Wave and Tidal Enabling Actions Report

Consolidation of wave and tidal EIA / HRA issues and research priorities

Technical Report

Final Report

January 2014

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Technical Report to The Crown Estate

Issued by Aquatera Ltd

January 2014

Final Report

www.aquatera.co.uk

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Executive Summary

Background

As part of the current initiative to assist with developing a coordinated approach to addressing the key strategic EIA/HRA issues associated with wave and tidal stream arrays (under, for example, an Offshore Renewables Joint Industry Programme (ORJIP) for wave and tide), Aquatera Limited was commissioned by The Crown Estate to undertake a short, focused consultancy project; 'Consolidation of wave and tidal EIA/HRA issues and research priorities'.

This report, produced by Aquatera Ltd, has been informed by an extensive consultation process including a workshop hosted by Natural Environment Research Council (NERC) which was attended by over 50 participants. The consultation process, which also included a Call for Evidence at the outset, has included regulators, Statutory Nature Conservation Bodies (SNCBs), developers, researchers and other stakeholders from across the UK and internationally. Therefore, the results presented within this report are considered to represent a consensus as to the key EIA/HRA issues and the current research gaps and priorities relevant to the wave and tidal sectors.

Project aims and objectives

The key driver for this project was the recognition of the benefits of a coordinated effort to obtain, translate and share learning, knowledge, experience, information and data from single device and particularly first array projects to larger array deployments. It is considered that a coordinated approach will ensure that the best possible information is available to developers, regulators, SNCBs and other stakeholders to inform the consenting process and project planning and design activities. As such, the main aims of this project are to:

- Produce a consolidated up-to-date list identifying the key strategic EIA/HRA issues facing the wave and tidal stream sectors
- Identify the priority research gaps relevant to wave and tidal stream demonstration scale arrays and then outline potential approaches to address them
- Identify strategic research priorities which could be addressed through a coordinated programme

It is intended that the outputs from this project, by guiding future research work, will assist with resolving the priority EIA/HRA issues relevant to wave and tidal stream arrays. It will do this by focusing any coordinated approach to research that is developed (e.g. via ORJIP Wave and Tide). However, it should be noted that the priorities identified in this project are not only relevant to any coordinated research programme but also to any research which individual developers, regulators/advisors, academic institutions etc. may plan to undertake.

An overview of the objectives and results are presented below.

Task 1 - Identification of key EIA/HRA issues

The principal objective of this task was not to simply identify the potential impacts of wave and tidal energy array projects but to identify the principal issues that developers and regulators are currently facing with regards to EIA and HRA in the context of the consenting process.

- A long list of relevant EIA/HRA issues was developed based on a review of existing information in consultation (including via a Call for Evidence) with key stakeholders. A screening process was then undertaken to identify 'key issues' as defined by the project objectives**.**

The key EIA/HRA issues identified are:

Topic	Key issue
Underwater noise	Agreed best practice approaches for measuring ambient noise in high energy wave and tidal environments are required
	Agreed best practice approaches for measuring noise from operational wave and tidal devices and construction activities are required
	Lack of available acoustic data from operational wave and tidal devices and arrays
	Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on diving birds is incomplete
	Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on marine mammals is incomplete
	Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on fish is incomplete
Collision risk	The nature of any potential interactions between diving birds and tidal turbines is uncertain
	The nature of any potential interactions between marine mammals and basking sharks and tidal turbines is uncertain
	The nature of any potential interactions between migratory fish and tidal turbines is uncertain
	There is uncertainty as to the possible physical consequences of potential collision events for marine mammals, diving birds and fish and tidal turbines
	Further development of suitable instrumentation and methodologies for monitoring wildlife behaviour around tidal devices and arrays and for detection of any collision events is required
Entanglement	Concern within the regulatory and advisory bodies that mooring lines pose an entanglement risk to marine mammals and large fish
Seal injuries from vessel propellers	Lack of understanding around the possible cause of death to seals with 'corkscrew' injuries
EMF	Further data and information regarding the possible effects of EMF from transmission cables on fish would improve confidence in EIA and HRA
Displacement	Potential displacement of essential activities of marine mammals, basking sharks and birds
Reef effects	Potential for positive effects such as use of development sites as feeding and nursery areas for fish and use of structures as fish aggregation devices
	Indirect effects on predators including potential for increased foraging opportunities
Introduction of non-native invasive species	Concern within the regulatory and advisory bodies that wave and tidal developments have the potential to result in the introduction or spread of non-native invasive species
Entrapment	Potential risk of entrapment of marine mammals and basking sharks from wave and tidal energy converters and associated moorings or support structures
Barrier to movement	It is uncertain whether wave and tidal developments will cause a barrier to movement for marine mammals and basking sharks
	It is uncertain whether wave and tidal developments will cause a barrier to movement for migratory fish
Impacts on benthic communities	Direct loss of habitat and near field effects (e.g. scour, deposition) on protected or sensitive sub-littoral seabed communities

Topic	Key issue
	The potential wider or secondary effects on protected or sensitive sub-littoral seabed communities due to installation and operation of wave and tidal energy converters and associated moorings or support structures is poorly understood
Ecological effects due to changes in hydrographic properties	Effects on predator-prey capture rates due to changes in hydrodynamic properties as a result of presence and operation of marine energy devices.
	Effects on ecosystem functioning due to changes in hydrodynamic properties as a result of presence and operation of marine energy devices.
General	Further strategic baseline data (distribution, abundance, seasonality, etc.) for marine mammals and basking sharks is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects.
	Further strategic baseline data (distribution, abundance, seasonality, etc.) for birds is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects.
	Further strategic baseline data (distribution, abundance, seasonality, etc.) for migratory fish is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects.
	An agreed approach to undertaking site characterisation and baseline surveys for marine mammals and birds to inform EIA and HRA is required.
	Further data for mobile species populations (particularly qualifying species of Natura sites and EPS) for use in population modelling would improve confidence in EIA/HRA
	Better understanding of population level impacts and methods to assess the significance of population level impacts would improve confidence in EIA/HRA
Impacts on commercial fisheries	Further baseline inshore fisheries activity data to inform CIA (Cumulative Impact Assessment)
	There is a lack of standardised approach to assessing the availability of alternative fishing grounds (outside development areas) and their ability to sustain existing /displaced commercial fishing levels.
	Lack of a standardised approach and guidance, specific to the wave and tidal industry, on effective engagement with the commercial fishing industry and local stakeholders
	Lack of a standardised approach and guidance, specific to the wave and tidal industry, on effective engagement with the commercial fishing industry and local stakeholders
Impacts on shipping and navigation	Further baseline data to inform cumulative aspects of Marine Navigational Impact Assessments
	Uncertain risks to navigation that may arise from a number of wave and tidal projects and therefore difficulties with assessing and mitigating the potential cumulative impacts
Impacts on seascape	Lack of regional and local coastal landscape character assessments to inform Seascape, Landscape and Visual Impact Assessment.
	Lack of understanding regarding the economic value of seascape and any change in this as a result of renewable activities.
Social and economic impacts on local communities	Difficulty with identifying, assessing, mitigating and managing potential cumulative social and economic impacts from marine energy development and changes to existing maritime activity.
Impacts on tourism and recreation	Difficult to predict and assess potential impacts on tourism and recreation
Carbon footprint	Ability to accurately calculate full life cycle carbon footprint
Impacts on physical processes	Lack of baseline field data to inform hydrographic models
	Development of hydrographic models to predict the effects of changes in water flow and energy removal caused by (a) the physical presence of the device in the water (b) the removal of energy and secondary effects of changes in water flow and energy removal.
	Validation of hydrographic models to help predict the effects of changes in water flow and energy removal at commercial scale.

Task 2 - Identification of relevant research/information and gap analysis

The objective here was to consider each of the key EIA/HRA issues defined during Task 1 and identify any relevant gaps based on a review of existing and planned research and available information. This work was informed by a number of Specialist Contributors and responses to the Call for Evidence.

This process resulted in a list of research gaps relevant to a number of the key issues identified during Task 1. For some areas, it became apparent that sufficient information either currently exists or the gaps are being tackled via research currently underway. However, for other areas, gaps in knowledge and information were identified. These were therefore taken forward to the next task for further consideration. For full details of the gap analysis, please refer to Table 3.1 in the main report.

Task 3 - Research recommendations and identification of priority research projects

The first objective of this task was to provide recommended research areas that could help address the gaps identified during Task 2. The second objective was to identify a number of priority research projects that could inform the priorities and focus of any coordinated research programme (e.g. ORJIP Wave and Tide). During this process, a number of high priority research areas were identified that would be best undertaken/coordinated by other bodies e.g. regulators, SNCBs. Many of these are of equal importance to the future development of the wave and tidal sectors.

Recommended research areas to address each gap identified during the gap analysis (Task 2) were proposed. 'Priority projects/research areas' were then identified based on the following criteria:

- Projects that could address research gaps which could help to resolve key issues relevant to demonstration arrays that are currently inhibiting the advancement of the wave and tidal sectors.
- Projects that could help address the key initial questions that need to be answered.
- **Note: Research projects that are dependent upon, or would largely benefit from the findings of other studies (yet to be completed or undertaken) were not considered priorities that could be addressed through a coordinated programme (e.g. ORJIP Wave and Tide) at this point in time.**
- Projects that could be carried out around single devices and/or at first demonstration array projects that will provide results to inform demonstration and future commercial scale projects; reducing risk, cost and timescales.
- Projects that ORJIP Wave and Tide would be best placed to undertake or support e.g. projects which would benefit from a coordinated approach to translate device and first array outcomes to commercial scale development.
- **Note: Gaps which have a clear wider relevance beyond the wave and tidal sectors were considered to be beyond the focus of ORJIP Wave and Tide and within the remit of other programmes/organisations.**

The priority projects/research areas identified during this process are summarised in the following table. For each project/research area, possible research coordinators are identified along with the relevant sector(s) i.e. wave or tidal. Issues not identified as priorities (Task 1) and issues where no gaps were apparent (Task 2) were not taken forward to this task and are therefore not included in this summary.

Recommended research areas and priority research projects identified are:

Key issue	Priority project/research area	Sector	Possible coordinator
Lack of available acoustic data from operational wave and tidal devices and arrays	Producing/monitoring acoustic signatures of devices to build evidence base of operational noise levels. It is important that there is standardisation in measuring operational acoustic data so that data are comparable across projects.	Wave and tidal	Coordinated research programme (e.g. ORJIP Wave and Tide)
The nature of any potential interactions between diving birds and tidal turbines is uncertain	Further research / monitoring studies around single test devices and first demonstration arrays to gather information on the behaviour of marine birds around operating devices and to quantify avoidance rates for input in Collision Risk Modelling (CRM). Need to build evidence base to assess whether collision is likely to be an issue or not for diving birds. It is important that data on avoidance and behaviour is collated and organised in a systematic manner so that data collected can feed into the development of Collision Risk Models (CRMs).	Tidal	Coordinated research programme (e.g. ORJIP Wave and Tide)
	Further research to investigate probability of collisions occurring and factors affecting the likelihood of collision e.g. size of animal, swim speed, device speed, etc.	Tidal	Coordinated research programme (e.g. ORJIP Wave and Tide)
	Further analysis of existing data to investigate species abundance and distribution against tidal cycle data to assess if key species are present in areas of greatest tidal flow to inform whether collision is likely to be a real issue (or not).	Tidal	Regulators or advisors
	Behavioural studies (including tagging) to look at diving behaviour to determine whether birds are at risk through their feeding ecology.	Tidal	Regulators or advisors
The nature of any potential interactions between marine mammals and basking sharks and tidal turbines is uncertain	Monitoring studies around single test devices and first demonstration arrays to gather information on the behaviour of marine mammals (cetaceans and seals) and basking sharks around operating devices and to quantify avoidance rates for input in Collision Risk Modelling. Need to build evidence base to assess whether collision is likely to be an issue or not for marine mammals and basking sharks. It is important that data on avoidance and behaviour is collated and organised in a systematic manner so that data collected can feed into the development of Collision Risk Models (CRMs).	Tidal	Coordinated research programme (e.g. ORJIP Wave and Tide)
	Further research to investigate probability of collision occurring and factors affecting the likelihood of collision e.g. size of animal, swim speed, device speed, responses to noise, etc.	Tidal	Coordinated research programme (e.g. ORJIP Wave and Tide)
	Studies to determine how marine mammals and basking sharks are using high tidal energy environments and the relative importance of these areas compared to surrounding (presumably less energetic) environments. Need to gather data prior to devices being installed to assess where areas or times of key overlap exist. If species do not occur in the highest tidal energy areas or at times of highest flow/energy then that is obviously important.	Tidal	Regulators or advisors
	Further analysis of existing data (species abundance and distribution, seal tagging data) against tidal cycle data to assess if marine mammals are present in areas of greatest tidal flow to inform whether collision is likely to be a real issue (or not).	Tidal	Regulators or advisors
	Tagging work to help inform about behaviour of marine mammals in the water column (dive profiles, diving depth, swimming orientation of marine mammals and basking sharks in relation to tidal flow) for use in estimating collision risk but sample size issues present challenges.	Tidal	Regulators or advisors
The nature of any potential interactions between migratory fish and tidal turbines is uncertain	Monitoring studies around single test devices and first demonstration arrays to gather information on the behaviour (e.g. aggregation or avoidance) of fish around operating devices and to quantify avoidance rates to help refine and validate (or otherwise) encounter risk models. Need to gather evidence to see whether collision is likely to be an issue or not for migratory fish.	Tidal	Coordinated research programme (e.g. ORJIP Wave and Tide)
	Further research to investigate probability of collisions occurring and factors affecting the likelihood of collision e.g. size of animal, swim speed, device speed, etc.	Tidal	Coordinated research programme (e.g. ORJIP Wave and Tide)
There is uncertainty as to the possible physical consequences of potential collision events for marine mammals, diving birds and fish and tidal turbines	The consequences of collision with a turbine (or passage through a turbine in the case of fish) can be investigated using computer modelling or laboratory studies (e.g. tank testing) to study the effects of rotational speed of the blade, distance along blade, etc. on severity of injury for a range of turbine designs and species. Computational Fluid Dynamics (CFD) studies to ascertain if some species may have 'protection' from collision through entrainment. CFD models of turbines and turbine arrays could be used to predict the pressure fluctuations experienced by species as they pass close to turbines. These pressure traces can be used to find effects on key marine species and their prey.	Tidal	Coordinated research programme (e.g. ORJIP Wave and Tide)
Further development of suitable instrumentation and methodologies for monitoring wildlife behaviour around wave and tidal devices and arrays and for detection of any collision events is required	Further development of suitable instrumentation and methodologies may require an integrated approach utilising a number of different technologies running in parallel e.g. development of acoustic tag technology, active sonar automatic detection/tracking ability, development of automated 3D PAM tracking, development of collision detection technology. Trial/test monitoring technologies (potentially at e.g. EMEC, WaveHub, FaBTest and other test sites) to inform improvements in technologies and cost reductions	Wave and tidal	Coordinated research programme (e.g. ORJIP Wave and Tide)
Potential displacement of essential activities of marine mammals, basking sharks and birds	Undertake a review of findings of offshore wind research into displacement and the assessment of potential population level effects. Determine whether or not displacement from demonstration scale / commercial scale wave and tidal arrays is ever likely to result in biologically significant effects. If necessary, develop a consistent approach to assessing/modelling the risk to populations from displacement form wave and tidal projects. To enable Regulators to assess the risk. If necessary, an agreed approach on how to measure/detect displacement is required. Can displacement be measured? What is a representative sample? How can potential significance of displacement be assessed?	Wave and tidal	Coordinated research programme (e.g. ORJIP Wave and Tide)
Further strategic baseline data (distribution, abundance, seasonality, etc.) for marine mammals and basking sharks is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects.	Better use of data already gathered for first projects (consented arrays and those near planning submission). Collation of information about priority species and priority areas (from existing installations and (potential) future installation areas around UK waters). Regular reviews of monitoring data (similar to the recent commissioned project by MMO (MMO 1031); reviewing post-consent monitoring collected from offshore wind farms in order to provide a synthesis of the evidence. Make existing data available to other developers through the Regulators – this would build a longer term data set to be used in EIA/HRA.	Wave and tidal	Regulators or advisors
	Detailed statistical analysis of data already gathered from a number of sites to investigate any actual impacts occurring and ability to detect change to determine what can be learnt from data already gathered.	Wave and tidal	Regulators or advisors
	Development and update of sensitivity mapping for key species and the incorporation of this information into marine spatial planning.	Wave and tidal	Regulators or advisors
Further strategic baseline data (distribution, abundance, seasonality, etc.) for birds is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects.	Make better use of data already gathered for first projects (consented arrays and those near planning submission). Collation of information about priority species and priority areas (from existing installations and (potential) future installation areas around UK waters). Regular reviews of monitoring data (similar to the recent commissioned project by MMO (MMO 1031); reviewing post-consent monitoring collected from offshore wind farms in order to provide a synthesis of the evidence. Make existing data available to other developers through the Regulators – this would build a longer term data set to be used in EIA/HRA.	Wave and tidal	Regulators or advisors
	Detailed statistical analysis of data already gathered from a number of sites to investigate any actual impacts occurring and ability to detect change to determine what can be learnt from data already gathered.	Wave and tidal	Regulators or advisors
Further data of mobile species populations (particularly qualifying species of Natura sites and EPS) for use in population modelling would improve confidence in EIA/HRA	Establish up-to date demographic parameters for key species to enable validation of models and to inform inputs to models. Lack of up-to-date data is a serious hindrance to research across the sector.	Wave and tidal	Regulators or advisors
	Establish consistent rationales for defining populations using the best available information. The definition of management units will be an adaptive process: when more evidence becomes available these units can be updated for following applications.	Wave and tidal	Regulators or advisors
	Connectivity (protected sites and species): Understanding linkages between birds at sea and SPAs. Plug gaps in seabird tracking studies; improve our understanding of foraging areas associated with different breeding colonies.	Wave and tidal	Regulators or advisors
	Understanding linkages between migratory salmon (Natura species) and SACs. How to apportion populations to rivers and SAC sites.	Wave and tidal	Regulators or advisors

