changes in specific population vital rates. Such models have a large number of parameters and thus have significant data requirements to ensure that prediction uncertainty is kept within ‘managerially useful’ bounds. A sensitivity analysis of such models will indicate the most pressing data requirements.

Harwood & King (2012) describe how the Interim and Full PCOD frameworks will require estimates of ten critical sets of information.

1. The sound field produced during construction and operation of a particular offshore renewables development (with associated uncertainty).
2. The sound levels that are likely to cause Temporary Threshold Shift (TTS). This information should, preferably, be in the form of a dose-response relationship, with associated uncertainty, for each priority species.
3. The sound levels that are likely to cause Permanent Threshold Shift (PTS), preferably in the form of a dose-response relationship, with associated uncertainty, for each priority species.
4. The sound levels that are likely to result in a "significant" behavioural response (defined as one that is likely to impair an individual's ability to survive, breed, reproduce, or raise young, or that is likely to result in that individual being displaced from an area for a longer period than normal). These should, preferably, be in the form of a dose-response relationship, with associated uncertainty, for each priority species.
5. The number of animals likely to be exposed to sound levels that could result in PTS, TTS or a "significant" behavioural response during one day of construction or operation of an offshore wind farm. The number of animals of each species (with associated uncertainty) that are likely to collide with or become entrapped in a marine renewables device or be exposed to sound levels that could result in a "significant" behavioural response during one day of construction or operation of this device.
6. The number of animals (with associated uncertainty) that are likely to be exposed to sound levels likely to result in PTS, TTS or a "significant" behavioural response over the entire course of construction of an offshore wind farm.
7. The potential effect of experiencing PTS at a specified frequency on the vital rates (probability of survival for one year, probability of giving birth) for an individual of each species, by age/stage class (e.g. adult males, adult females, calves, juveniles), with associated uncertainty;
8. A mathematical function linking the number of days on which an individual experiences TTS or a "significant" behavioural response and its vital rates (probability of survival for one year, probability of giving birth), with associated uncertainty, for the different age classes of each priority species.
9. The current population size and population history for each Management Unit (MU) of the five priority species, with associated uncertainty.
10. The key demographic parameters (adult survival, calf survival, juvenile survival, annual probability of pupping/calving, age at first pupping/calving, longevity) for each species, in each MU (if parameters are likely to vary between MUs) with an indication of likely levels of variation between years.

Where there are insufficient data (or even no data) to adequately parameterise these models Lusseau *et al.* (2012) describe a process of incorporating expert advice. This expert panel approach (Marcot *et al.* 2012) has the attraction of proffering provisional scientific advice on time-critical issues. However considerable caution must be used in panel composition, questionnaire construction and subsequent analysis to avoid significant output bias.

A preliminary expert opinion elicitation exercise is being carried out as part of the preliminary work for the ORJIP process. The results of this exercise will be used to define the important remaining information requirements for developing a series of PCOD models. Developing and implementing PCOD models has been identified as a major research requirement under the ORJIP programme and forms **Project 2: Evidence gathering for a Population Consequences of Acoustic Disturbance (PCAD) model to predict impacts to marine mammals from underwater noise.**

This section of the current review will be further developed when the results of this exercise are available. Inevitably this will lead to an increase in and changes to the

5.2.2 Marine mammal conservation targets

The environmental monitoring and mitigation requirements imposed on developers are designed in part to reduce the impact of marine renewables on species of conservation concern. Conservation legislation is usually written in terms of population or stock management, usually with specific management targets such as maintaining favourable conservation status. It is becoming increasingly clear that regulators need to consider the population consequences of any management decisions in order to fulfil their requirements under national and international legislation.

Where lethal takes are involved, it is a “relatively” simple task to assess the likely impacts on a population. However in a case such as the development of a new marine renewables industry where novel and as yet untested technologies are being deployed in the real world such relatively easy methods are not suitable. We are not yet sure of the extent or intensity of any effects, we are not even certain that there will be any directly injurious interactions.

The EU Habitats Directive, now supplemented by the Marine Strategy Framework Directive (MSFD), sets the requirements for conservation management of marine mammals in European waters. These provide very little guidance beyond a requirement that populations be “favourable” in size, range and prospects. The only fixed reference point they give are that things must be no worse than when the Habitats Directive came into force; 1994 in the UK. The interpretation of the directives has largely been devolved to EU member states, though with a threat of facing legal proceedings if their efforts are not considered adequate (Lonergan 2011; Lonergan 2012).