Key issue	Priority project/research area	Sector	Possible coordinator
Better understanding of population level impacts and methods to assess the significance of population level impacts would improve confidence in EIA/HRA.	Review of existing modelling tools and of need for development of new tools to predict population level consequences of impacts on survival and reproductive success of individuals and hence population size. Establish an appropriate methodology e.g. such as using a modified version of PVA/PBR. Review of PBR approach to regulation including a consideration of alternatives. Briefing paper for Regulators and developers.	Wave and tidal	Regulators or advisors
	The PCoD project and ORJIP offshore wind PCAD project should help to provide frameworks for determining thresholds for impacts in terms of disturbance or mortality levels, but there is likely to be a need for some additional work to ascertain thresholds that fully meet the requirements of the Habitat Regulations and which are relevant to wave and tidal projects. Develop a modelling and management framework appropriate for assessing the risks. Link results to the management of potential impacts on Favourable Conservation Status of protected sites/species.	Wave and tidal	Regulators or advisors
Further baseline inshore fisheries activity data to inform CIA (Cumulative Impact Assessment)	Roll out of projects akin to ScotMap for key areas outside Pentland Firth and Orkney Waters Strategic Area.	Wave and tidal	Regulators or advisors
Lack of regional and local coastal landscape character assessments to inform Seascape, Landscape and Visual Impact Assessment.	Character-based coastal landscape assessment at national level.	Wave and tidal	Regulators or advisors
	For areas where clusters for development are planned then a regional scale character based assessment should also be undertaken (or at a finer level than regional may be required on some complex areas of coast).	Wave and tidal	
	Detailed assessment at a local scale is appropriate to impact assessment of specific coastal or marine based developments.	Wave and tidal	Project developers
Difficulty with identifying, assessing, mitigating and managing potential cumulative social and economic impacts from marine energy development and changes to existing maritime activity.	Data collection in order to better understand the potential socio-economic impacts on local communities.	Wave and tidal	Relevant local authority
	The methodology and baseline produced by ABPmer could be used to undertake a cumulative socio economic impact assessment at a regional basis if determined necessary/beneficial by the local authority/regulator(s)/advisors.	Wave and tidal	Relevant local authority in conjunction with regulator(s)/advisors and project developers
	A review of work underway in offshore wind ORJIP could be adapted / aligned with the needs of the wave and tidal industry. A cumulative social impact assessment similar to ABPmer's ongoing socio-economic case studies, but where the emphasis is on the potential social impacts and benefits from development of a wave and/or tidal industry, with particular emphasis on the impacts on small rural communities.	Wave and tidal	Relevant local authority in conjunction with regulator(s)/advisors and project developers

Task 4 – Development of outline plans for priority research projects

Using consistent, transparent criteria, and informed via a significant amount of information (including that generated from the many responses received via the Call for Evidence), five high priority projects, which appear appropriate for a coordinated research programme (such as ORJIP Wave and Tide) to undertake, have been identified:

- **Project 1** - Research and monitoring studies around single devices and first arrays to gather further information on the behaviour of marine mammals, birds and fish around operating wave and tidal devices
- **Project 2** – Further investigation into the possible physical consequences of collision for marine mammals, diving birds and fish with operating tidal turbines
- **Project 3** - Further development of suitable instrumentation and methodologies for monitoring wildlife behaviour around wave and tidal devices and arrays and for detection of any collision events
- **Project 4** - Development of an agreed approach to assessing the potential effects of displacement of marine mammals and birds from wave and tidal arrays
- **Project 5** - Establishment of an acoustic 'evidence base' for operational wave and tidal devices and first arrays

Note: these projects are listed in no particular order.

It is recommended that these projects form the principal / initial focus of any coordinated research programme that is established for the wave and tidal energy sectors. However, it is clear that several other areas remain in need of further research by the relevant organisation(s) or group(s). It should be noted that the priorities identified in this project are not only relevant to any coordinated research programme but also to any research which individual developers, regulators/advisors, academic institutions etc. may plan to undertake.

The gap analysis demonstrated that significant work has already gone into furthering our understanding of many of the key issues. However, in order to ensure the best possible information is available to those involved in the consenting process and to enable the sustainable development of the wave and tidal energy sectors, there is an urgent need to progress a number of these priority project/research areas, particularly, but not exclusively, the five listed above.

Contents

1 Introduction

1.1 Background

As part of the current initiative to assist with developing a coordinated approach to addressing the key strategic EIA/HRA issues associated with wave and tidal stream arrays (under, for example, an Offshore Renewables Joint Industry Programme (ORJIP) for wave and tide), Aquatera Limited was commissioned by The Crown Estate to undertake a short, focused consultancy project; 'Consolidation of wave and tidal EIA/HRA issues and research priorities'.

This report has been published by The Crown Estate as part of its Pentland Firth and Orkney Waters (PFOW) Enabling Actions work to support the development of wave and tidal stream projects. **Whilst funded by the PFOW Enabling Actions programme, this report is relevant to the wave and tidal stream sectors across the UK.**

The Enabling Actions programme aims to accelerate and de-risk the development process for wave and tidal stream projects, looking at a range of key issues. Work is selected, commissioned and steered by The Crown Estate in close discussion with the PFOW project developers. For more information on The Crown Estate's work in wave and tidal energy, see www.thecrownestate.co.uk/energy/wave-and-tidal/ or contact waveandtidal@thecrownestate.co.uk.

1.2 Project aims and objectives

The key driver for this project was the recognition of the benefits of a coordinated effort to obtain and translate learning, knowledge, experience, information and data from single device and particularly first array projects to larger array deployments. It is considered that a coordinated approach will ensure that the best possible information is available to developers, regulators, Statutory Nature Conservation Bodies (SNCBs) and other stakeholders to inform the consenting process and project planning and design activities.

A number of barriers to this have been identified including:

- Limited deployment of devices to date
- Variety of device designs
- Range of environmental receptors
- Range of potential impacts
- Varying degree of dissemination and sharing of data and learning from individual deployments and research projects
- Lack of clarity around the current degree of understanding about the key issues and residual uncertainties

As such, the main aims of this project are to:

- Produce a consolidated up-to-date list identifying the key strategic EIA/HRA issues facing the wave and tidal stream sectors
- Identify the priority research gaps relevant to wave and tidal stream demonstration scale arrays and then outline potential approaches to address them
- Identify strategic research priorities which could be addressed through a coordinated programme

The approach developed and implemented by Aquatera was designed to meet the following objectives:

1. To identify the key strategic EIA/HRA issues for wave and tidal stream array projects utilising relevant existing documents and stakeholder input
2. To identify relevant research (including work from industry, statutory agencies, government, academic institutions, The Crown Estate, NGOs etc.) and undertake a gap analysis against the key strategic issues
3. To recommend research areas to fill the key strategic gaps, focused on those relevant to demonstration array scale projects and produce an updated set of prioritised research areas for the first wave and tidal stream arrays
4. To outline priority research projects separately (where appropriate/necessary) for wave and for tidal stream to resolve the priorities identified.

It is intended that the outputs from this project, by guiding future research work, will assist with resolving the priority EIA/HRA issues relevant to wave and tidal stream arrays. It will do this by focusing any coordinated approach to research that is developed (e.g. via ORJIP Wave and Tide). However, it should be noted that the priorities identified in this project are not only relevant to any coordinated research programme but also to any research which individual developers, regulators/advisors, academic institutions etc. may plan to undertake.

1.3 Overview of approach

Aquatera developed the following approach to meet the study objectives:

Stage 1. Initial stakeholder consultation (refer to Section 1.3.2)
Stage 2. Production of a Draft Report (refer to Section 1.3.3)
Stage 3. Further stakeholder consultation (refer to Section 1.3.4)
Stage 4. Production of a Final Report (refer to Section 1.3.5)

Each stage is described in the following sections and an overview is provided in Figure 1.1.

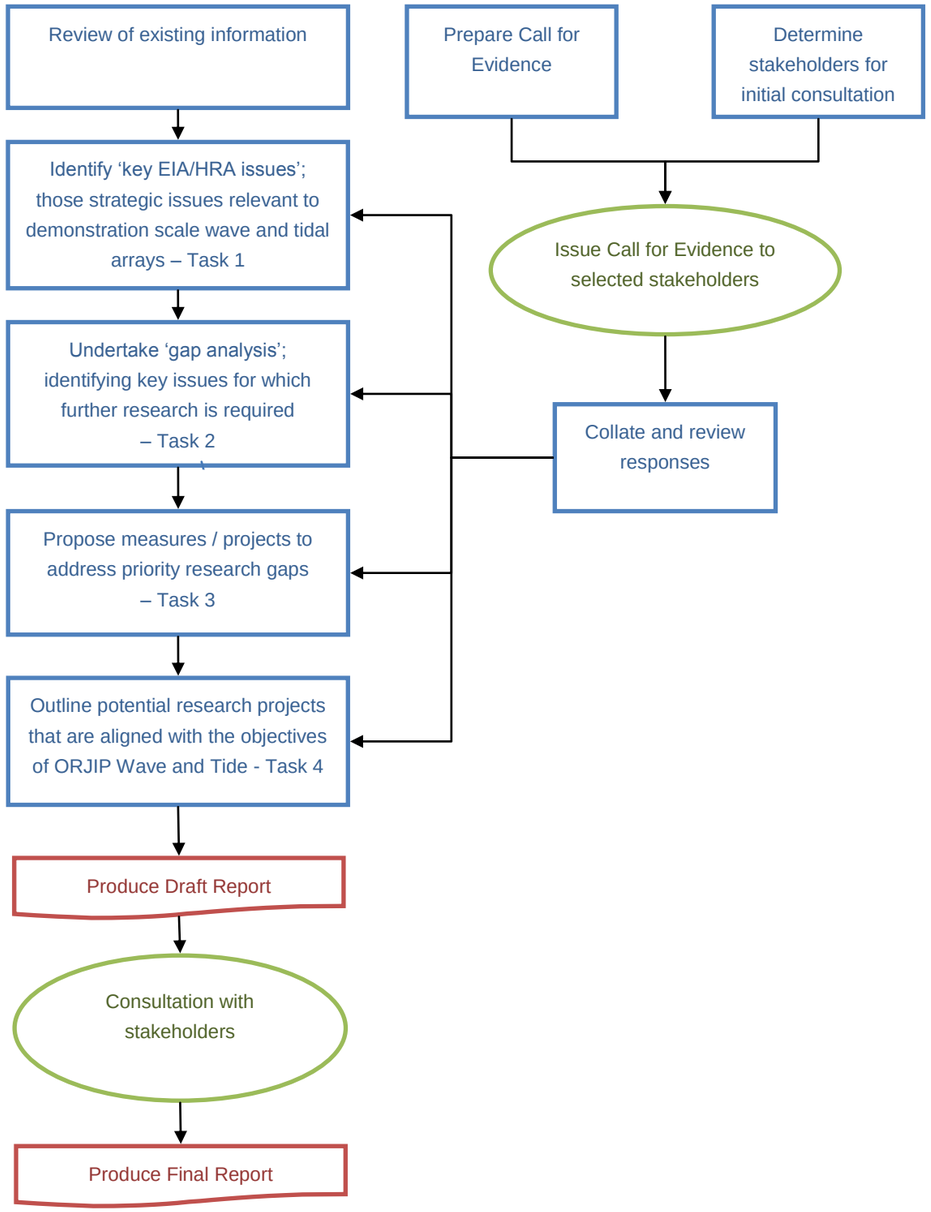

Figure 1.1 Overview of approach

1.3.2 Stage 1 - Initial stakeholder consultation – Call for Evidence

Given the strategic importance of this project, it was essential that project outputs were fully informed and that the best and most up-to-date information was available to the team. To meet this aim, a Call for Evidence was issued to key stakeholders along with a pro forma. Stakeholders were identified in collaboration with The Crown Estate and included the following organisations and companies:

- Regulators/devolved administrations/government departments
  - Marine Scotland
  - Marine Management Organisation (MMO)
  - Natural Resources Wales (Licencing)
  - Department of Energy and Climate Change (DECC)
  - Department of Environment, Food and Rural Affairs (DEFRA)
  - Department of the Environment (Northern Ireland)
  - Department of Enterprise, Trade and Investment (Northern Ireland)
  - Welsh Assembly Government (Agriculture and Fisheries Policy Division)
- Developers
  - Open Hydro, Scottish and Southern Energy Renewables, Scottish Power Renewables, Marine Current Turbines, Aquamarine Power Ltd, Pelamis Wave Power, MeyGen Ltd, E.On, DP Energy, Tidal Energy Ltd and Scotrenewables Tidal Power Ltd
- SNCBs
  - Scottish Natural Heritage (SNH)
  - Natural England (NE)
  - Natural Resources Wales (Advisory)
  - Department of the Environment (Northern Ireland)
- Researchers
  - SEACAMS, Centre for Applied Marine Sciences
  - Low Carbon Research Institute (LCRI)
  - Scottish Association for Marine Science (SAMS) & Marine Alliance for Science and Technology for Scotland (MASTS)
  - NERC Marine Renewable Energy Knowledge Exchange Programme (MREKEP)
  - Cardiff University
  - Aberdeen University
- Trade associations
  - Renewable UK
  - Scottish Renewables
  - Renewable Energy Association
  - Marine Energy Pembrokeshire
- Other stakeholders
  - WavEC Offshore Renewables
  - Pacific Northwest National Lab (PNNL)
  - Oregon Wave Energy Trust (OWET)
  - Oregon State University (National Northwest Marine Renewable Energy Centre (NNMREC))
  - Fundy Environmental Research Network, Fundy Ocean Research Centre for Energy (FORCE)
  - US Department of Energy – Wind and Water Programme Managers (DOE)

At this stage, Aquatera also engaged a number of other Specialist Contributors:

- Xodus Group (Liz Foubister)
- Royal Haskoning DHV (Frank Fortune)
- European Marine Energy Centre (EMEC) (Matthew Finn)
- SMRU Marine (Carol Sparling)

These Specialist Contributors were commissioned to input into the Call for Evidence process. Each provided valuable contributions at the initial stages of the project and provided an ongoing peer review role throughout the project.

The questions posed in the Call for Evidence were:

- **Question 1a** – What do you see as the key strategic EIA/HRA issues/uncertainties for wave and tidal energy array projects at the present time? Are these issues relevant to wave projects, tidal projects or both?
- **Question 1b** – For each issue identified, do you see this as a near term consideration, i.e. relevant to demonstration arrays or is it a long term issue that is more relevant to commercial scale projects?
- **Question 2** - Are you aware of any **other**[1] sources of information/data that should be considered during this project; in particular, any past, ongoing or planned monitoring/research projects that might be relevant to each particular issue? For each recommended source, please state whether or not it is currently available to the Project Team.
- **Question 3** - What do you think are the present key strategic research gaps with regards to each key issue? Do you have any recommendations as to what could be done to address these gaps and who might undertake this work?

Sixteen responses to the Call for Evidence were received (a full collated set of responses is available separately, upon request). All responses were collated and analysed and used to inform the core project tasks as described in the following sections.

1.3.3 Stage 2 - Production of a Draft Report

Four core tasks were undertaken in preparing the Draft Report, with Tasks 1-3 filtering the issues to produce a final list of priority projects:

- **Task 1 – Identification of the key EIA/HRA issues**
  - Issues relevant to all/a number of technology or project types (wave and tidal).
  - Issues relevant to demonstration scale arrays.
  - Issues that have been identified as high priorities for the wave and tidal sectors[2] and for which strategic research at demonstration scale would inform commercial scale EIA/HRA.
  - Issues that should be addressed at a project/site specific level were not considered to be key issues.
  - **Note:** criteria used to identify key issues are presented in Section 2.2 and the results are presented in Table 2.1.
  - **Output – A list of key issues for consideration in Task 2 – Research Gap Analysis.**
- **Task 2 – Research Gap Analysis**
  - Past, ongoing and planned research and available information was identified, and a research gap analysis was undertaken in relation to each key issue identified during Task 1.
  - **Output - A list of research relevant to each key issue and a list of research gaps for further consideration in Task 3.**
- **Task 3 – Development of research recommendations and identification of priority projects for ORJIP Wave and Tide**
  - Recommendations for research projects to address gaps identified during Task 2 were developed.
  - Priority research projects to focus upon were then identified.
  - **Output – A list of recommended research areas to address research gaps and a list of priority research projects for ORJIP Wave and Tide**
- **Task 4 – Development of outline plans for priority research projects**
  - Outline plans were developed for those research projects identified during Task 3 as research priorities for ORJIP Wave and Tide to focus upon.
  - **Output – A series of outline research project plans**

Each task and the associated outputs were informed by key existing documents and information gathered during the Call for Evidence.

Note: An overview of the approach implemented during each task and the relevant results are provided in Chapters 2, 3, 4 and 5.

1.3.4 Stage 3 – Further Stakeholder Consultation

The Draft Report was produced and circulated to a limited set of stakeholders for initial comment[3]. This report was then revised based on the comments and feedback received.

1.3.5 Stage 4 - Production of a Final Report

Following consultation on the Draft Report, a Final Draft was presented at a workshop hosted by NERC in Edinburgh in November 2013. The purpose of this workshop was to review the gap analysis and the priority projects identified and (more importantly) to work towards a consensus across the organisations present as to the key strategic EIA/HRA research priorities for demonstration arrays in the near term.

This Final Report was then produced, incorporating any amendments required. A summary of the workshop proceedings and outcomes is presented in Annex A of this report.

1.4 Report structure

This report is structured around the core tasks (1 – 4) and the associated outputs as outlined in Section 1.3:

- Chapter 2: Identification of key EIA/HRA issues
- Chapter 3: Identification of relevant research and information, and gap analysis
- Chapter 4: Research recommendations and identification of priority research projects
- Chapter 5: Outline ‘Priority Research Project’ plans

[1] Within the Call for Evidence, stakeholders were provided with a list of information and references that The Crown Estate and Aquatera already held which this question refers to.

[2] These issues were identified as high priorities during the Draft Report consultation process for this project.

[3] Due to the project’s tight timescales and the planned workshop where the report was to be discussed, only a limited set of stakeholders were included in this initial review

2 Task 1 - Identification of key EIA/HRA issues

2.1 Objective

The initial core task of this project was to identify the key EIA/HRA issues associated with wave and tidal stream array projects. The objective of this task was not to simply identify the potential impacts of wave and tidal energy array projects but to identify the key issues that developers and regulators are currently facing with regards to EIA and HRA in the context of the consenting process. Another objective of this task was to distinguish, where possible, between issues relevant to demonstration scale and commercial scale projects and those relating to wave and tidal projects.

2.2 Approach

A 'long list' of key EIA/HRA issues was produced based on a preliminary review of the following key documents:

- Development of Offshore Renewable Energy in Scotland's Seas: Research Implementation Strategy (Marine Scotland, 2012)
- MMO Research Priorities on Offshore Research, Summary for ORRSG 5th February 2013
- The Crown Estate research list (related to marine renewables), last updated 21/8/2013
- Marine Renewable Energy: Knowledge needs and issues - July 2013 update
- Overview of research priorities/key knowledge gaps: Offshore wind, wave and tidal (revised version with ORRSG comments from February 2013 meeting included)
- SNH Research Programme (Marine Renewables), last updated 2nd July 2013
- Offshore Renewable Energy Licensing Group Issues List, ORELG 02/11/12
- Research Priorities for managing consenting risks in relation to marine renewables, January 2013 – combined recommendations from the Statutory Nature Conservation Bodies
- Robinson, S.P and Lepper, P.A. (2013) "Scoping study: Review of current knowledge of underwater noise emissions from wave and tidal stream energy devices". The Crown Estate
- Slaski, R.J, Hirst, D and Gray, S (2013) PFOW wave and tidal stream projects and migratory salmonids
- Malcolm, I.A., Armstrong, J.D., Godfrey, J.D., Maclean, J.C., Middlemas, S.J., (2013) Marine Scotland Science Report 05/13. The Scope of Research Requirements for Atlantic Salmon, Sea Trout and European Eel in the Context of Offshore Renewables
- Copping, A.; Hanna, L.; Whiting, J.; Geerlofs, S.; Grear, M.; Blake, K.; Coffey, A.; Massaua, M.; Brown-Saracino, J.; Battey, H. (2013) Environmental Effects of Marine Energy Development around the World: Annex IV Final Report. (pp. 97), Pacific Northwest National Laboratory; Ocean Energy Systems
- DECC Offshore Energy SEA Programme – Potential Research Projects (2013)
- Countryside Council for Wales (CCW) recommendations for research into the environmental effects of wave and tidal stream technologies, undated
- Strategic Environmental Assessments (Scottish Government 2007, DETI 2009, DECC 2011)
- EIAs (e.g. Scottish Power Renewables, 2010; MCT 2011, 2012 and 2013; MeyGen, 2012; Aquamarine 2012)
- A review of the potential impacts of wave and tidal renewable energy developments on Scotland's marine environment (Aquatera Ltd, 2012 and Aquatera Ltd, in prep.)
- Renewable UK, Scottish Renewables, NERC Wave and Tidal Consenting Position Paper Series:
    - Kirby, A.D., Hawkins, K.R., Freeman, S.M., McCall, R.A., Furness, R., Edhouse, E.S. (2013) Ornithological Impacts.
    - Freeman, S.M., Hawkins, K.R., Kirby A.D., McCall, R.A., Blyth-Skyrme, R.E., Edhouse, E.S. Impacts on Fish and Shellfish Ecology
    - Sparling, C.E., Coram, A.J., McConnell, B., Thompson, D., Hawkins, K.R., Northridge, S.P. (2013) Marine Mammals Impacts.

This 'long list' was further informed by the responses to the Call for Evidence and direct input from the Specialist Contributors (refer to Section 1.3.2).

A screening process was then undertaken to identify 'key issues' as defined by the project objectives (refer to Section 1.2).

Within the context of this project and the study objectives, the following criteria were used to identify the key EIA/HRA issues:

- **Project type – is the issue relevant to wave projects, tidal stream projects or both?** Issues relevant to all/a number of wave/tidal technology or project types were identified as key issues.

- **Strategic relevance – can and should the issue be addressed at a strategic level?** Issues that should be addressed at a project/site specific level were **not** considered as key issues.

- **Project scale – is the issue relevant to demonstration scale or commercial scale projects?** At this stage, issues relevant to demonstration scale arrays were identified as key issues. It was considered that issues likely to be relevant at commercial scale only can be tackled in the longer term and are therefore not priorities in the immediate/near term. However, issues considered to be only relevant at commercial scale that were identified as high priorities by the wave and tidal energy sectors[4] and for which strategic research at demonstration scale would inform commercial scale EIA/HRA, were also identified as key issues during this process.

Note: A number of issues identified are also relevant to other industries and activities. Where this is the case, these have been identified in Table 2.1.

2.3 Results

The 'long list' of EIA/HRA issues along with the 'key issues' identified during the screening process are presented in Table 2.1.

[4] These issues were identified as high priorities during the Draft Report consultation process for this project

Table 2.1 Identification of key EIA/HRA issues (note: not in order of priority)

Ref No. and Topic	Ref No. and EIA/HRA issue	Receptor	Project type	Strategically relevant?	Relevant to other sectors / industries?	Commercial or demonstration scale?	Key issue?
Ecological environment							
1. Underwater noise	1.1: Agreed best practice approaches for measuring ambient noise in high energy wave and tidal environments are required	N/A	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
	1.2: Agreed best practice approaches for measuring noise from operational wave and tidal devices and construction activities are required	N/A	Wave and tidal	Yes, relevant to all wave and tidal projects.	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
	1.3: Lack of available acoustic data from operational wave and tidal devices and arrays	N/A	Wave and tidal	Yes, relevant to all wave and tidal projects.	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
	1.4: Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on diving birds is incomplete	Birds	Wave and tidal	Yes, relevant to all wave and tidal projects.	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
	1.5: Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on marine mammals is incomplete	Marine mammals	Wave and tidal	Yes, relevant to all wave and tidal projects.	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
	1.6: Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on fish is incomplete	Fish	Wave and tidal	Yes, relevant to all wave and tidal projects.	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
2. Collision risk	2.1: The nature of any potential interactions between diving birds and tidal turbines is uncertain	Birds	Tidal	Yes, all tidal projects	No, only relevant to tidal projects	Demonstration and commercial	Yes
	2.2: The nature of any potential interactions between marine mammals and basking sharks and tidal turbines is uncertain	Marine mammals and basking shark	Tidal	Yes, all tidal projects	No, only relevant to tidal projects	Demonstration and commercial	Yes
	2.3: The nature of any potential interactions between migratory fish and tidal turbines is uncertain	Migratory fish	Tidal	Yes, all tidal projects	No, only relevant to tidal projects	Demonstration and commercial	Yes
	2.4: There is uncertainty as to the possible physical consequences of potential collision events for marine mammals, diving birds and fish and tidal turbines	Marine mammals, birds and fish	Tidal	Yes, all tidal projects	No, only relevant to tidal projects	Demonstration and commercial	Yes
	2.5: Further development of suitable instrumentation and methodologies for monitoring wildlife behaviour around wave and tidal devices and arrays and for detection of any collision events is required	Marine mammals, birds and fish	Wave and tidal	Yes, relevant to all wave and tidal projects.	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
3. Entanglement	3.1: Concern within the regulatory and advisory bodies that mooring lines pose an entanglement risk to marine mammals and large fish	Marine mammals, Fish	Wave and tidal	Yes, for all projects with mooring lines	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
4. Seal injuries from vessel propellers	4.1: Lack of understanding around the possible cause of death to seals with 'corkscrew' injuries	Seals	Projects proposing to use DP vessels (with ducted propellers).	Yes, relevant to wave and tidal projects proposing to use vessels with ducted propellers	Yes, relevant to other offshore industries utilising DP vessels (with ducted propellers).	Demonstration and commercial	Yes
5. EMF	5.1: Further data and information regarding the possible effects of EMF from transmission cables on fish would improve confidence in EIA and HRA	Fish	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
6. Displacement	6.1: Potential displacement of essential activities of marine mammals, basking sharks and birds	Marine mammals, birds and basking shark	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Commercial - this issue was identified as a high priority during the Draft Report consultation process.	Yes
7. Reef effects	7.1: Potential for positive effects such as use of development sites as feeding and nursery areas for fish and use of structures as fish aggregation devices	Fish	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Commercial	No
	7.2: Indirect effects on predators including potential for increased foraging opportunities	Marine mammals, birds and fish	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Commercial	No
8. Introduction of non-native invasive species	8.1: Concern within the regulatory and advisory bodies that wave and tidal developments have the potential to result in the introduction or spread of non-native invasive species	All	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Commercial	No
9. Entrapment	9.1: Potential risk of entrapment of marine mammals and basking sharks from wave and tidal energy converters and associated moorings or support structures	Marine mammals and basking shark	Wave and tidal	No, technology specific	No, only relevant to wave and tidal projects	Demonstration and commercial	No

Ref No. and Topic	Ref No. and EIA/HRA issue	Receptor	Project type	Strategically relevant?	Relevant to other sectors / industries?	Commercial or demonstration scale?	Key issue?
10. Barrier to movement	10.1: It is uncertain whether wave and tidal developments will cause a barrier to movement for marine mammals and basking sharks	Marine mammals and basking shark	Wave and tidal	No, site/project specific	No, only relevant to wave and tidal projects	Demonstration and commercial	No
	10.2: It is uncertain whether wave and tidal developments will cause a barrier to movement for migratory fish	Migratory fish	Wave and tidal	No, site/project specific	No, only relevant to wave and tidal projects	Demonstration and commercial	No
11. Impacts on benthic communities	11.1: Direct loss of habitat and near field effects (e.g. scour, deposition) on protected or sensitive sub-littoral seabed communities	Benthic communities	Wave and tidal	No, site/project specific	Yes, relevant to other offshore industries	Demonstration and commercial	No
	11.2: The potential wider or secondary effects on protected or sensitive sub-littoral seabed communities due to installation and operation of wave and tidal energy converters and associated moorings or support structures is poorly understood	Benthic communities	Wave and tidal	No, site/project specific	Yes, relevant to other offshore industries	Commercial	No
12. Ecological effects due to changes in hydrographic properties	12.1: Effects on predator-prey capture rates due to changes in hydrodynamic properties as a result of presence and operation of marine energy devices.	Marine mammals, birds and fish	Wave and tidal	Yes, relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Commercial	No
	12.2: Effects on ecosystem functioning due to changes in hydrodynamic properties as a result of presence and operation of marine energy devices.	Marine mammals, birds and fish	Wave and tidal	Yes, relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Commercial	No
13. General	13.1: Further strategic baseline data (distribution, abundance, seasonality, etc.) for marine mammals and basking sharks is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects.	Marine mammals and basking shark	Wave and tidal	Yes, relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
14. General	14.1: Further strategic baseline data (distribution, abundance, seasonality, etc.) for birds is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects.	Birds	Wave and tidal	Yes, relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
15. General	15.1: Further strategic baseline data (distribution, abundance, seasonality, etc.) for migratory fish is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects.	Migratory fish	Wave and tidal	Yes, relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
16. General	16.1: An agreed approach to undertaking site characterisation and baseline surveys for marine mammals and birds to inform EIA and HRA is required.	Marine mammals and birds	Wave and tidal	Yes, relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
17. General	17.1: Further data of mobile species populations (particularly qualifying species of Natura sites and EPS) for use in population modelling would improve confidence in EIA/HRA	Marine mammals, birds and fish	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
18. General	18.1: Better understanding of population level impacts and methods to assess the significance of population level impacts would improve confidence in EIA/HRA	Marine mammals, birds and fish	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
Human environment							
19. Impacts on commercial fisheries	19.1: Further baseline inshore fisheries activity data to inform CIA (Cumulative Impact Assessment)	Commercial fisheries	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
	19.2: There is a lack of standardised approach to assessing the availability of alternative fishing grounds (outside development areas) and their ability to sustain existing /displaced commercial fishing levels.	Commercial fisheries	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
	19.3: Lack of a standardised approach, specific to the wave and tidal industry, for identifying appropriate mitigation measures to mitigate the potential impact on commercial fisheries	Commercial fisheries	Wave and tidal	Yes, relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
	19.4: Lack of a standardised approach and guidance, specific to the wave and tidal industry, on effective engagement with the commercial fishing industry and local stakeholders	Commercial fisheries	Wave and tidal	Yes, relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
20. Impacts on shipping and navigation	20.1: Further baseline data to inform cumulative aspects of Marine Navigational Impact Assessments	Shipping and navigation	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Demonstration and commercial	Yes

Ref No. and Topic	Ref No. and EIA/HRA issue	Receptor	Project type	Strategically relevant?	Relevant to other sectors / industries?	Commercial or demonstration scale?	Key issue?
	20.2: Uncertain risks to navigation that may arise from a number of wave and tidal projects and therefore difficulties with assessing and mitigating the potential cumulative impacts	Shipping and navigation	Wave and tidal	Yes, relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
21. Impacts on seascape	21.1: Lack of regional and local coastal landscape character assessments to inform Seascape, Landscape and Visual Impact Assessment.	Landscape and seascape	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Demonstration and commercial	Yes
	21.2: Lack of understanding regarding the economic value of seascape and any change in this as a result of renewable activities.	Landscape and seascape	Wave and tidal	Yes, relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Demonstration and commercial	Yes
22. Social and economic impacts on local communities	22.1: Difficulty with identifying, assessing, mitigating and managing potential cumulative social and economic impacts from marine energy development and changes to existing maritime activity.	Local communities	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Commercial scale and 'clusters' of demonstration scale projects	Yes
23. Impacts on tourism and recreation	23.1: Difficult to predict and assess potential impacts on tourism and recreation	Local communities	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Commercial	No
24. Carbon footprint	24.1: Ability to accurately calculate full life cycle carbon footprint	N/A	Wave and tidal	Yes, relevant to all wave and tidal projects	Yes, relevant to other offshore industries	Commercial	No
Physical environment							
25. Impacts on physical processes	25.1: Lack of baseline field data to inform hydrographic models	Physical environment	Wave and tidal	No – site/project specific	Yes, relevant to other offshore industries	Commercial	No
	25.2: Development of hydrographic models to predict the effects of changes in water flow and energy removal caused by (a) the physical presence of the device in the water (b) the removal of energy and secondary effects of changes in water flow and energy removal.	Physical environment	Wave and tidal	Yes – relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Commercial but valuable research could be undertaken around demonstration array projects	Yes
	25.3: Validation of hydrographic models to help predict the effects of changes in water flow and energy removal at commercial scale	Physical environment	Wave and tidal	Yes – relevant to all wave and tidal projects	No, only relevant to wave and tidal projects	Commercial but valuable research could be undertaken around demonstration array projects	Yes

3 Task 2 - Identification of relevant research/information and gap analysis

3.1 Objective

The objective of this task was to consider each of the key EIA/HRA issues defined during Task 1 and to identify any relevant research gaps based on relevant research and existing information and responses to the Call for Evidence.

3.2 Approach

A research gap analysis was undertaken in relation to each key issue identified during Task 1. This was informed by a high-level review of existing, relevant, available research and key documents outlining research that is planned or underway; including, but not limited to those documents listed in Section 2.2. For each key issue, any relevant past, ongoing and planned research identified during the review process was recorded (refer to Section 3.3).

This process was also informed by the responses to the Call for Evidence and input from the Specialist Contributors

Where a gap has been identified and there is currently sufficient ongoing or planned work which may address the issue, this has been classified in Table 3.1 as a 'HOLD'. For each of these, the research gap analysis should be revisited once the relevant studies have been completed and results are available. The remaining gaps have been taken forward to the next stage of the process where those that are priorities for ORJIP Wave and Tide have been identified.