Internationally, the main method used to set allowable "takes" of marine mammals is the Potential Biological Removal (PBR). This was developed within the US Marine Mammal Protection Act and allows a small proportion of any population to be removed (Wade 1998). While it is often presented as an having objectively determined target population size, use of PBR will tend to drive a population towards a proportion of its carrying capacity that is implicitly determined by the details of how density dependence affects individuals' chances of survival and reproduction. This approach is currently used by the Scottish Government in determining applications for licences to shoot seals around fish farms and set nets. It is also used to determine whether the number of animals predicted to suffer fatal interactions with renewables (or other industry) is acceptable. The International Whaling Commission (IWC) uses a more detailed calculation to set notional catch limits for large cetaceans, though it has not actually agreed to any commercial hunting (Lonergan 2011).

The setting of conservation goals is clearly a societal and political decision. While that decision lies outside science, it does depend on knowledge of the implications and balances of risks and benefits of potential courses of action. Choosing appropriate targets therefore needs to be an iterative process with scientists being able to provide progressively more detailed information as the range of potentially acceptable options is narrowed.

Research gap				
Title	**Code**	**Details**	**Status**	**Reporting date**
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, On-going	Sept 2013

6 Research Gaps

6.1 Marine mammal

The following tables collate the Research Gaps identified in the body of this report. We group separately those that are already on-going, planned with funding identified, and proposed.

Funded Research gaps				
Title	**Code**	**Details**	**Status**	**Reporting**
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 *et al.* 2008). Abiotic variables (e.g. depth, sediment type) will be used as candidate co-variates.	Funded by MS & DECC	2014
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 *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	2013
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 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.	Funded by MS & SNH	2013

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, 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.	Funded by MS	2013
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 (Len Thomas, CREEM).	Funded by MS	2014
Harbour porpoise behaviour in tidal rapids	PTID2	Use towed 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	2013
Do harbour seals exhibit auditory permanent threshold shift	DECC1	Audiograms for all harbour seals captured as part of DECC2 will be obtained using standard auditory evoked potential measurements during capture events (Wolski *et al.*	Funded by DECC	2013

in the presence of piling activity?		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.		
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	2013
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	2013
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.	Funded by MS	2015
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	Funded by MS	2013

		grey and harbour seals 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.		
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	2013
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	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	Part Funded by SNH	2014

		in the vicinity of turbines		
Effects of disturbance on hypothalamic pituitary adrenal axis.	DIS	Repeated disturbance of animals (seals from haulout sites for example) may have impacts on their ability to respond normally to novel stressors (through 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.	Funded by MASTS	2016
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 the. 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	2013

Unfunded/partially funded Research gaps			
Title	**Code**	**Details**	**Priority**
Fine scale marine mammal behaviour in the vicinity of a working tidal array.	ARRY	1. Building on the recommendations of the Marine Scotland 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
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
Fine scale habitat use by porpoises in tidal rapids	EDDIE	Combinations of towed 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
Telemetry studies targeted on specific areas to improve map confidence intervals.	TAG	In light of results of current telemetry studies (3.1.1.4) and results of MR5, targeted deployments on particular species and regions will improve confidence intervals on at sea distribution maps.	MEDIUM
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

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
Marine mammal responses to artificial lights	LIGHT	Investigate responses to different light sources to identify possible illumination for night-time video surveillance.	MEDIUM
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
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
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
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

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. The Centre for Environment, Fisheries and Aquaculture Science (CEFAS) (2010) conducted a strategic review of offshore wind farm monitoring data associated with 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. 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.

At present it does not appear that the available information from such monitoring programmes will allow regulators to reduce the conditions attached to licences. The CEFAS study clearly highlighted the potential advantages of increased standardisation of survey and analytical methodologies to aid in future comparison and assessment.

7 Appendix 1. Details of Task descriptions

7.1 MR1

Map out the current marine renewables research landscape with respect to marine mammals and other relevant issues. This study will deliver:

- A report detailing current and recently completed research into the interactions of marine mammals and marine renewables developments.
- An assessment of the relevance of both on-going and recently completed research programmes in terms of their generality and applicability to specifically Scottish marine renewable developments.
- Regular updates of the review as a live document throughout the life of the project.

Objectives

MR1.

At the start of the research programme we will provide a review of the current marine renewables research landscape with respect to marine mammals and other relevant issues:

- Develop a wide understanding of the range and depth of research into the effects of marine renewable devices on marine mammals.
- Assess the relevance of both on-going and recently completed research programmes in terms of their generality and applicability to specifically Scottish marine renewable developments.
- Identify and assess the research portfolios of relevant working groups (Scottish, UK, European, and International)
- Maintain and update the review as a live document throughout the life of the project.