3.3 Results

Table 3.1 Research gap analysis

Topic	Key Issue	Research published / underway / planned	Gap analysis
Ecological environment			
1. Underwater noise	1.1: Agreed best practice approaches for measuring ambient noise in high energy wave and tidal environments are required	**Published:** • Bassett, C., (2010) Underwater ambient noise at a proposed tidal energy site in Puget Sound. M.S. Thesis, University of Washington, Seattle. • Bassett, C., Thomson, J., and Polagye, B., (2010) Characteristics of Underwater Ambient Noise at a 338 Proposed Tidal Energy Site in Puget Sound. In OCEANS 2010, pp. 1-8. • BSH, (2011) Offshore wind farms. Measuring instruction for underwater sound monitoring. Report by Muller-BBM • Carter, C. and Wilson, B. (2011) Mapping underwater ambient noise in the Sound of Islay tidal-stream: A potential tidal energy extraction area, Proceedings of the Institute of Acoustics, vol. 33, part 5. • European Marine Strategy Framework Directive Good Environmental Status (MSFD-GES), (2012).Report of the Technical Subgroup on Underwater Noise and other forms of energy. • Harland, E.J. (2013) Fall of Warness Tidal Test Site: Additional Acoustic Characterisation. Scottish Natural Heritage Commissioned Report No. 563. • Hildebrand, J.A. (2009) Anthropogenic and natural sources of ambient noise in the ocean. Marine Ecology Progress Series: 395, 5–20. • Lepper, PA, Harland, E, Robinson, SP, Theobald, P, Hastie, G, Quick, N (2013) Acoustic Noise Measurement Methodology for the Billia Croo Wave Energy Test Site: ANNEX A: Summary of operational underwater noise TESTs for a Pelamis P2 system at EMEC May 2011, pp.1-36, Scottish Government. • Natural Resources Wales (workshop 23 April 2013) 'NRW suggestions for the development of guidance to assist advisors in the provision of advice on underwater noise'. • Robinson, S.P and Lepper, P.A. (2013) Pentland Firth and Orkney Waters Enabling Actions Report: Scoping Study: Review of current knowledge of underwater noise emissions from wave and tidal stream energy devices The Crown Estate. • TNO report, (2011) Standard for measurement and monitoring of underwater noise, Part I: physical quantities and their units • TNO report, (2011) Standard for measurement and monitoring of underwater noise, Part II: procedures for measuring underwater noise in connection with offshore wind farm licensing • Willis, M., R., Broudic, M., Haywood, C., Masters, I. & Thomas, S., (2012) Measuring underwater background noise in high tidal flow environments, Renewable Energy 49:255-258. doi:10.1016/j.renene.2012.01.020. **Underway:** • Life+ project BIAS (Project aims: Develop standards and guidelines for measuring underwater noise and produce an underwater noise map of the Baltic Sea) (http://www.bias-project.eu/) [due August 2016] • National Physical Laboratory (NPL) Good Practice Guidance for Underwater Noise Measurements. Report for The Crown Estate. [not yet published] • National Physical Laboratory (NPL) Good Practice Guidance for Underwater Noise Metrics. Report for Marine Scotland.[not yet published] • Robinson, S., Lepper, P., Humphrey, V. Underwater Acoustic Data Collection and Reporting: A Guide for Regulators. [not yet published] **Planned:** • DECC (potential research project) Tidal stream noise propagation.	**HOLD** **Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** Reports by National Physical Laboratory (NPL) for The Crown Estate and Marine Scotland (yet to be published) should provide clear guidance for measurement of underwater noise including: • Choice of instruments; • Deployment methods; • Calibration requirements; • Measurement of radiated noise from specific sources and ambient noise; • Data analysis and derivation of source level; • Identification of the acoustic metrics most useful in describing underwater noise; • Definitions and units for the above metrics; and • Recommendations of how these metrics should be reported.
1. Underwater noise	1.2: Agreed best practice approaches for measuring noise from operational wave and tidal devices and construction activities are required	**Published:** • Bassett, C., Thomson, J., Polagye, B., Rhinefrank, K., (2011). Underwater noise measurements of a 1/7th scale wave energy converter. In OCEANS 2011, pp. 1-6. • BSH, (2011) Offshore wind farms. Measuring instruction for underwater sound monitoring. Report by Muller-BBM • Haikonen, K., Sundberg, J., Leijon, M. (2013) Characteristics of the Operational Noise from Full Scale Wave Energy Converters in the Lysekil Project: Estimation of Potential Environmental Impacts. Energies 6: 2562-2582. • Lepper, PA, Harland, E, Robinson, SP, Theobald, P, Hastie, G, Quick, N (2013) Acoustic Noise Measurement Methodology for the Billia Croo Wave Energy Test Site: ANNEX A: Summary of operational underwater noise TESTs for a Pelamis P2 system at EMEC May 2011, pp.1-36, Scottish Government. • Patricio, S., Soares, C., Sarmento, A., (2009). Underwater noise modelling of wave energy devices. In Proceedings of the Eighth European Wave and Tidal Energy Conference, Uppsala, Sweden. • Robinson, S.P and Lepper, P.A. (2013) Pentland Firth and Orkney Waters Enabling Actions Report: Scoping study: Review of current knowledge of underwater noise emissions from wave and tidal stream energy devices. The Crown Estate. • TNO report, (2011) Standard for measurement and monitoring of underwater noise, Part I: physical quantities and their units • TNO report, (2011) Standard for measurement and monitoring of underwater noise, Part II: procedures for measuring underwater noise in connection with	**HOLD** **Relevant to both wave and tidal projects** Reports by National Physical Laboratory (NPL) for The Crown Estate and Marine Scotland (yet to be published) should provide clear guidance for measurement of underwater noise including: • Choice of instruments; • Deployment methods; • Calibration requirements; • Measurement of radiated noise from specific sources and ambient noise; • Data analysis and derivation of source level; • Identification of the acoustic metrics most useful in

Topic	Key Issue	Research published / underway / planned	Gap analysis
		offshore wind farm licensing • TSB Strangford Lough MCT device monitoring (Workshop Oct 2012). **Underway:** • Low Carbon Research Institute LCRI Modelling of environmental effects of ambient noise. [not yet published] • National Physical Laboratory (NPL) Good Practice Guidance for Underwater Noise Measurements. Report for The Crown Estate. [not yet published] • National Physical Laboratory (NPL) Good Practice Guidance for Underwater Noise Metrics. Report for Marine Scotland.[not yet published] • Robinson, S., Lepper, P., Humphrey, V. Underwater Acoustic Data Collection and Reporting: A Guide for Regulators. [not yet published] • WAVEC Environmental monitoring of the Waveroller project, Peniche ends October 2013 [not yet published]. **Planned:** • Marine Scotland Proposed research projects for 2013/2014 – 'Operational noise modelling for wave and tidal devices'	describing underwater noise; • Definitions and units for the above metrics; and • Recommendations of how these metrics should be reported.
1. Underwater noise	1.3: Lack of available acoustic data from operational wave and tidal devices and arrays	**Published:** • Bassett, C., Thomson, J., Polagye, B., Rhinefrank, K., (2011) Underwater noise measurements of a 1/7th scale wave energy converter. In OCEANS 2011, pp. 1-6. • Haikonen, K., Sundberg, J., Leijon, M. (2013) Characteristics of the Operational Noise from Full Scale Wave Energy Converters in the Lysekil Project: Estimation of Potential Environmental Impacts. Energies 6: 2562-2582. **Underway:** • National Physical Laboratory (NPL) Good Practice Guidance for Underwater Noise Measurements. Report for The Crown Estate. [not yet published] • Robinson, S., Lepper, P., Humphrey, V. Underwater Acoustic Data Collection and Reporting: A Guide for Regulators. [not yet published]	**Gap identified – Relevant to both wave and tidal projects** **GAP:** • There is a limited amount of available acoustic data from operational wave and tidal devices and arrays.
1. Underwater noise	1.4: Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on diving birds is incomplete	**Published:** • Martin (2012) Through birds' eyes: insights into avian sensory ecology. Journal of Ornithology. Vol. 153 Issue 1 Supplement, pp23-48. • RPS (2011) (Unpublished report to SNH) The effects of underwater noise on diving birds: a literature review. **Underway:** • NERC, RESPONSE project. Understanding How Marine Renewable Device Operations Influences Fine Scale Habitat Use and Behaviour of Marine Vertebrates [due 2014]	**Gaps identified. Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** Existing information does not yet provide the information to fully assess the impact (without adopting a precautionary approach) of underwater noise on diving birds. **GAPS:** • The noise levels capable of causing impacts of differing significance (e.g. lethal, sub-lethal, permanent, and temporary) for diving seabird species. • Effects of operational noise (behavioural changes, disturbance and displacement effects) from underwater devices and construction activities on diving birds.

Topic	Key Issue	Research published / underway / planned	Gap analysis
1. Underwater noise	1.5: Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on marine mammals is incomplete	***Underwater noise*** **Published:** • Finneran, J.J. (2012) Auditory effects of underwater noise in odontocetes. Advances in experimental medicine and biology, 730, 197-202. • Gotz, T. & Janik, V.M. (2011) Repeated elicitation of the acoustic startle reflex leads to sensitisation in subsequent avoidance behaviour and induces fear conditioning. BMC Neuroscience, 12. • Koschinski, S, Culik, B.M., Damsguard Henriksen, O., Tregenza, N., Ellis, G., Jansen, C., Kathe, G., (2003) Behavioural reactions of free-ranging porpoises and seals to the noise of a simulated 2MW windpower generator. Marine Ecology Progress Series: 265:263–273. • Madsen, PT, M Wahlberg, J Tougaard, K Lucke, and P Tyack (2006) Wind turbine underwater noise and marine mammals: implications of current knowledge and data needs. Marine Ecology Progress Series: 309:279-295. • McConnell, B., Lonergan, M. and Dietz, R. (2012) Interactions between seals and offshore wind farms. Report to The Crown Estate: ISBN: 978-1-906410-34-6. • Nabe-Nielsen, J., Tougaard, J. Teilmann, J., and Sveegaard, S., (2011) Effects of wind farms on harbour porpoise behaviour. Report commissioned by The Environmental Group under the Danish Environmental Monitoring Programme. • Nedwell, J.R.; Edwards, B.; Turnpenny, A.W.H. (2004) Fish and Marine Mammals Audiograms: A Summary of Available Information. Subacoustech Report ref: 534R0214. • Southall, B.L.; Bowles, A.; Ellison, W.T.; Finneran, J.J.; Gentry, R.L.; Greene, C.R.; Kastak, D.; Ketten, D.R.; Miller, J.H.; Nachtigall, P.E., (2007) Marine mammal noise exposure criteria: Initial scientific recommendations. Aquatic Mammals. 2007, 33, 411–521. • Teilmann, J., Tougaard, J., and Carstensen, J., (2006) Summary on Harbour Porpoise Monitoring 1999-2006 around Nysted and Horns Rev Offshore Wind Farms. (Denmark Ministry of the Environment, Trans.). National Environmental Research Institute (pp. 14). • Teilmann, J., J. Tougaard, J. Carstensen, R. Dietz, and S. Tougaard. (2006) Summary on Seal Monitoring 1999-2005 around Nysted and Horns Rev Offshore Wind Farms. (Denmark Ministry of the Environment, Trans.). National Environmental Research Institute (pp. 22). • With regards to offshore wind farms there have been various impact monitoring studies done in Belgium, Denmark, Germany and the Netherlands for construction and operational noise. See e.g. ICES 2010 **Underway:** • Marine Scotland Research project MM8 'Noise tolerance of bottlenose dolphins, harbour porpoises and seals' [estimated completion 2013] **Planned:** • ORJIP offshore wind Project 2 (under consideration as a Priority Research project) 'Evidence Gathering for Population Consequences of Acoustic Disturbance (PCAD)/Population Consequences of Disturbance (PCoD) model to predict the impacts (population consequences) for marine mammals from exposed to sources of disturbance'. ***Operational noise*** **Published:** • Carter (2013): Tidal Energy, Underwater Noises & Marine Mammals. Doctoral thesis SNH PhD awarded. Published. Underwater acoustic interactions between emerging tidal-energy technologies and vulnerable vertebrates. • Polagye, B., Bassett, C., Thomson, J., (2011) Estimated Received Noise Levels for Marine Mammals from OpenHydro Turbines in Admiralty Inlet, Washington. Technical Report UW-2011-01, Northwest National Marine Renewable Energy Centre, University of Washington, Seattle. **Underway:** • NERC RESPONSE Understanding How Marine Renewable Device Operations Influences Fine Scale Habitat Use and Behaviour of Marine Vertebrates.[due 2014] • SMRU, (NERC RESPONSE funded), Investigation of responses of marine mammals to playback of turbine noise. [due 2013, not yet published] • U.S. DOE study at Oregon State University to record WEC noise and at University of Washington to observe marine mammal behavioural response to turbine noise from two Open Hydro turbines in Puget Sound. [recently funded] ***Construction-related noise*** **Published:** • Bailey, H., Senior, B., Simmons, D., Rusin, J., Picken, G. & Thompson, P.M. (2010) Assessing underwater noise levels during pile-driving at an offshore windfarm and its potential effects on marine mammals. Marine Pollution Bulletin, 60, 888-897. • Brandt, M.J., Diederichs, A., Betke, K. & Nehls, G. (2011) Responses of harbour porpoises to pile driving at the Horns Rev II offshore wind farm in the Danish North Sea. Marine Ecology-Progress Series, 421, 205-216. • DEFRA (2013) An analysis of potential broad-scale impacts on harbour porpoise from proposed pile driving activities in the North Sea. • Hull, S., San Martin, E., Elmes, M. 2011. Collation and analysis of offshore wind farm piling records. The Crown Estate, 14 pages.	**Gaps identified. Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** Existing information does not yet provide the information to fully assess the impact (without adopting a precautionary approach) of underwater noise on marine mammals. **GAPS:** • The noise levels capable of causing impacts of differing significance (e.g. lethal, sub lethal, permanent, temporary) for marine mammal species of concern. • Effects of operational noise (behavioural changes, disturbance and displacement effects) from underwater devices and construction activities on marine mammals. **NOTE:** Work undertaken by the Offshore Wind industry to investigate construction-related noise (e.g. pile driving noise) impacts on marine mammals could be used to inform the wave and tidal industries.

Topic	Key Issue	Research published / underway / planned	Gap analysis
		• Thompson, P.M., Brookes, K.L., Graham, I.M., Barton, T.R., Needham, K., Bradbury, G. & Merchant, N.D. (2013) Short-term disturbance by a commercial two-dimensional seismic survey does not lead to long-term displacement of harbour porpoises. Proceedings of the Royal Society Biological Sciences 208: 20132001 **Underway:** • Marine Scotland research project MM3 Displacement of marine mammals during installation – strategic placement of c-pods [due 2013, not yet published] • SMRU, (DECC funded) Harbour seals behavioural responses to the presence of piling activity [due 2013, not yet published] **Planned:** • Marine Scotland research project MM10 Sound of Islay Demonstration Pilot – seal disturbance monitoring. To study the disturbance of seals (e.g. pup abandonment, disuse of haul-out sites) caused by vessel movements and construction activity during the installation of tidal turbines. • SNH. Desktop review of underwater noise from survey equipment. [project delayed] ***Noise propagation modelling:*** **Published:** • Marine Scotland research project MM2 (Dec 2012) Validation of noise dissipation models. • Marmo, B., Roberts, I., Buckingham, M.P., King, S., Booth, C. (2013). Modelling of Noise Effects of Operational Offshore Wind Turbines including noise transmission through various foundation types. Edinburgh: Scottish Government. ***Mitigation*** **Published:** • Herschel, A., Stephenson, S., Sparling, C., Sams, C., Monnington, J. (2013) ORJIP Project 4 Phase 1: Use of Deterrent Devices and Improvements to Standard Mitigation during Piling. Report for ORJIP. • Wilson (2011) The use of acoustic devices to warn marine mammals of tidal-stream energy renewable devices. Report to Marine Scotland. • Wilson and Carter (2013). The use of acoustic devices to warn marine mammals of tidal-stream energy devices. Report to the Scottish Government.	

1. Underwater noise	1.6: Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on fish is incomplete	**Published:**
		• Gill, A.B. & Bartlett, M. (2010). Literature review on the potential effects of electromagnetic fields and subsea noise from marine renewable energy developments on Atlantic salmon, sea trout and European eel. Scottish Natural Heritage Commissioned Report No.401
		• Halvorsen, M.B., Casper, B.M., Woodley, C.M., Carlson, T.J., Popper, A.N., (2012) Threshold for onset of injury in chinook salmon from exposure to impulsive pile driving sounds. PLoS ONE, 7, e38968: doi:10.1371/journal.pone.0038968.
		• Popper, A.N., Hastings, M.C. (2009) The effects of anthropogenic sources of sound on fishes. Journal of Fish Biology 75: 455-489.
		• Slaski, R.J, Hirst, D., and Gray, S. (2013). PFOW wave and tidal stream projects and migratory salmonids. The Crown Estate.
		Underway:
		• DEFRA, The impact of anthropogenic noise on fish and invertebrates at the individual, population and community level [estimated completion 2013, not yet published]
		• NERC (to March 2013) internship with HR Wallingford - improving ecological responses of sea bass to noise.
		• NERC MREKE (to June 2013) internship KTP with HR Wallingford to develop Hydro-Acoustic Model for Mitigation and Ecological Response (HAMMER) for predicting behavioural responses of fish to noise.
		• Marine Scotland commissioned projects:
		  ○ Marine Scotland research project MF1: 'Measurements of audiograms for key fish species - salmon, sea trout, eels, herring, cod and sandeels to improve hearing characteristics of these species';
		  ○ Marine Scotland research project MF2: 'Modelling the consequences for salmon of exposure to piling and operational noise';
		  ○ Marine Scotland research project MF3: 'Modelling exercise of potential offshore wind farms to investigate audibility to migrating salmon and sea trout';
		  ○ Marine Scotland research project MF4: 'Investigation into sandeel interactions with offshore renewable energy construction methods'; and
		  ○ Marine Scotland research project MF5:'Field investigation of effects of installation noise on fish hearing'.
		Planned:
		• Marine Scotland Proposed research projects for 2013/2014 Acoustics and salmon project – This project would measure the response of salmon to noise in controlled conditions (dumbbell tank).
		• Marine Scotland Proposed research projects for 2013/2014 – 'Operational noise modelling for wave and tidal devices' (repeat of a similar project (see Marmo *et al*. 2013) that has been successfully completed for wind turbine foundation types. Report would provide reference source for EIA.
			HOLD
			
			Relevant to both wave and tidal projects
			Note: This is also an issue relevant to other sectors / industries
			
			Await findings of Marine Scotland commissioned research projects underway. Taken together, it is considered that these projects will provide sufficient information to inform EIA of the potential impacts of noise from marine renewable energy devices on diadromous fish species.
			