Map out the current marine renewables research landscape with respect to marine mammals and other relevant issues, this should take an international perspective and include projects that have completed in the past 12 months. This should also include a description of relevant working groups (Scottish, UK, European, and International) and their purpose where groups have a research portfolio. Illustrate how this research will interact with the wider research landscape. This assessment should be delivered within the first three months and be maintained as a live document throughout the life of the project.

7.2 MR2

Assess the data gaps with regard to marine mammals and marine renewables. This study will deliver

- An assessment of the data gaps with regard to marine mammals and marine renewables.
- A prioritised list of the data gaps and an assessment of the risk to marine mammal populations and renewables development t should these gaps not be filled.

The report will provide an assessment of the data gaps with regard to marine mammals and marine renewables, some of which are listed in Appendix A. Relate these back to the mapping exercise to extrapolate where data gaps still exist and where further work is necessary. Make an assessment of which data gaps should be classed as a priority and assess the risk to marine mammal populations and renewables development should these gaps not be filled. Data gaps should be split by technology, wind / wave / tidal and cover the lifecycle of a renewables development from survey work to decommissioning, it may also be necessary for data gaps to be area and species specific. How this research is contributing to filling these data gaps should also be stated. The outputs should be developed to form a series of research questions that will inform work strands in this research project and future research. This assessment should be delivered within the first three months and be maintained as a live document throughout the life of the project.

Objectives

On the basis of the output of MR1 we will

- Provide an assessment of the data gaps with regard to marine mammals and marine renewables.
- Prioritise the data gaps and assess the risk to marine mammal populations and renewables development should these gaps not be filled.

8 Appendix 2. 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 Marine Energy Spatial Planning Group (MESPG) recently renamed the MS- SNH Marine Renewables Research Group

MESPG 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 MESPG consists of Scottish Government (Marine Scotland 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). MESPG 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 MESPG structure and responsibilities can be downloaded at www.scotland.gov.uk/Resource/Doc/295194/0099734.pdf

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. 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 (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 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

http://www.eera-set.eu

EERA is an alliance of energy research organisations across Europe. 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

The aim of SOWFIA is to facilitate the development of European wide coordinated, unified and streamlined Environmental and Socio-economic Impact Assessment (IA) tools for offshore wave energy developments.

This will be achieved through two key approaches:

- Knowledge Collection & Transfer: By utilising the findings from technology specific monitoring at these sites, SOWFIA will facilitate knowledge transfer and augment European-wide expertise on environmental and socio-economic IA of large scale wave energy projects.
- Two-Way Information Flow: this information will be communicated and shared with the wave energy community across Europe. Through a two-way process, developers will have the opportunity to contribute their experiences to date with consenting processes, environmental and socio-economic impact assessment. This will facilitate the development of best practice guidance for future offshore wave energy developments.

SOWFIA will produce 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.

One of the initial outputs will be a catalogue that identifies all European locations where wave energy devices are being tested, specifying all the impact assessments that have been carried out to date. This information will feed into a dynamic online database that will be useful to both the developers and regulatory bodies as well as accessible to the public.

Subsequent to compilation and analysis of the relevant data, the project will engage in extensive and continuous stakeholder participation. This will give policy makers, governments, investors, engineering firms, manufacturers, device developers and NGOs the opportunity to share their experience in order to improve the effectiveness and relevance of future impact assessments.

8.1.2.3 Marine Renewables Infrastructure Network (MARINET)

http://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 ICES Working Group on Marine Mammal Ecology.

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 work shop reports are available at

8.1.2.5 ASCOBANS

The Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS) 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 Centres; 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 relocatable 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.

8.2.2 EUROPE

8.2.2.1 SEAI_OEDU - Wave Energy Test Site

Belmullet, Co. Mayo Ireland

The project is 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.

8.2.2.2 SEAI_OEDU - 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.

Typical projects/examples:

Testing of ¼ scale prototype devices.

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.

WAVEC - status unclear. Air column test generator facility may be operational but probably of little relevance to issues relating to OREG in Scottish waters

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.

Nova Scotia Power tested a 1 megawatt OpenHydro turbine at this site between November 2009 and December 2010. The land-based facility is now complete and open to the public.

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

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/Department of Environment, Food and Rural Affairs (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.

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. The deadline for applications is noon on 16 January 2013.

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 of 24 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.

9 Appendix 3. Species List

Marine mammals of direct interest in Scottish waters are listed below with brief summaries of population structure and abundance where estimates are available.