			Proposed research projects should provide further evidence as to whether the possible effects of operational noise from underwater devices and construction-related noise is likely to be an issue for further consideration (or not) for the marine renewables industry.

Topic	Key Issue	Research published / underway / planned	Gap analysis
2. Collision risk	2.1: The nature of any potential interactions between diving birds and tidal turbines is uncertain	**Published:** • Loughrey, J. *et al*., (RPS) (2011) Assessment of Risk to Diving Birds from Underwater Marine Renewable Devices in Welsh Waters. Phase 1 Desktop Review of Birds in Welsh Waters and Preliminary Risk Assessment. Marine Renewable Energy Strategic Framework for Wales (MRESF). Report for The Welsh Assembly Government. • MeyGen Tidal Energy Limited (2012). MeyGen Tidal Energy Project Phase 1, Environmental Statement. Chapter 12, Ornithology • RPS (2010) The determination of foraging range and diving depths by diving seabirds, especially in the Orkney and Pentland Firth wave and tidal resource areas. Unpublished report to SNH. • RPS (2011) Assessment methodology for determining collision risk of marine renewable energy devices (excluding offshore wind farms) on marine birds. Unpublished report to SNH • Wilson, B. Batty, R. S., Daunt, F. & Carter, C. (2007) Collision risks between marine renewable energy devices and mammals, fish and diving birds. Report to the Scottish Executive. Scottish Association for Marine Science, Oban, Scotland, PA37 1QA. **Underway:** • NERC PhD, Modelling Foraging Strategies in high energy environments (FORSITE) – **Paper in review:** Modelling the movements of diving predators in complex and heterogeneous landscapes: the impact of tidal renewable devices on foraging seabirds. • PhD study: Helen Wade ERI: Habitat use by seabird species in high-velocity current flows: investigating the potential effects of tidal-stream renewable energy developments. • NERC RESPONSE Understanding How Marine Renewable Device Operations Influences Fine Scale Habitat Use and Behaviour of Marine Vertebrates.[due 2014] • NERC FLOWBEC Flow, water column and Benthic Ecology 4D [due 2014] • SNH Development of a diving bird collision risk assessment framework for tidal turbines [underway]	**Gaps identified. Relevant to tidal projects only** More information/research would provide further confidence in assessments (and reduce the need for adopting a precautionary approach) of the possible risk of encounters or collisions between tidal stream devices and diving birds. **GAPS:** • Behaviour of diving birds (including avoidance and evasion behaviour and the attraction of species) around tidal turbines to better understand the real level of risk of collisions including: o Probability of occurrence; o The extent to which devices, moorings and inter-array areas may act as fish aggregation devices and therefore increase potential for collision risk for predatory species of birds • Assessing collision risk for diving birds • Use of tidal stream areas by diving birds: o Improved understanding of the functional importance of tidal stream areas; o Improved understanding of the spatial and temporal patterns of site use of tidal stream areas (and relative importance of these areas); and o Improved understanding of behaviour (e.g. diving depth, dive profiles, and the proportion of time spent at the operating depth of tidal turbines is key information).
2. Collision risk	2.2: The nature of any potential interactions between marine mammals and basking sharks and tidal turbines is uncertain	**Published:** • Carlson, T.J., Elster, J.L., Jones, M.E., Watson, B.E., Copping, A.E., Watkins, M., Jepsen, R., Metzinger, K., (2012) Assessment of strike of adult killer whales by an OpenHydro tidal turbine blade, Pacific Northwest National Laboratory and Sandia National Laboratory, Richland, Washington. • Gordon J, Thompson D, Leaper R, Gillespie D, Pierpoint C, Calderan S, Macauley J and Gordon T (2011). Assessment of Risk to Marine Mammals from Underwater Marine Renewable Devices in Welsh Waters. Marine Renewable Energy Strategic Framework Phase 2 – Studies of Marine Mammals in Welsh High Tidal Waters. Report to the Welsh Assembly Government. • Keenan, G., Sparling, C., Williams, H., Fortune, F., (2011) SeaGen Environmental Monitoring Programme Final Report, Haskoning U.K. Ltd., Edinburgh, U.K. Marine Current Turbines • Marine Scotland (2011) Estimates of collision risk of harbour porpoises and marine renewable energy devices at sites of high tidal stream energy. • Special Committee on Seals (SCOS) reports • SMRU (2013). Grey and Harbour seal usage maps. Marine Mammal Scientific Support Research Programme MMSS/001/11. Report to Scottish Government. • McConnell, B., Gillespie, D., Gordon, J., Hastie, G.D., Johnson, M. & Macaulay J, (2013) Methods for tracking fine scale movements of marine mammals around marine tidal devices. Edinburgh: Scottish Government. Marine Scotland research project MM12, • MeyGen Tidal Energy Limited (2012). MeyGen Tidal Energy Project Phase 1, Environmental Statement. Chapter 11, Marine Mammals. • Northridge, S., SMRU Bycatch reports (SMRU recently pledged to seek to provide improved bycatch estimates for the UK agreed Mammal Management Units) • The Crown Estate - (Swansea University) (Oct 2010) Modelling collision risk for marine mammals. • Thompson, D., Hall, A.J., Lonergan, M., McConnell, B. & Northridge, S. (2013) Current status of knowledge of effects of offshore renewable energy generation devices on marine mammals and research requirements. Edinburgh: Scottish Government.	**Gaps identified. Relevant to tidal projects only.** More information/research would provide further confidence (and reduce the need for adopting a precautionary approach) in assessments of the possible risk of encounters or collisions between tidal stream devices and marine mammals (cetaceans and seals) and basking sharks. **GAPS:** • Behaviour of marine mammals and basking sharks (including avoidance and evasion behaviour and the attraction of inquisitive species e.g. bottlenose dolphin and minke whale) around tidal turbines to better understand the real level of risk of collisions including: o Probability of occurrence; o The extent to which devices, moorings and inter-array areas may act as fish aggregation devices and therefore increase potential for collision risk for marine mammals. • Assessing collision risk for marine mammals and basking

Topic	Key Issue	Research published / underway / planned	Gap analysis
		• Thompson, D., (SMRU/RPS) (July 2012) Assessment of Risk to Marine Mammals from Underwater Marine Renewable Devices in Welsh Waters. Marine Renewable Energy Strategic Framework Phase 2 Annex 1 Movements and Diving Behaviour of Juvenile Grey Seals in Areas of High Tidal Energy Marine Environments. Report to the Welsh Assembly Government. • Tollit, D., Wood, J., Broome, J. & Redden, A. (2011) Detection of Marine Mammals and Effects Monitoring at the NSPI (OpenHydro) Turbine Site in the Minas Passage during 2010 FINAL REPORT prepared by SMRU Ltd and Arcadia University for Fundy Ocean Research Centre for Energy (FORCE). Publication No. 101 of the Acadia Centre for Estuarine Research (ACER) Acadia University, Wolfville, NS, Canada. • US Department of Energy (2012) Admiralty Inlet pilot tidal project, FERC project no. 12690, Application for a new pilot project license, (minor water power project): Appendix K – Assessment of Strike of Adult Killer Whales by an OpenHydro Tidal Turbine Blade. pp. 48 • Wilson, B. Batty, R. S., Daunt, F. & Carter, C. (2007) Collision risks between marine renewable energy devices and mammals, fish and diving birds. Report to the Scottish Executive. Scottish Association for Marine Science, Oban, Scotland, PA37 1QA. • Wilson, B., Gordon, J. (SAMS / RPS) (2011) Assessment of Risk to Marine Mammals from Underwater Marine Renewable Devices in Welsh Waters. Marine Renewable Energy Strategic Framework Phase 1 - Desktop Review of Marine Mammals and Risks from Underwater Marine Renewable Devices in Welsh waters. Report for The Welsh Assembly Government. **<u>Underway:</u>** • DEFRA, Cetacean Strandings Investigation Programme (CSIP) Cetacean strandings around UK coast. (TBC 2014) • EMEC Monitoring Report Synthesis [due 2013] • EMP planning underway for two sites: Sound of Islay and Skerries • MCT, Pacific North West Lab study – strike analysis. [outputs likely available mid 2014] • NERC EBAO Optimising array form for Maximising Energy Extraction and Environmental Benefit • NERC FLOWBEC Flow, water column and Benthic Ecology 4D [due 2014] • NERC RESPONSE Understanding How Marine Renewable Device Operations Influences Fine Scale Habitat Use and Behaviour of Marine Vertebrates.[due 2014] • SAMS, (in preparation) Interaction with devices: For SNH and Scottish Environmental Protection Agency [not yet published] • SAMS, Hebridean Marine energy Futures 'Methods for detecting porpoises at wave energy sites' [ends April 2014] • SMRU; (Marine Scotland and DECC funded) Determining the factors affecting UK grey and harbour seal habitat preference. [due 2014] • SMRU / SAMS (Marine Scotland funded) Harbour porpoise behaviour in tidal rapids. [due 2013, not yet published] • SMRU (SNH funded) Collision damage assessment (assessment trials with carcasses of seals) [due 2014] • SMRU Marine/MCT Strangford Lough trial of removal of shut down mitigation at SeaGen, active sonar monitoring of seals around turbine to determine empirical encounter rates and measure avoidance/evasion.[outputs likely mid 2014] • SNH / MS / SMRU Collision risk model for marine mammals and tidal turbines [due to report in 2014] • TCE / Swansea University Modelling of avoidance and interactions of mammals and other biota with tidal turbines. [currently underway]- **<u>Planned:</u>** • DECC Offshore Energy SEA Programme – Potential Research Project 'Tidal turbine interactions with large marine animals' (Potential contribution to the Tidal Energy Ltd (TEL) monitoring programme for the DeltaStream turbine deployment in Ramsey Sound, Pembrokeshire to facilitate collection of data of generic, wider application to such developments. • Marine Scotland Identified Research gap 'Behaviour of grey seal adults in relation to high current regimes in the Pentland Firth'.(unfunded gap) • Marine Scotland Identified Research gap 'Fine-scale habitat use by porpoises in tidal rapids'(unfunded gap) • ORJIP offshore wind Project 2 'Evidence Gathering for Population Consequences of Disturbance (PCoD) model to predict the impacts (population consequences) for marine mammals from exposed to sources of disturbance.' (under consideration as a Priority Research project)	sharks • Use of tidal stream areas by marine mammals and basking sharks: o Improved understanding of the functional importance of tidal stream areas; o Improved understanding of the spatial and temporal patterns of site use of tidal stream areas (and relative importance of these areas); o Improved understanding of routes used for movement and migration; and o Improved understanding of behaviour (e.g. diving depth, dive profiles, and the proportion of time spent at the operating depth of tidal turbines is key information).
2. Collision risk	2.3: The nature of any potential interactions between migratory fish and tidal turbines is uncertain	**<u>Published:</u>** • ABPmer (2010) Collision risk of fish with wave and tidal devices. Commissioned by RPS Group Plc. on behalf of the Welsh Assembly Government. Ref: R/3836/01 Report number: R.1516 • Amaral, S., Perkins, N., Giza, D., McMahon, B. (2011) Evaluation of fish injury and mortality associated with hydrokinetic turbines. (pp. 108, Electric Power Research Institute • Deng, Z., Carlson, T.J., Dauble, D.D., Ploskey, G.R. (2011) Fish passage assessment of an advanced hydropower turbine and conventional power turbine using blade-strike modelling. Energies 4: 57 – 67. • Jacobson, P., Amaral, S., Castro-Santos, T., Giza, D., Haro, A., Hecker, G., McMahon, B., Perkins, N., Pioppi, N., 2013. Effects of Hydrokinetic Turbines on Fish:	**Gaps identified. Relevant to tidal projects only.** More information/research would provide further confidence in assessments of the possible risk of encounters or collisions between tidal stream devices and migratory fish. **GAPS:** • Behaviour of migratory fish (including avoidance and

Topic	Key Issue	Research published / underway / planned	Gap analysis
		Desktop and Laboratory Flume Studies, Electric Power Research Institute. • Slaski, R.J, Hirst, D., and Gray, S. (2013). PFOW wave and tidal stream projects and migratory salmonids. The Crown Estate. • Verdant Power research. • Wilson, B. Batty, R. S., Daunt, F. & Carter, C. (2007) Collision risks between marine renewable energy devices and mammals, fish and diving birds. Report to the Scottish Executive. Scottish Association for Marine Science, Oban, Scotland, PA37 1QA. **Underway:** • Tagging work being undertaken by MSS in 2013 with funding support from The Crown Estate, this project will involve satellite tagging of adult salmon caught on the north coast. It should provide information on swimming depth, as well as migratory routes. • ERI work on migratory fish – Funded by The Crown Estate, this particle modelling project involves a significant review and a compilation and assessment of historical data. Its main aim is to bring together particle behaviour assessments (based on considerable hydrodynamic information available for the Pentland Firth) and biological characteristics.	evasion behaviour) around tidal turbines to better understand the real level of risk of collisions including: o Probability of occurrence • Assessing collision risk for migratory fish • Use of tidal stream areas by migratory fish (research gaps identified in (Slaski *et al*., 2013): o Migratory pathways / behaviour – to what extent are migratory salmonids likely to be geographically co-incident with the locations of wave and tidal energy projects o Swimming behaviour – if fish are geographically co-incident (in any significant numbers), to what extent are they likely to be physically co-incident. Swimming depth preference and avoidance capability appear to be the key questions o Mode of transport in high current speeds – the degree to which passive transportation through areas of high energy takes place, and potential implications. o Encounter Effects – if some fish do make physical (or equivalent) contact with the wave or tidal energy device, what are the outcomes?
2. Collision risk	2.4: There is uncertainty as to the possible physical consequences of potential collision events for marine mammals, diving birds and fish and tidal turbines	**Published:** • Carlson, T.J., Elster, J.L., Jones, M.E., Watson, B.E., Copping, A.E., Watkins, M., Jepsen, R., Metzinger, K., (2012) Assessment of strike of adult killer whales by an OpenHydro tidal turbine blade, Pacific Northwest National Laboratory and Sandia National Laboratory, Richland, Washington. • US Department of Energy (2012) Admiralty Inlet pilot tidal project, FERC project no. 12690, Application for a new pilot project license, (minor water power project): Appendix K – Assessment of Strike of Adult Killer Whales by an OpenHydro Tidal Turbine Blade. pp. 48 **Underway:** • MCT, Pacific North West Lab study – strike analysis. [outputs likely available mid 2014] • SMRU (SNH funded) Collision damage assessment (assessment trials with carcasses of seals) [due 2014]	**Gap identified. Relevant to tidal projects only** In current collision risk assessment models, the assumption is made that any collision results in mortality but very little information is available on the likely physical consequences to wildlife colliding with or passing through the blades of an operating turbine. **GAP:** • Severity of injury should strike occur
2. Collision risk	2.5: Further development of suitable instrumentation and methodologies for monitoring wildlife behaviour around wave and tidal devices and arrays and for detection of any collision events is required	***Birds*** **Published:** • RPS (2010) Unpublished report to SNH Review of techniques to detect seabird presence and movement below the sea surface and determine potential application in the vicinity of tidal turbines. • RPS (2011) Assessment of Risk to Diving Birds from Underwater Marine Renewable Devices in Welsh Waters. Phase 2: Field methodologies and site assessments. Marine Renewable Energy Strategic Framework for Wales (MRESF). Report for The Welsh Assembly Government. **Underway:** • NERC FLOWBEC Flow, water column and Benthic Ecology 4D [due 2014] • SNH, A Review of the Potential Use of Sonar to Observe the Underwater Behaviour of Diving Birds near Tidal Energy Devices. (not yet published) ***Marine mammals*** **Published:** • Hastie, G.D. (2012) Tracking marine mammals around marine renewable energy devices using active sonar. SMRU Ltd report number SMRUL-DEC-2012-002 to the Department of Energy and Climate Change, pp. 93. SMRU Ltd, St Andrews. • Macaulay, J., Gillespie, D., Northridge, S., Gordon, J. (2013) Porpoises and tidal turbines, finescale tracking using passive acoustics to assess and mitigate collision risk. Presented at the 6th International Workshop on Detection, Classification, Localization, and Density. • McConnell, B., Gillespie, D., Gordon, J., Hastie, G.D., Johnson, M. & Macaulay J, (2013) Methods for tracking fine scale movements of marine mammals	**Gaps identified. Relevant to both wave and tidal projects** The 'deploy and monitor' approach to early deployments of wet renewables will require (and benefit from) technologies ability to accurately detect and identify wildlife in the vicinity of a device and whether a collision with a device has occurred. This will build an evidence base of wildlife behaviour around operating devices. **GAPS:** • Further development of suitable technologies/tools and methods for use in high energy tidal environments to: o monitor behaviour of wildlife in the vicinity of devices and support structures , and o detect and record collision events to quantify the incidence/frequency of collisions.

Topic	Key Issue	Research published / underway / planned	Gap analysis
		around marine tidal devices. Edinburgh: Scottish Government. • MESPG (completed March 2011) Peer review of land based visual monitoring methods and protocols for wave and tidal test sites • MESPG (April 2011): Scoping study to investigate the development and establishment of a marine mammal stranding scheme in Orkney and Pentland Firth. • SMRU (2010) Approaches to marine mammal monitoring at marine renewable energy developments. A review of methods which can be used for monitoring populations of marine mammals at proposed OREI sites, and methods which can be used for assessing impacts on populations. Recommendations for monitoring of marine mammals. • SMRU/ACER (2011) Detection of Marine Mammals and Effects Monitoring at the NSPI (OpenHydro) Turbine Site in the Minas Passage during 2010. Report for Fundy Ocean Research Centre for Energy (FORCE). • TCE (2013): Interaction of biota with tidal turbines. • TEL's Ramsey Sound project planned monitoring (active sonar and 3D PAM localisation). • Thompson, D., Hall, A.J., Lonergan, M., McConnell, B. & Northridge, S. (2013) Current status of knowledge of effects of offshore renewable energy generation devices on marine mammals and research requirements. Edinburgh: Scottish Government. http://www.scotland.gov.uk/Resource/0043/00434726.pdf • Wilson and Carter (2013). The use of acoustic devices to warn marine mammals of tidal-stream energy devices. Report to the Scottish Government. **Underway:** • Marine Renewable Energy Knowledge Exchange Programme (MREKEP): Automation and standardisation of a passive acoustic monitoring (PAM) system (estimated August 2013). • SMRU Marine / MCT Strangford Lough trial of removal of shut down mitigation at SeaGen, active sonar monitoring of seals around turbine to determine empirical encounter rates and measure avoidance/evasion. [outputs likely mid 2014] • SMRU, (MS funded), Acoustic deterrence for mitigation of pile driving activities. [due 2015] • TCE, MCT Anglesey Skerries SMRU/LCRI. Passive Acoustic Monitoring trial - Installation of 3 PAM buoys to establish feasibility of monitoring method and data acquisition. [outputs likely mid 2014] • ETI ReDAPT. Integrated underwater environmental monitoring pod developed and commissioned under ETI ReDAPT project; awaiting redeployment for ongoing development and testing (pending successful funding application). **Planned:** • Hastie, G.D., Gillespie, D., Gordon, J., Macaulay, J., McConnell, B., and Sparling, C.E. (In Press). Tracking technologies for quantifying marine mammal interactions with tidal turbines: pitfalls and possibilities. In Shields, M.A. and Payne, A. (Eds.). Marine renewable Energy and Society. Springer, Dordrecht. • PRIMARE PAM at Wave Hub; MS PAM array east coast of Scotland. • Marine Scotland Research Project MM11 - Sound of Islay demonstration pilot - development of methods for direct observations of seal collisions. ***Fish*** **Planned:** • DECC: Fish behaviour in vicinity of renewable energy devices (possible extension of NERC DEFRA project QBEX).	
3. Entanglement	3.1: Concern within the regulatory and advisory bodies that mooring lines pose an entanglement risk to marine mammals and large fish	**Published:** • Northridge, S., Cargill, A., Coram, A., Mandleberg, L., Calderan, S. & Reid, R.J. (2010) Entanglement of minke whales in Scottish waters; an investigation into occurrence, causes and mitigation. Final Report to Scottish Government CR/2007/49, pp. 54pp +Appendices. Sea Mammal Research Unit, University of St Andrews. **Underway:** • SNH study (by SAMS / Exeter University) Review of the potential for marine megafauna entanglement risk from renewable marine energy developments. [due to report in 2014]	**HOLD** **Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** Await findings of research study currently underway (SNH study by SAMS & Exeter University). This study should establish if entanglement is an issue requiring further consideration (or not) for the marine renewables industry.

Topic	Key Issue	Research published / underway / planned	Gap analysis
4. Seal injuries from vessel propellers	4.1: Lack of understanding around the possible cause of death to seals with 'corkscrew' injuries	**Published:** • Bexton, S., Thompson, D., Brownlow, A., Barley, J., Milne, R. & Bidewell, C. (2012) Unusual Mortality of Pinnipeds in the United Kingdom Associated with Helical (Corkscrew) Injuries of Anthropogenic Origin. Aquatic Mammals, 38, 229-240. • MESPG (April 2011): Scoping study to investigate the development and establishment of a marine mammal stranding scheme in Orkney and Pentland Firth. • Thompson, D., Bexton, S., Brownlow, A.,Wood, D., Patterson, A., Pye, K., Lonergan, M.& Milne, R. (2010) Report on recent seal mortalities in UK waters caused by extensive Lacerations. October 2010. **Underway:** • Marine Scotland funded study 'Unexplained Seal Deaths'	**HOLD** **Relevant to both wave and tidal projects (proposing to use vessels with ducted propellers)** **Note: This is also an issue relevant to other sectors / industries utilising DP vessels with ducted propellers** Await findings of Marine Scotland research study currently underway. This study should establish if corkscrew injuries in seals is an issue requiring further consideration (or not) for the marine renewables industry.
5. EMF	5.1: Further data and information regarding the possible effects of EMF from transmission cables on fish would improve confidence in EIA and HRA	**Published:** • CMACS (2003). A baseline assessment of electromagnetic fields generated by offshore wind farm cables. COWRIE Report EMF -01-200266. • Fisher, C., Slater, M., (2010) Effects of electromagnetic fields on marine species: A literature review. Oregon Wave Energy Trust • Gill, A.B. & Bartlett, M. (2010). Literature review on the potential effects of electromagnetic fields and subsea noise from marine renewable energy developments on Atlantic salmon, sea trout and European eel. Scottish Natural Heritage Commissioned Report No.401. • Gill, A.B., Gloyne-Phillips, I., Neal, K.J., Kimber, J.A. (2005) The potential effects of electromagnetic fields generated by sub-sea power cables associated with offshore wind farm developments on electrically and magnetically sensitive organisms – a review. COWRIE 1.5 Electro-magnetic fields review. COWRIE-EM FIELD 2-06-2004 • Gill, A.B., Huang, Y., Gloyne-Philips, I., Metcalfe, J., Quayle, V., Spencer, J. & Wearmouth, V. (2009). COWRIE 2.0 Electromagnetic Fields (EMF) Phase 2: EMF-sensitive fish response to EM emissions from sub-sea electricity cables of the type used by the offshore renewable energy industry. Commissioned by COWRIE Ltd (project reference COWRIE-EMF-1-06) • Normandeau, Exponent, T. Tricas, and A. Gill. 2011. Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo, CA. OCS Study BOEMRE 2011-09. • Olsson T., Bergsten, P., Nissen, J., Larsson, A., (2010) Impact of electric and magnetic fields from submarine cables on marine organisms – The current state of knowledge. Vattenfall Power. **Underway:** • Marine Scotland Research Project MF11 Migratory fish research – Phase 1- Construction of a coil system to investigate the electromagnetic force impacts on Salmonids • NERC RESPONSE Understanding How Marine Renewable Device Operations Influences Fine Scale Habitat Use and Behaviour of Marine Vertebrates.[due 2014] • Scottish Government Laboratory-based research on behavioural impacts of EMF. (report due in Q4 2013)	**HOLD** **Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** There are many studies completed, currently underway or planned investigating the potential effects of EMF on fish including understanding the nature and significance, if any, of EMF effects upon potentially sensitive species groups (such as elasmobranchs and salmonids). Consider need for any further research when work that is currently underway has been completed.
6.Displacement	6.1: Potential displacement of essential activities of marine mammals, basking sharks and birds	**Published:** • MacLean, I., Rehfisch, M., Skov, H., Thaxter, C. (2013) Evaluating the statistical power of detecting changes in the abundance of seabirds at sea. IBIS The International Journal of Avian Science, 155: 113-126 • McDonald, C., Searle, K, Wanless, S., Daunt, F., (2012) Effects of Displacement from Marine Renewable Development on Seabirds Breeding at SPAs: A Proof of Concept Model of Common Guillemots Breeding on the Isle of May. Report for Marine Scotland Science. • Marine Scotland research project MM4 Offshore Renewables Research: Work Package A3 (2012) Request for advice about the displacement of marine mammals around operational offshore windfarms. Report for Scottish Government. • Rexstad, E., and Buckland, S. (2012) Displacement analysis boat surveys Kentish Flats. SOSS Report 1A. CREEM University of St Andrews. • SMRU (2010) Approaches to marine mammal monitoring at marine renewable energy developments. A review of methods which can be used for monitoring populations of marine mammals at proposed OREI sites, and methods which can be used for assessing impacts on populations. Recommendations for monitoring of marine mammals. **Underway:** • NERC FLOWBEC Flow, water column and Benthic Ecology 4D[due 2014] • SNH, MS, EMEC Analysis of the Land Based Wildlife Observation Programme at EMEC [estimated completion Q1 2015]	**Gaps identified: Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** **Gaps:** • An agreed approach to assessing the potential effects of displacement from wave and tidal arrays. • Potential for displacement to occur – research around demonstration scale arrays may provide an opportunity to gather data to inform commercial scale EIA/HRA.

Topic	Key Issue	Research published / underway / planned	Gap analysis
13. General	13.1: Further strategic baseline data (distribution, abundance, seasonality, etc.) for marine mammals and basking sharks is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects	***Cetaceans and basking sharks*** **Published:** • APEM (2013) Suitability of existing PFOW aerial digital data to inform wave and tidal EIA and HRA work. APEM Technical Report 512708 to The Crown Estate. 20pp. • Drewery, H. M., (2012) Basking Shark (*Cetorhinus maximus*) Literature Review, Current Research and New Research Ideas. Marine Scotland Science Report 24/12 • Evans, P.G.H., Baines, M.E. & Coppock, J. (2011). Abundance and behaviour of cetaceans and basking sharks in the Pentland Firth and Orkney Waters. Report by Hebog Environmental Ltd & Sea Watch Foundation. Scottish Natural Heritage Commissioned Report No.419. • Marine Scotland Research project MM9 (August 2012) Advice on populations of cetaceans that might be involved in significant interactions with offshore energy development – SMRU literature review. • Marine Scotland Research project MR6b: characterisation of cetacean populations. • Marine Scotland Research project MR7 (Dec 2012): Information on the distribution of key mammal species in East Scotland. • MeyGen Tidal Energy Limited (2012). MeyGen Tidal Energy Project Phase 1, Environmental Statement. Chapter 11, Marine Mammals. • ORJIP offshore wind project - PCoD funding for Harbour porpoises Vattenfall. • Robbins, A. (2012) Analysis of Bird and Marine Mammal Data for Billia Croo Wave Test Site, Orkney. Scottish Natural Heritage Commissioned Report No. 592. • SNH (completed 2011) Analysis of Bird and Marine Mammal Data for the Fall of Warness Tidal Test Site, Orkney. • Thompson, P.M., Cheney, B., Ingram, S., Stevick, P., Wilson, B. & Hammond, P.S. (2011) Distribution, abundance and population structure of bottlenose dolphins in Scottish waters. Scottish Natural Heritage Commissioned Research Report No. 354. • Witt, M.J., Doherty, P.D., Hawkes, L.A., Brendan J. Godley, B.J., Graham, R.T., and Henderson, S.M. (2013) Basking shark satellite tagging project: post-fieldwork report. Scottish Natural Heritage Commissioned Report No. 555. **Underway:** • EMEC Monitoring Report Synthesis • Marine Scotland project Review of the utility of the Joint Cetacean Protocol JCP [due 2013, not yet published] • Marine Scotland SB9 Statistical modelling of bird and cetacean distributions in offshore renewables development areas. SB9 (CR/2012/05). [due Sept 2013, not yet published] • SMRU (Marine Scotland funded) Harbour porpoise behaviour in tidal rapids. [due 2013, not yet published] • SNH, MS, EMEC Analysis of the Land Based Wildlife Observation Programme at EMEC [estimated completion Q1 2015] • SNH / University of Exeter. Basking shark tagging project in Inner Hebrides (ongoing) ***Seals*** **Published:** • MESPG (completed April 2010): Seal population viability study. • MESPG (completed August 2010): To develop a PBR for seals across Scotland. • Marine Scotland research project MS MR6a: characterisation of seal population. • SMRU (2013). Grey and Harbour seal usage maps. Marine Mammal Scientific Support Research Programme MMSS/001/11. Report to Scottish Government • SMRU Ltd. (2011) Grey Seals: Report to SNH. (Covers N Scotland only.) • SMRU seal telemetry studies - Kyle Rhea 2012, Pentland Firth 2011 and Sound of Islay 2011 deployments • SMRU Ltd (2011). Utilisation of space by grey and harbour seals in the Pentland Firth and Orkney waters. Scottish Natural Heritage Commissioned Report No. 441 • TCE (2012) Tagging of seals and analysis of behaviour in the vicinity of offshore windfarms. **Underway:** • SMRU; (Marine Scotland and DECC funded) Determine factors affecting UK grey and harbour seal habitat preference. [due 2014] • SMRU; (Marine Scotland and SNH funded) .Haul-out connectivity of grey and harbour seals. [due 2014]	**Gap identified. Relevant to both wave and tidal projects** **GAP:** • There is a requirement for: o improved estimates of temporal and spatial variation in local density o improved estimates of site fidelity o improved information on population size and range o improved information on routes used for movement and migration

Topic	Key Issue	Research published / underway / planned	Gap analysis

14. General	14.1: Further strategic baseline data (distribution, abundance, seasonality, etc.) for birds is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects	**Published:**
		• APEM (2013) Suitability of existing PFOW aerial digital data to inform wave and tidal EIA and HRA work. APEM Technical Report 512708 to The Crown Estate. 20pp.
		• APEM (2013a) Investigation of the utilisation of sea space by sea birds in the Pentland Firth & Orkney area. APEM Technical Report 411122 Report to Scottish Government. 101pp.
		• APEM (2013b) Pentland Firth and Orkney Waters aerial bird survey: 2010 / 11 additional image analysis. APEM Scientific Report 512699. Report to The Crown Estate. 180pp.
		• APEM (2013c) Year 2: Investigation of the utilisation of sea space by sea birds in the Pentland Firth & Orkney area 2012 / 13. Technical Report 511639 Report to Scottish Government. 246 pp.
		• Lewis, M., Lye, G., Pendlebury, C., Walls, R., (2012) Population Sizes of Seabirds breeding in Scottish Special Protection Areas. Report for Scottish Government.
		• Malcolm, F., Lye, G., Lewis, M. (2012) Population trends of breeding seabird colonies in Scottish SPAs. Report to Scottish Government (Marine Scotland)
		• McDonald, C., Searle, K, Wanless, S., Daunt, F., (2012) Effects of Displacement from Marine Renewable Development on Seabirds Breeding at SPAs: A Proof of Concept Model of Common Guillemots Breeding on the Isle of May. Report for Marine Scotland Science.
		• MESPG (completed May 2010): Surveys of marine birds in and around areas proposed for wave and tidal energy developments off the west coast of Scotland.
		• MESPG (2011) Investigation of the utilisation of sea space by sea birds in the Orkney/Pentland area, emphasising those areas indicated as having potential for tidal turbine installation.
		• MESPG (Mar 2012) Land-based visual observations at the Scapa Flow nursery site and Shapinsay Sound tidal nursery site.
		• Mitchell, P.I, Newton, S.F, Ratcliffe, N., Dunn, T.E. (2004) Seabird Populations of Britain and Ireland. T&AD Poyser. London.
		• Natural England/MMO (April 2013) MMO1034 – Updated assessment of seabird density in English waters and associated sensitivity of these species to marine development.
		• Oedekoven, C.S., Mackenzie, M.L., Scott-Hayward, S., Rexstad, E., (2013) Statistical modelling of bird and cetacean distributions in offshore renewables development areas: Literature Review
		• Robbins, A. (2012) Analysis of Bird and Marine Mammal Data for Billia Croo Wave Test Site, Orkney. Scottish Natural Heritage Commissioned Report No. 592.
		• Wright, L.J., Ross-Smith, V.H., Massimino, D., Dadam, D., Cook A.S.P., Burton, N.H.K., Strategic Ornithological Support Services Project SOSS-05 Assessing the risk of offshore wind farm development to migratory birds designated as features of UK Special Protection Areas (and other Annex 1 species) BTO Research Report No. 592
		Underway:
		• DECC Comparison of results of data collected in three representative areas of the North Sea with older data. [Completion TBC]
		• Future of the Atlantic Marine Environment (FAME) seabird tagging project.[due 2014]
		• ERI – Hebridean Marine Energy Futures 'Interactions between seabirds and wave energy converters'. (ends April 2014) Relevant projects:
		  ○ Project 2: Site surveys (ecological) – Three potentially suitable wave sites are being monitored, and,
		  ○ Project 4: Monitoring interactions and gathering data for consenting activities (monitoring around 2 Pelamis P2 machines).
		• Marine Scotland research project SB9 Statistical modelling of bird and cetacean distributions in offshore renewables development areas. SB9 (CR/2012/05). [due Sept 2013, not yet published]
		• Marine Scotland research project MS SB3: Population Dynamics of Forth and Tay Breeding Seabirds - Review of Available Models and Modelling of Key Breeding Populations [not yet published]
		• Marine Scotland research project MS SB7: Population consequences of displacement from proposed offshore wind energy developments for seabirds breeding at Scottish SPAs. (CR/2012/03). [due July 2013, not yet published]
		• NERC CASE studentship Beth Scott University of Aberdeen with RSPB and Marine Scotland. [underway from April 2013]
		• NERC PhD 'How do abiotic and biotic factors control distribution / abundance of birds?' - Aberdeen University and NOC (Alice Jones). [underway]
		• SNH Monitoring of North and East Caithness Cliff SPAs.[estimated completion Q3 2013, not yet published]
		• SNH, MS, EMEC Analysis of the Land Based Wildlife Observation Programme at EMEC [estimated completion Q1 2015]
			Gap identified. Relevant to both wave and tidal projects
			