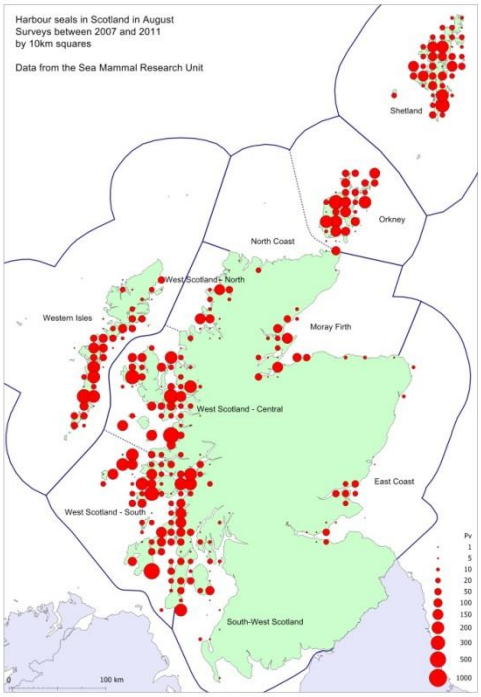
9.1 Seals

9.1.1 Harbour seal

Harbour seals (*Phoca vitulina*) are widespread around the west coast of Scotland and throughout the Hebrides and Northern Isles. On the east coast, their distribution is more restricted with concentrations in the major estuaries of the Thames, The Wash, Firth of Tay and the Moray Firth. Approximately 26,000 harbour seals were counted in the U.K. up to 2012, giving an estimated total population of 36,500. Scotland holds approximately 80% of the UK harbour seal population, with 15% in England and 5% in Northern Ireland. Approximately 30% of European harbour seals are found in the UK; this proportion has declined from approximately 40% in 2002.

Major declines have now been documented in harbour seal populations around Scotland with declines since 2000 of 66% in Orkney, 50% in Shetland, 36% in the Outer Hebrides, 46% in the Moray Firth and 84% in the Firth of Tay. These declines are not thought to be linked to the 2002 Phocine Distemper Virus (PDV) epidemic that seems to have had little effect in Scotland.

This map shows the number and distribution of harbour seals in the 8 seal Management Areas around the coast of Scotland during the summer months, from surveys carried out between August 2007 and 2011.

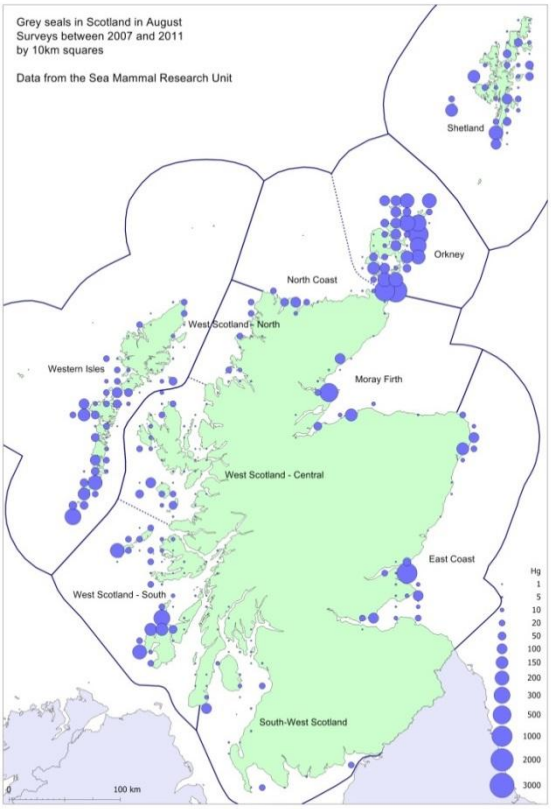


9.1.2 Grey seal

Approximately 38% of the world's grey seals (*Halichoerus grypus)* breed in the UK and 88% of these breed at colonies in Scotland with the main concentrations in the Outer Hebrides and in Orkney. There are also breeding colonies in Shetland, on the north and east coasts of mainland Britain and in SW England and Wales. Although the number of pups throughout Britain has grown steadily since the 1960s when records began, there is clear evidence that the growth is levelling off in all areas except the central and southern North Sea where growth rates remain high. The numbers born in the Hebrides have remained approximately constant since 1992 and growth has been levelling off in Orkney since the late 1990s.

The most recent UK grey seal pup production estimate in 2010 was approximately 50,000 (approx. 44,000 in Scotland) which produces an estimated all age UK grey seal population of approximately 104,000 (95% CI 85,300-130,000).

This map shows the number and distribution of grey seals in Management Areas around the coast of Scotland during the summer months, from surveys carried out between August 2007 and 2011. All areas were surveyed by helicopter using a thermal imaging camera.