			GAP:
			• There is a requirement for:
			  ○ improved estimates of local density
			  ○ improved estimates of site fidelity
			  ○ improved information on population size and range

Topic	Key Issue	Research published / underway / planned	Gap analysis
15. General	15.1: Further strategic baseline data (distribution, abundance, seasonality, etc.) for migratory fish is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects	**Published:** • Ellis, J.R., Milligan, S.P., Readdy, L., Taylor, N. and Brown, M.J. 2012. Spawning and nursery grounds of selected fish species in UK waters. Science Series Technical Report, Cefas Lowestoft, 147: 56 pp. • LCRI - Field studies of fisheries and migratory fish (2011 - 2013) • Malcolm, I., Godfrey, J. and Youngson, A.F., (2010) Review of migratory routes and behaviour of Atlantic salmon, sea trout and European eel in Scotland's coastal environment: implications for development of marine renewables. Scottish Marine and Freshwater Science Report, 1(14). Scottish Government Marine Scotland commissioned projects: • Marine Scotland research project MF9 (July 2012) : Collation of data on salmonid populations in the Solway Firth region to assess the potential influence of Robin Rigg offshore wind farm ; • Marine Scotland research project MF10 (Jan 2013) Analysis of fish and fisheries data to assess the potential impact of offshore wind development on Solway rivers. • Marine Scotland research project MF12 (August 2011) Evaluation of genetic methods for assigning fish caught in coastal zones to river of origin • Marine Scotland research project MF13 (August 2012) Evaluation of options for establishing the migration routes of Atlantic salmon in coastal rivers. • Marine Scotland Science (2013) The Scope of Research Requirements for Atlantic salmon, sea trout and European eel in the context of offshore renewables. Marine Scotland Science Report 05/13. • Mork, K.A. and 13 other authors. 2012 Modelling the migration of post-smolt Atlantic salmon (Salmo salar) in the Northeast Atlantic. ICES Journal of Marine Science doi:10.1093/icesjms/fss108 • SALSEA-MERGE (2012) Final report: Advancing understanding of Atlantic salmon at sea: merging genetics and ecology to resolve stock-specific migration and distribution patterns. • TCE (July 2013) Pentland Firth and Orkney Waters Enabling Actions Report - PFOW wave and tidal stream projects and migratory salmonids. **Underway:** • TCE (TBC end 2013) Atlantic salmon tagging and behavioural interactions Atlantic salmon with wave and tidal devices • TCE (summer 2013) Workshop on PFOW projects and migratory fish • Marine Scotland research project MF14 Potential for marine renewable power developments to affect diadromous fishes in Scottish waters: informing EIAs [estimated completion April 2015] • Marine Scotland Science is currently updating the fish nursery and spawning maps that were produced by Coull *et al.* 1998. • MAREE project (ERI) / University of Plymouth (PRIMaRE)	**HOLD** **Relevant to both wave and tidal projects** Await findings of studies underway (see Key Issue 2.3).
16. General	16.1: An agreed approach to undertaking site characterisation and baseline surveys for marine mammals and birds to inform EIA and HRA is required	**Published:** • Chambers, C., McAlesse, L., Hull, S., Barham, P., Goodchild, R., Cooper, D., Pearson, A., Brutto, D., Pitts, J., Bussell, J.A., Fawcett, A. & Woodcock, T.2012. Potential for joined up marine monitoring and data collection between Statutory Nature Conservation Bodies and industry. Marine Planning Consultants, in consortium with ABPmer and Peter Barham Associates. Natural England Commissioned Reports, Number 115. • Gordon J, Thompson D, Leaper R, Gillespie D, Pierpoint C, Calderan S, Macauley J and Gordon T (2011). Assessment of Risk to Marine Mammals from Underwater Marine Renewable Devices in Welsh Waters. Marine Renewable Energy Strategic Framework Phase 2 – Studies of Marine Mammals in Welsh High Tidal Waters. Report to the Welsh Assembly Government. • MacLean, I., Rehfisch, M., Skov, H., Thaxter, C. (2013) Evaluating the statistical power of detecting changes in the abundance of seabirds at sea. IBIS The International Journal of Avian Science, 155: 113-126 • MMO 1031 - Review of post-consent offshore wind farm monitoring data associated with marine licence conditions. • Marine Scotland Research project MM1 (Oct 2012) 'Methods for monitoring marine mammals' – (to provide MS with an evidence base on which to ascertain the best survey approach to count marine mammal populations in sea areas). • Northridge, S., (2012), MS Offshore Renewables Research: Work Package C2: Advice on the populations of cetaceans that might be involved in significant interactions with marine renewable energy developments in Scottish marine waters. Report for Scottish Government. • RPS (2011) Assessment of Risk to Diving Birds from Underwater Marine Renewable Devices in Welsh Waters. Phase 2: Field methodologies and site assessments. Marine Renewable Energy Strategic Framework for Wales (MRESF). Report for The Welsh Assembly Government. • SNH (completed 2010) Boat and aerial survey protocols for seabirds at wave and tidal search areas in north western Scotland. • SNH (completed 2011) Guidance on Survey and Monitoring in relation to marine (wave and tide) renewable deployments in Scotland. • SMRU (2010) - Approaches to marine mammal monitoring at marine renewable energy developments. A review of methods which can be used for monitoring populations of marine mammals at proposed OREI sites, and methods which can be used for assessing impacts on populations. Recommendations for monitoring of marine mammals.	**HOLD** **Relevant to both wave and tidal projects** There is an urgent need to determine the most appropriate methods for collecting baseline data on birds and mammals in wave and tidal areas. SNH and Marine Scotland are in the process of updating and finalising the draft survey and monitoring guidance in relation to marine renewable deployments in Scotland. Await release of SNH/MS guidance which may help to address this. There is a need to review the draft Scottish guidelines and establish if they are fit for purpose for sites across the whole of the UK or whether additional guidance is required. Where possible there should be consistency in approach.

Topic	Key Issue	Research published / underway / planned	Gap analysis
		Underway: • Hebridean Marine Energy Futures Project 2 – Site surveys and Project 4 – monitoring interactions and gathering data for consenting activities [ends April 2014] • Marine Scotland research project MS SB1 'Assistance with assessment of survey methods, data assessment and analyses for renewable energy developments'. (CREEM staff to assist in assessing protocols and subsequent ESs. Provision of a peer-review process for Regulators regarding statistical validity of site characterisation and impact monitoring studies).(due 2014) • SNH, Development of a monitoring protocol for assessing the use of seal haul out sites in the Sound of Islay [estimated completion Q2 2014] • SNH and Marine Scotland. Updating and finalising the SNH draft monitoring guidance. • SNH, MS, EMEC Analysis of the Land Based Wildlife Observation Programme at EMEC [estimated completion Q1 2015]	
17. General	17.1: Further data of mobile species populations (particularly qualifying species of Natura sites and EPS) for use in population modelling would improve confidence in EIA/HRA	***Marine Mammals*** **Published:** • IMMWG (inter agency marine mammal working group) paper on marine mammal management units for the UK. • SMRU (2012) Request for advice on the populations of cetaceans that might be involved in significant interactions with marine renewable energy developments in Scottish marine waters. **Underway:** • SMRU NERC MREKE initiative. Sensitivity analysis [underway] • Marine Scotland project Review of the Utility of Joint Cetacean Protocol JCP [due 2013, not yet published] ***Marine Birds*** **Published:** • Furness, R.W, Wade, H.M, Robbins, M.C, Masden, E.A., 2012. Assessing the sensitivity of seabird populations to adverse effects from tidal stream turbines and wave energy devices. ICES Journal of Marine Science, 69: 1466-1479. • McDonald, C., Searle, K, Wanless, S., Daunt, F., (2012) Effects of Displacement from Marine Renewable Development on Seabirds Breeding at SPAs: A Proof of Concept Model of Common Guillemots Breeding on the Isle of May. Report for Marine Scotland Science. • SNH (2011) SNH Commissioned Report 390: Literature review to assess bird species connectivity to Special Protection Areas. • SOSS 04 (2012) Gannet PVA Report to The Crown Estate. • Thaxter, C.B., Lascelles, B., Suagr, K., Cook, A.S.C.P., Roos, S., Bolton, M., Langston, R.H.W. & Burton, N.H.K. (2012). Seabird foraging ranges as a preliminary tool for identifying candidate marine protected areas. Biological Conservation. Vol. 156, 53-61. • Workshop held on 17-18th October 2012 Assigning predicted effects of marine renewable energy projects to seabird populations in the context of complying with the Habitats Regulations". **Underway:** • BTO & UHI Measuring the interaction between marine features of Special Protection Areas (SPAs) with offshore wind farm development zones through telemetry. Lesser black backed gulls on the Skokholm & Skomer SPA and Morecambe Bay SPA. • Marine Scotland research project SB3 Population dynamics of Forth and Tay breeding seabirds : review of available models and modelling of key breeding populations (yet to be published) • Marine Scotland research project MS SB7 Population consequences of displacement from proposed offshore wind energy developments for seabirds breeding at Scottish SPAs. (CR/2012/03). [estimated July 2013, not yet published] • SNH. Investigating the Connectivity Seabird SPAs and Areas Proposed for Tidal and Wave Renewable Energy Development in Scottish Waters. (release delayed)	**Gaps identified. Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** **GAPS:** • Further data such as demographic parameters (e.g. adult survival, juvenile survival, productivity rates, etc.) for mobile species populations (particularly qualifying species of Natura sites and EPS) for use in population modelling. Current information on other sources of mortality and disturbance acting on marine mammal populations, such as fisheries bycatch, is sparse. • Agreement on the reference populations (and current status and trends) against which changes are assessed. **NOTE:** The Interagency Marine Mammal Working Group (IMMWG) has agreed management units for the five species that are considered to be of greatest concern: grey seal, harbour seal, harbour porpoise, bottlenose dolphin, and minke whale for reporting Favourable Conservation Status (FCS); however there has been some debate on the appropriateness for their use in project assessment. The definition of management units will be an adaptive process: when more evidence becomes available these units can be updated for following applications. • Approaches to determining connectivity of mobile qualifying features
18. General	18.1: Better understanding of population level impacts and methods to assess the significance of population level impacts would improve confidence in EIA/HRA	**Published:** • Lusseau, D., Christiansen, F., Harwood, J., Mendes, S., Thompson, P.M., Smith, K., Hastie, G.D., (2012) Assessing the risks to marine mammal populations from renewable energy devices: An interim approach. • Northridge, S., (2012), MS Offshore Renewables Research: Work Package C2: Advice on the populations of cetaceans that might be involved in significant interactions with marine renewable energy developments in Scottish marine waters. Report for Scottish Government. **Planned:** • ORJIP Project 2 (under consideration as a Priority Research project) Evidence Gathering for Population Consequences of Acoustic Disturbance (PCAD) model to predict impacts on marine mammals from underwater noise. The purpose of the proposed project is to undertake strategic scientific work to fill gaps in this model for key marine mammal species in UK waters: harbour porpoise, grey and harbour seals, dolphins.	**Gaps identified. Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** **GAPS:** • Improved understanding of population level impacts • Establishing the limits of acceptable impact under the terms of the Habitats Regulations for both European Protected Species and qualifying species of SACs and SPAs.

Topic	Key Issue	Research published / underway / planned	Gap analysis
Human environment			
19. Impacts on commercial fisheries	19.1: Further baseline inshore fisheries activity data to inform CIA (Cumulative Impact Assessment)	**Published:** • Cefas, 2012. Low-cost VMS data analysis: Assessment and applications. Report for DEFRA. • des Clers, S., Lewin, S., Edwards, D., Searle, S., Lieberknecht, L. and Murphy, D., (2008). FisherMap. Mapping the Grounds: Recording fishermen's use of the seas. Final Report. A report published for the Finding Sanctuary project. • Marine Scotland, (2012). Draft report on ScotMap: the Inshore Fishing Study Pilot in Pentland Firth and Orkney Waters. • MMO, (2013). UK Sea Fisheries Statistics 2012. • Seafish, 2011. Development and piloting of low-cost Vessel Monitoring Technology on English Inshore Vessels. Report for DEFRA. **Underway:** • Countryside Council for Wales, 2013. FishMap Môn. Available at: http://fishmapmon.naturalresourceswales.gov.uk • The Crown Estate PFOW Enabling Actions. Orkney Shellfish Research Project. [First year of project to be complete by circa end 2013] • Marine Scotland, 2012. Research Implementation Strategy: Project G5 - Mapping Sea Fishing Activity in Scottish waters: ScotMap Project (MROW 2) [Estimated completion date March 2013 but not yet published].	**Gap identified. Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** **GAP**: There is currently limited information on the spatial distribution of inshore/coastal fishing activities outside the Pentland Firth and Orkney Waters Strategic Area, particularly creel fishing activity and the relative importance of different fishing grounds, especially those utilised by fishing vessels under 15m, which are not required to have a VMS transponder. All EU, Faroese and Norwegian vessels which exceed 15m overall length must be fitted with VMS units. From 2012, this will change to an overall length of 12m for EU vessels. The ScotMap project will help to fill this gap for Scottish waters however: • There remains a gap in other UK waters, although the gap may only be related to areas where wave and/or tidal projects are clustered (i.e. less of a gap where individual projects are concerned).
19. Impacts on commercial fisheries	19.2: There is a lack of standardised approach to assessing the availability of alternative fishing grounds (outside development areas) and their ability to sustain existing /displaced commercial fishing levels	**Published:** • Blyth, R. E., Kaiser, M. J., Edwards-Jones, G. and Hart, P. J. B., (2004). Implications of a zoned fishery management system for marine benthic communities. Journal of Applied Ecology, 41: 951–961. • Blyth-Skyrme, R.E., (2011). Benefits and disadvantages of Co-locating windfarms and marine conservation zones; report to Collaborative Offshore Wind Research Into the Environment Ltd., London, December 2010. 37 pp. • Defew, E., Wood, C., Bates, R., Wilson, L., Wilson, J., (2012). An assessment of the potential impact of no-take zones upon benthic habitats: a case study from SE Scotland. Report for The Crown Estate. • EMEC, (2012). Monitoring of the fishery in a no-take zone established at the Billia Croo wave test sites at EMEC. Report for The Scottish Government. • MMO (2013) Potential for co-location of activities in marine plan areas. A report produced for the Marine Management Organisation, pp 98. MMO Project No: 1010. • Munro, C. D. and Baldock, B.M., (2012). Lyme Bay Closed Area: measuring recovery of benthic species in cobble reef habitats - analysis of data collected by SCUBA divers September 2008, August 2009 and July 2010. A Marine Bio-images report. Marine Bio-images, Exeter, Devon, UK. • Rodwell, L.D., de Groot, J., Ashley, M., Campbell, M., Linley, A., (2013). Fisheries and Marine Renewable Energy Interactions: Assessment and Mitigation: A summary report on an expert workshop for the Marine Renewable Energy Knowledge Exchange Programme. **Underway:** • Ashley, M. The effects of implementing no take marine protected areas around offshore wind farms. (PhD completed, due to be published in early 2014). PhD at Plymouth University. • Broadhurst, M., PhD with UCL and OpenHydro looked at lobster distribution around their devices at EMEC [end date unknown] • Fisheries displacement and mitigation working group. Fisheries and marine renewable energy interactions. Funded by the Marine Renewable Energy Knowledge Exchange Programme (MREKEP) [in progress]. • QBEX - Quantifying benefits and impacts of fishing exclusion zones on bioresources around Marine Renewable Energy Installations. NERC/DEFRA funded Project through the NERC Marine Renewable Energy Knowledge Exchange Programme. [due to finish end of 2014) • Statoil Hywind is planning to undertake research to identify what fisheries activities can co-locate with a floating wind farm. Presently in process of finalising project aims and funding sources. [Due for completion in 2015]	**HOLD** **Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** The effect of no take zones on surrounding fishing grounds is being examined by ongoing studies (the QBEX study and MESPG study at EMEC). Ongoing work by MREKEP (Marine Renewable Energy Knowledge Exchange Programme): Fisheries displacement and mitigation working group are developing a best practice approach to assessing fisheries displacement.