9.2 Cetaceans

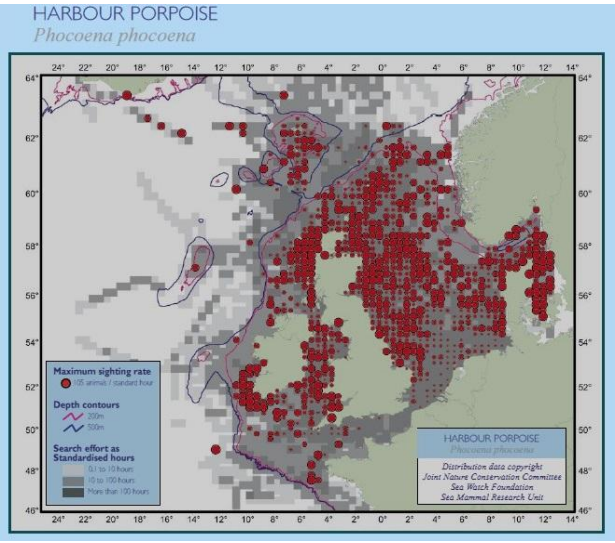
9.2.1 Harbour porpoise

Harbour porpoises (*Phocoena phocoena)* occur throughout Scottish waters. Population estimate from the SCANS-II survey for waters from Loch Sunart to Fraserburgh and north to 62^{o} was around 60,000 animals and coastal waters from Fraserburgh to Norfolk held around 17,000 animals. No estimate is available for the west coast/Inner Hebrides population.

Porpoises from the North Sea and Southwest England demonstrate genetic differences (Walton 1997; Tolley & Rosel 2006). An ASCOBANS-HELCOM workshop (Evans & Teilmann 2009) has suggested two populations in the North Sea (North and West as one and South and East as the other), and has further suggested a Northwest Ireland and West Scotland ("NWIS") management unit. (ICES 2012) preferred to keep the entire North Sea as one management unit, but maintained the "NWIS" unit. Norwegian and British North Sea animals exhibit some degree of difference (Tolley & Rosel 2006; De Luna *et al.* 2012).

Few studies have looked at Scottish west coast porpoises from a population genetics perspective, and relatedness of Scottish west coast animals to other groups is unclear. Walton (1997) found no significant difference between North Sea and Western Scottish animals, nor any difference between Western Scottish and Celtic Sea animals, but sample size was small.

The distribution map below is taken from Reid *et al.* 2003.

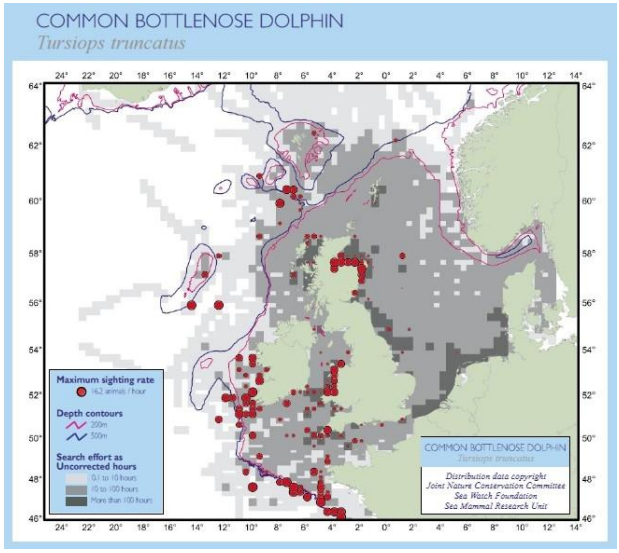


9.2.2 Bottlenose dolphin

There are two local populations of bottlenose dolphins (*Tursiops truncatus)* in Scottish waters; an east coast group centred on the Moray Firth and a West Coast group. Although both Moray Firth' and west of Scotland animals do occur outside their 'normal' home ranges, these can be regarded as two discrete stocks. The total population in Scottish waters is around 200-300 individuals with around 80% along the east coast and 20% along the west coast population (Thompson *et al.* 2011). There are sightings of animals in the central North Sea which may also be from the same population, though none has been photo-identified to our knowledge.

Although genetic data indicated that the Moray Firth population is more closely related to Welsh animals than to West coast of Scotland animals (Parsons *et al.* 2002) suggesting little or no mixing of east and west coast animals, photo-identification data from multiple studies have also shown that coastal bottlenose dolphins do move between the east and west coast of Scotland and between Scottish and Irish waters (Thompson *et al* 2011; Robinson *et al*. 2009). There is some evidence that there may be two or more 'communities' of dolphins on the West coast, one centred around the Sound of Barra, and the other in the Inner Hebrides with sightings from Kintyre to Gairloch, and some suggestion of further partitioning of the inshore habitat among two groups of individuals. Bottlenose dolphins also occur further offshore and beyond the 200nm limit; we don't know how much mixing there is between the two inshore populations and those animals further offshore, nor do we know how animals sighted in Northern Scotland or the central North Sea relate to other groups.

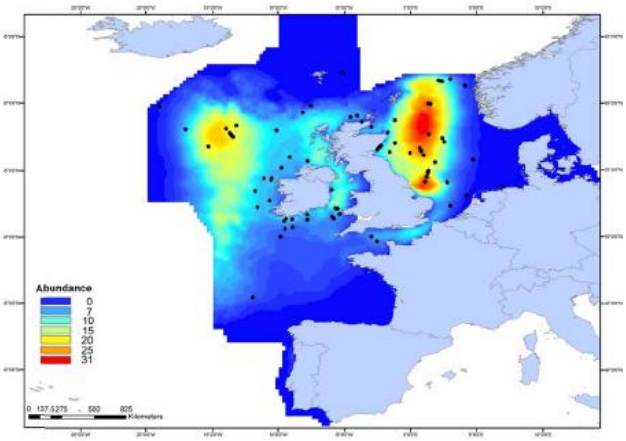
The distribution map below is taken from Reid *et al.* 2003.



9.2.3 Minke whale

Minke whales (*Balaenoptera acutorostrata)* occur throughout Scottish waters. Population estimate from the SCANS-II survey for waters from Loch Sunart to Fraserburgh and north to 62^{o} was around 3,000 animals and coastal waters from Fraserburgh to Norfolk held around 1,000 animals. No estimate is available for the west coast/Inner Hebrides population. There is some evidence of population sub-structure (Anderwald *et al.* 2011) but this is not at present taken into account in management decisions. Although there is evidence that some individual minke whales return to the same area in different years (Northridge et al 2010), these animals range over large distances and the population is treated by the IWC as a single Northeast Atlantic stock. The latest abundance estimate is around 174,000 individuals in the Central and NE Atlantic combined (IWC 2012 Website).

The map below is taken from Hammond et al. (2010) and shows the results of a spatial model prediction of minke abundance in the coloured (surveyed) area covered by SCANSII, CODA and TNASS. The line transect survey estimate of abundance for this region was about 38,000 animals (CI: 27-54 000)

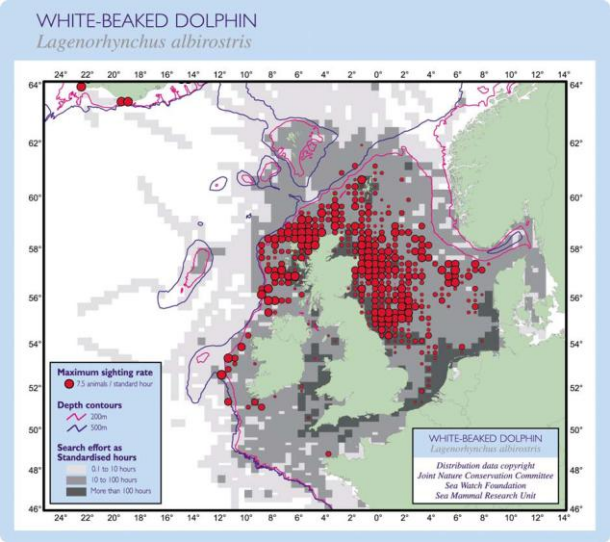


9.2.4 White beaked dolphin

White beaked dolphin (Lagenorhynchus albirostris) occurs throughout Scottish waters. Population estimate from the SCANS-II survey for waters from Loch Sunart to Fraserburgh and north to 62^{o} was around 1150 animals and coastal waters from Fraserburgh to Norfolk held around 2350 animals. No estimate is available for the west coast/Inner Hebrides population. Individuals are likely to be found inside and outside of the 200nm limit, but the bulk of the BI management stock is likely found inside the UK and Irish 200nm limits, and the with the majority of these inside the Scottish 200nm limit. Total abundance on European shelf waters was estimated at around 22,700 animals (Hammond *et al.* 2010). Sightings data suggest a population centred on Scottish waters (North Sea and West coast), extending further south into the North Sea with a distinct hiatus between Scottish and Norwegian waters. (Northridge et al 1997). A more recent study on white-beaked dolphin genetics also suggests some genetic difference between UK and Norwegian waters (Banguera-Hinestroza *et al.* 2010).

However, ICES' WGMME recommends treating animals around the British Isles and in the North Sea as a single management unit (ICES 2012 in prep).

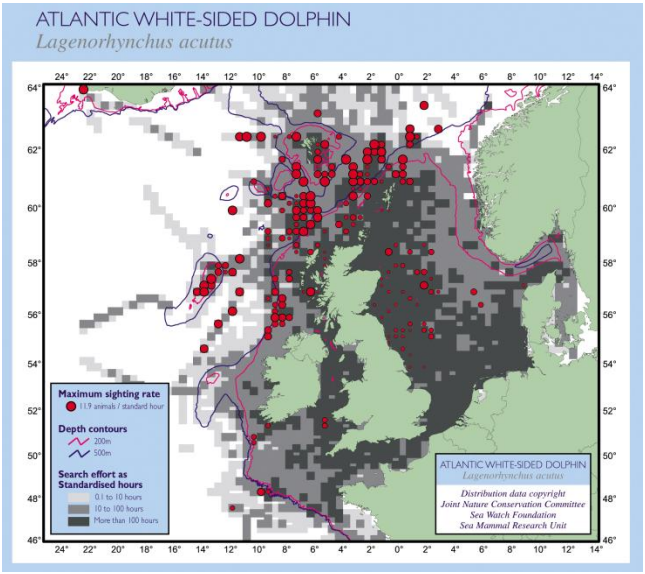
The distribution map below is taken from Reid *et al.* 2003.



9.2.5 White sided dolphin

No evidence of local Scottish population of White sided dolphin (*Lagenorhynchus acutus).* This species is mainly distributed offshore in the northeast Atlantic (Northridge *et al.* 1997) and is abundant throughout its range. There are an estimated 96,000 (CV=54%) off the west coast of Scotland (MacLeod 2004) comprising around 21,000 to the west of the Outer Hebrides and 75,000 in the Faroe Shetland Channel. (MacLeod 2004). No overall, UK or Scottish estimate is available. Population genetics work suggests a single wide-ranging population in the north-eastern Atlantic (Mirimin *et al.* 2011) but there is some suggestion of slight differences between animals from the North Sea and further west (Banguera-Hinestroza 2010).

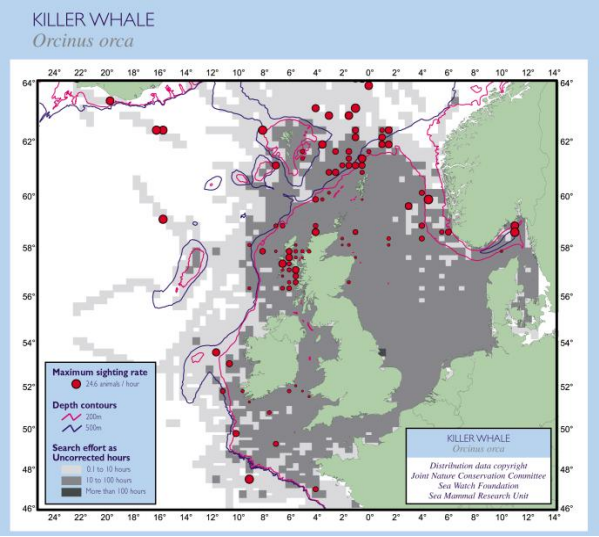
The distribution map below is taken from Reid *et al.* 2003.



9.2.6 Killer whale

There appears to be a single population of killer whales (*Orcinus orca)* around the British Isles. Abundance near UK is unknown. Much of the UK 'population' appears to occur in Scottish waters, notably the Hebrides and Shetland. A recent analysis of Killer Whale population genetics found three significantly differentiated populations centred on Iberia, the British Isles and Norway/Iceland, with some overlap between the last two around Shetland (Foote *et al.* 2009). Line-transect surveys have resulted in estimates of abundance in several regions in the North Atlantic, including approximately 3,100 in Norwegian waters, and 6,600 in Iceland and Faroe Islands waters (Taylor *et al.* 2008).

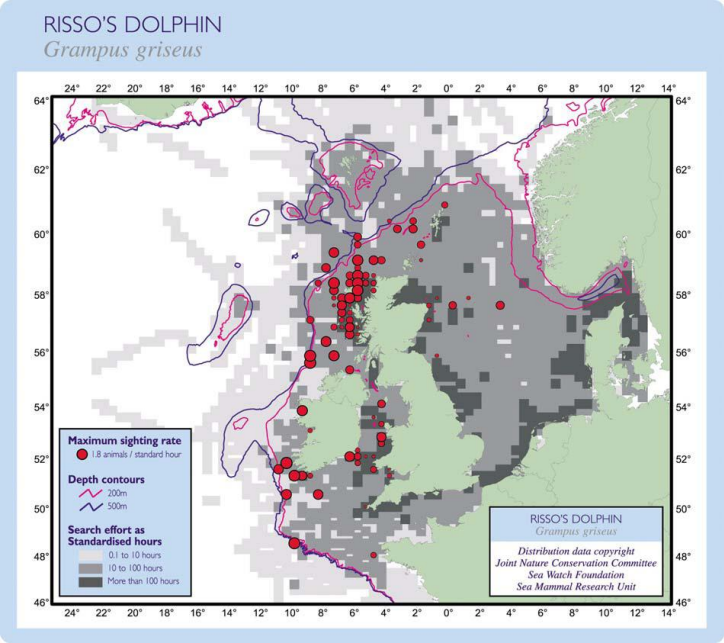
The distribution map below is taken from Reid *et al.* 2003.



9.2.7 Risso's dolphin

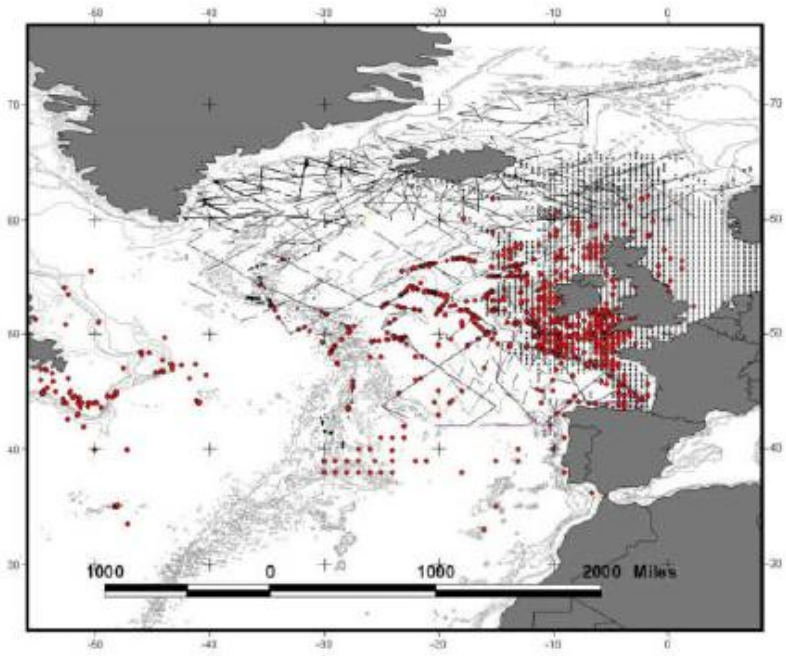
Some discrete groups of Risso's dolphin (*Grampus griseus)* are well known around Britain, especially one resident community in the Western Isles, off Lewis. But, sightings actually found throughout western Isles and Minch. There are also sightings around Shetland and a few in North Sea. (Reid, Evans & Northridge 2003). Results of one population genetics study found limited genetic variability among 18 samples collected from Orkney, the west coast, Wales and southern England, suggesting "that the UK Risso's dolphin population should be identified as a separate management unit when considering conservation Strategies" (Gaspari, Airoldi & Hoelzel 2007).

The distribution map below is taken from Reid *et al.* 2003. There is no current population estimate for UK waters.



9.2.8 Common dolphin

Common dolphins (*Delphinus delphis)* are regularly sighted in the Minches and occasionally further east (e.g. sightings in Orkney in summer 2012). This population is wide ranging from Portugal to Norway and mainly in deeper water; they are more abundant on the shelf in winter, but more common in Scotland in summer. No local populations known. Around 345,000 common dolphins (including sightings characterised as common or striped) estimated by SCANS-II and CODA in the North Atlantic. Population structure has been subject of recent examination by ICES and by ASCOBANS and has been classed as a single NE Atlantic stock between Scotland and Portugal.



9.2.9 Other cetacean species

Other cetacean species sighted occasionally in Scottish waters include:

Long finned pilot whales *Globicephala melas*

Striped dolphin *Stenella coeruleoalba*

Fin whale *Balaenoptera physalus*

Sei whale *Balaenoptera borealis*

Humpback whale *Megaptera novaeangliae*

Sperm whale *Physeter macrocephalus*

Sowerby's beaked whale *Mesoplodon bidens*

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