Topic	Key Issue	Research published / underway / planned	Gap analysis
19. Impacts on commercial fisheries	19.3: Lack of a standardised approach, specific to the wave and tidal industry, for identifying appropriate mitigation measures to mitigate the potential impact on commercial fisheries	**Published:** • Blyth-Skyrme, R.E. (2010). Options and opportunities for marine fisheries mitigation associated with windfarms. Final report for Collaborative Offshore Wind Research into the Environment contract FISHMITIG09. COWRIE Ltd, London. 125 pp. • Rodwell, L.D., de Groot, J., Ashley, M., Campbell, M., Linley, A., (2013). Fisheries and Marine Renewable Energy Interactions: Assessment and Mitigation: A summary report on an expert workshop for the Marine Renewable Energy Knowledge Exchange Programme. **Underway:** • Fisheries displacement and mitigation working group. Fisheries and marine renewable energy interactions. Funded by the Marine Renewable Energy Knowledge Exchange Programme (MREKEP) [in progress].	**HOLD** **Relevant to both wave and tidal projects** A standardised approach to identifying appropriate mitigation measures for the offshore wind industry has been developed (Blyth-Skyrme, R.E. (2010). The overall aim of the project was to develop a menu of possible mitigation options which would be of use to fishermen, developers, regulatory and statutory bodies and marine resource managers in discussions related to current and future windfarm developments, as well as in other offshore industry developments and in any future consideration of marine spatial planning issues. Work is ongoing by MREKEP's Fisheries displacement and mitigation working group on mitigation measures for mitigating the interaction between fisheries and the marine renewables industry to update and broaden the scope of the earlier COWRIE work to encompass all marine renewable technologies.
19. Impacts on commercial fisheries	19.4: Lack of a standardised approach and guidance, specific to the wave and tidal industry, on effective engagement with the commercial fishing industry and local stakeholders	**Underway:** • Fishing Liaison with Offshore Wind and Wet Renewables Group (FLOWW) Recommendations for fisheries liaison; Best Practice guidance for offshore renewables developers (BERR, 2008) and updates currently in progress [available early 2014)	**HOLD** **Relevant to both wave and tidal projects** Ongoing work by Fishing Liaison with Offshore Wind and Wet Renewables Group (FLOWW) has already produced best practice guidance on effective engagement with the commercial fishing industry and updates currently in progress will ensure that this guidance is relevant to the wave and tidal industries as well as offshore wind.
20. Impacts on shipping and navigation	20.1: Further baseline data to inform cumulative aspects of Marine Navigational Impact Assessments	**Published:** • Anatec Limited and Halcrow (2012). Shipping Study of the Pentland Firth and Orkney Waters. Report for The Scottish Government. **Planned:** • Marine Scotland, 2012. Research Implementation Strategy: Marine Scotland; Shipping and Navigation – Pentland Firth & Orkney Waters**:** Study concentrating on the types of shipping not included in stage 1 of the Pentland Firth project [Planned, funding to be confirmed]	**HOLD** **Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** Lack of baseline data to inform cumulative aspects of Marine Navigational Impact Assessments. Specifically, there is currently a lack of baseline vessel traffic data for vessels that are not required to carry AIS/VMS. Although the Marine Scotland project will help to fill this gap for Pentland Firth and Orkney Waters, there remains a gap in other UK waters where there are clusters of wave and/or tidal projects (which may require assessment of cumulative impacts). Await results of Marine Scotland study for Pentland Firth and Orkney Waters.

Topic	Key Issue	Research published / underway / planned	Gap analysis
20. Impacts on shipping and navigation	20.2: Uncertain risks to navigation that may arise from a number of wave and tidal projects and therefore difficulties with assessing and mitigating the potential cumulative impacts	**Underway:** • Anatec. PFOW Strategic Area Navigation Appraisal (SANAP). Report for The Crown Estate: [in progress, Final Discussion Paper expected early January 2014].	**HOLD** **Relevant to both wave and tidal projects** Await results of PFOW Strategic Area Navigation Appraisal (SANAP). This Project may progress further, bringing together developers and key shipping and navigation stakeholders in PFOW to discuss the key risks/challenges of deploying the first wave and tidal arrays in PFOW. This will result in the production of a short PFOW focused guidance /report identifying the key risks, potential mitigation measures and ways forward.
21. Impacts on seascape	21.1: Lack of regional and local coastal landscape character assessments to inform Seascape, Landscape and Visual Impact Assessment	**Published:** • Briggs, J. and White, S. (2009). Welsh seascapes and their sensitivity to offshore developments: Method Report. Report for Countryside Council for Wales. • Hill, M., Briggs, J., Minto, P., Bagnall, D., Folay, K., Williams, A., (2001). Guide to Best Practice in Seascape Assessment. Report for Maritime Ireland / Wales INTERREG • Scott, K.E., Anderson, C., Dunsford, H., Benson, J.F. and MacFarlane, R. (2005). An assessment of the sensitivity and capacity of the Scottish seascape in relation to offshore windfarms. Scottish Natural Heritage Commissioned Report No.103 (ROAME No. F03AA06). • Scottish Natural Heritage, (2008). Guidance on Landscape/Seascape Capacity for Aquaculture. • Scottish Natural Heritage. (2012). Offshore Renewables - Guidance on Assessing the Impact on Coastal Landscape and Seascape: Guidance for Scoping an Environmental Statement. • Smith K, Briggs J, Hamer J, Hill A and Walker P (2011). Natural Heritage evidence to support planning for marine renewable energy. CCW Policy Research Report no. 11/3. Chapter 4.4.	**Gaps identified. Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** **GAPS**: • Baseline coastal landscape character assessments at a national level outside of Scotland and Wales. • Baseline coastal landscape character assessments at a regional character level. • Baseline coastal landscape character assessments at a local character level. It is not possible to do a strategic study to assess the sensitivity to wave and tidal developments, as has been possible for offshore wind, due to the range of wave and tidal device concepts still in development.
	21.2: Lack of understanding regarding the economic value of seascape and any change in this as a result of renewable activities	**Planned:** • Marine Scotland, 2012. Research Implementation Strategy: Seascape – Pentland Firth & Orkney Waters: [Planned, funding to be confirmed].	**HOLD** **Relevant to both wave and tidal projects** Lack of understanding regarding the economic value of seascape and any change in this as a result of renewable activities. Await results of Marine Scotland study on seascape which aims to model impact upon seascape of planned renewable activities and assess the potential changes in the economic values associated with changes in seascape. Similar studies could be repeated for other strategic areas.

Topic	Key Issue	Research published / underway / planned	Gap analysis
22. Social and economic impacts on local communities	22.1: Difficulty with identifying, assessing, mitigating and managing potential cumulative social and economic impacts from marine energy development and changes to existing maritime activity	**Published:** • ABPmer, (2012). Pentland Firth and Orkney Waters Enabling Actions Report: A Socio-economic Methodology and Baseline for Pentland Firth and Orkney Waters Wave and Tidal Developments. Report for The Crown Estate. • ABPmer, (2013). Planning Scotland's Seas: Developing the Socio-Economic Evidence Base for Offshore Renewable Sectoral Marine Plans in Scottish Waters Final Report. Report for Marine Scotland. • ABPmer and RPA, (2012). Marine Scotland: Socio-economic Baseline Review Methodology and Data Gap Analysis for Offshore Renewables in Scottish Waters, Report for Marine Scotland. • Crown Estate, (2011). Wave and Tidal energy in the Pentland Firth and Orkney waters: How the projects could be built **Underway:** • ABPmer. Pentland Firth and Orkney Waters Wave and Tidal Developments: Trial Application of Methodology for Supply Chain and Carbon Savings Assessments [in progress]. • Marine management Organisation Project No. MO 1035: Social Impacts of Fisheries, Aquaculture, Recreation and Tourism, and Marine Protected Areas (MPAs) in Marine Plan Areas in England [Due to be completed in August 2013].	**Gaps identified. Relevant to both wave and tidal projects** **Note: This is also an issue relevant to other sectors / industries** **GAPS**: • It is unclear what level and type of employment will be required to support wave and tidal projects. This makes assessing key socio-economic impacts difficult. • The potential cumulative economic impacts on local communities resulting from increased employment opportunities, supply chain development, or changes to existing industries from multiple demonstration projects within a region. • The potential cumulative social impacts on local communities resulting from development of the wave and tidal industry (such as the effects on local services from any change in population during construction and operation).
Physical environment			
25. Impacts on physical processes	25.2: Development of hydrographic models to predict the effects of changes in water flow and energy removal caused by (a) the physical presence of the device in the water (b) the removal of energy and secondary effects of changes in water flow and energy removal	**Published:** • Amoudry, L.; Bell, P.S.; Black, K.S.; Gatliff, R.W.; Helsby, R.; Souza, A.J.; Thorne, P.D.; Wolf, J. (2009). A Scoping Study on: Research into Changes in Sediment Dynamics Linked to Marine Renewable Energy Installations. (pp. 221), Natural Environment Research Council. • McNaughton, J. PhD University of Manchester; Turbulence Modelling in the near-field of an axial flow tidal turbine using Code_Saturne (2013) ReDAPT research on near-field CFD • Reza Ahmadian, Roger A. Falconer, Assessment of array shape of tidal stream turbines on hydro-environmental impacts and power output, Renewable Energy, Volume 44, August 2012, Pages 318-327, ISSN 0960-1481, http://dx.doi.org/10.1016/j.renene.2012.01.106. • Palha A, Mendes L, Fortes CJ, Brito-Melo A, Sarmento A., (2010) The impact of wave energy farms in the shoreline wave climate: Portuguese pilot zone case study using Pelamis energy wave devices. Renewable Energy. 35(1):62–77. • Roberts, J.; Jones, C.; Magalen, J. (2012/09/01). WEC Farm Effects on Wave, Current, and Sediment Circulation: Coupled Wave, Hydrodynamic, and Sediment Transport Model of Santa Cruz, Monterey Bay, CA. (pp. 27), Sandia National Laboratories, Sea Engineering. • Shapiro, G.I., (2011). Effect Of Tidal Stream Power Generation On The Region-wide Circulation In A Shallow Sea. Ocean Science Discussion, 7(5), 165-174.A **Underway:** • The Crown Estate PFOW Enabling Actions. Hydrodynamic modelling work in PFOW. [ongoing] • Bangor University and High Performance Computing (HPC) Wales research project on investigating impacts of tidal turbines around Welsh coastline and beaches [3 year PhD project due to commence in 2013]. • EPSRC: Interactions of flow, tidal stream turbines and local sediment bed under combined wave and tidal conditions (INSTRON) [Due to finish in September 2015] • EPSRC/MASTS/MSS: Large Scale Interactive coupled 3D modelling for wave and tidal energy resource and environmental impact [Due to finish Spring 2015] • Marine Scotland, 2012. Research Implementation Strategy: Project G1. Scottish Shelf modelling (MROW 1)[ongoing] • TeraWatt: TeraWatt: large scale interactive coupled 3D modelling for wave and tidal energy resource and environmental impact. [Due to finish in 2015]	**HOLD** **Relevant to both wave and tidal projects** Although the fundamental physics of energy extraction and its influence on wave and tidal fields is largely known, there are areas where modelling needs to be improved (as outlined in Environmental Effects of Marine Energy Development around the World, Annex IV Final Report): • Effects from specific marine energy devices • Coupling the nearfield with the farfield • Cumulative effects And the Scottish Marine Renewables SEA: • Detailed prediction of the effects of wave energy extraction • Increased theoretical understanding on the influence of tidal or wave energy extraction on soft mobile coastlines However there is work ongoing in this field by various parties which may address these issues.

Topic	Key Issue	Research published / underway / planned	Gap analysis
25. Impacts on physical processes	25.3: Validation of hydrographic models to help predict the effects of changes in water flow and energy removal at commercial scale	**Published:** • Blondel, P., H., and Williamson, B., J., (2013). Long term multibeam measurements around a tidal turbine test site in Orkney, Scotland. Proceedings of the Institute of Acoustics, Institute of Acoustics Spring Conference, Nottingham, 13 May 2013, Vol 35 Pt 1. p. 322-329. • Colby, J., A., Adonizio, M., A., Hydrodynamic analysis of kinetic hydropower arrays. Waterpower XVI, vol. 204; 2009 • Keenan, G., Sparling, C., Williams, H., Fortune, F., 2011. SeaGen Environmental Monitoring Programme Final Report, Haskoning U.K. Ltd., Edinburgh, U.K. Marine Current Turbines. • ORPC, (2012). Cobscook Bay Tidal Energy Project 2012 Environmental Monitoring Report. • Tidal Energy Limited, (2009). DeltaStream Demonstrator Project, Ramsey Sound, Non-Technical Summary, Environmental Statement. **Underway:** • Flow, Water Column & Benthic Ecology 4D (FLOWBEC). Principal investigator: Dr Paul Bell, National Oceanography Centre. Funded by DEFRA and NERC Marine Renewables Sandpit. http://noc.ac.uk/project/flowbec [Due to finish in 2015] • Marine Current Turbines (Anglesey Skerries) – SEACAMS modelling [Outputs likely available late 2014] • ReDAPT (Reliable Data Acquisition Platform for Tidal) consortium project funded by Energy Technologies Institute (ETI). [Due to finish in 2014]	**HOLD** **Relevant to both wave and tidal projects** Various studies are currently ongoing and should provide further information on this in the near future.

4 Task 3 - Research recommendations and identification of priority research projects

4.1 Objective

The first objective of this task was to provide recommended research areas that could help address the data gaps identified during the gap analysis. The second objective was to identify a number of priority research projects that could inform the priorities and focus of any coordinated research programme (e.g. ORJIP Wave and Tide). However, it is important to note that the areas identified are also relevant to any individual research that developers/regulators/advisors/wider research community may plan to carry out.

4.2 Approach

A set of recommendations was produced to address each data gap identified during the gap analysis (Task 2). These recommendations were informed by a high level review of the relevant information listed in Table 3.1 the responses to the Call for Evidence and input from the Specialist Contributors. These recommendations are presented in full in Table 4.1.

Following this process, given the large number of gaps identified, it was necessary to apply a filter to identify those of highest priority. A number of priority research projects were then identified that could inform the priorities of a coordinated research programme aiming to resolve the EIA/HRA issues facing the wave and tidal energy sectors.

The priority projects were identified based on the following criteria and considerations:

- Projects that could address research gaps which could help to resolve key issues relevant to demonstration arrays that are currently inhibiting the advancement of the wave and tidal sectors.
- Projects that could help address the key initial questions that need to be answered.

  Note: Research projects that are dependent upon, or would largely benefit from the findings of other studies (yet to be completed or undertaken) were not considered to be priorities for any coordinated approach (e.g. ORJIP Wave and Tide) at this point in time.
- Projects that could be carried out around single devices and/or at first demonstration array projects that will provide results to inform demonstration and future commercial scale projects; reducing risk, cost and timescales.
- Projects that ORJIP Wave and Tide would be best placed to undertake or support e.g. projects which would benefit from a coordinated approach to translate device and first array outcomes to commercial scale development.

Note: Based on the project objectives, the team considered it essential that proposed priority research projects for ORJIP Wave and Tide were specific and achievable. The results of these projects will help to address those issues that are currently facing demonstration scale projects in the wave and tidal sectors. Gaps which have a clear wider relevance beyond the wave and tidal sectors were considered to be beyond the focus of ORJIP Wave and Tide and within the remit of other programmes/organisations.

4.3 Results

Table 4.1 Research recommendations and identification of priority research projects for ORJIP Wave and Tide

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
Ecological environment				
1. Underwater noise	1.3: Lack of available acoustic data from operational wave and tidal devices and arrays	There is a limited amount of available acoustic data from operational wave and tidal devices and arrays.	Producing/monitoring acoustic signatures of devices to build evidence base of operational noise levels. It is important that there is standardisation in measuring operational acoustic data so that data are comparable across projects. Acoustic signature data from operational devices and first arrays could be used to increase understanding of array effects and inform noise propagation models for commercial scale EIA and HRA (and CIA). Data exchange and collaboration - establish a specific 'evidence base' regarding device-specific operational noise levels from ongoing work by developers (possibly alongside an expert forum) to ensure that data collected to meet licence conditions, and data from any publically funded research programme, is made available in the public domain to allow developers and researchers to learn from existing work.	**Yes** **Relevant to both wave and tidal projects** **Refer to outline project plan in Chapter 5 - Project 5 - Establishment of an acoustic 'evidence base' for operational wave and tidal devices and first arrays**
Underwater noise	1.4: Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on diving birds is incomplete	The noise levels capable of causing impacts of differing significance (e.g. lethal, sub-lethal, permanent, and temporary) for diving seabird species.	Research on the sensory ecology of diving seabirds: • Expansion of range of species for which hearing capacities (i.e. audiograms) are available for key species in wave and tidal development areas. • Studies should focus on species identified by Furness *et al.,* (2012) as being particularly sensitive to wave and tidal energy developments.	**HOLD** **Relevant to both wave and tidal projects** Await establishment of the 'evidence base' regarding operational noise levels from ongoing work by developers. Priority is to first understand the potential acoustic output of operational devices (refer to outline project plan in Chapter 5 - **Project 5**). **Note:** This is also an issue relevant to other marine industries (e.g. offshore wind) therefore may not be a priority for ORJIP Wave and Tide. Operational noise from wave and tidal devices is not likely to be at levels likely to cause injury or significant behavioural effects (Robinson and Lepper, 2013, Harland *et al.*, 2013).
		Effects of operational noise (behavioural changes, disturbance and displacement effects) from underwater devices and construction activities on diving birds.	Further research / monitoring studies around single test devices and first demonstration arrays to gather information on the behaviour of birds around operating devices to gather evidence to see whether noise is likely to be an issue or not for diving birds. Dose/response relationships are needed to understand the amplitude and frequencies of sounds that elicit reactions in animals of concern. Determine if device noise is audible to diving birds to elicit avoidance behaviour (may be linked to potential collision risk). Measuring noise doses on individuals around devices will be useful and can be integrated into studies of behavioural responses. An approach using computational acoustic models, based on anatomical data might be preferable.	**HOLD** **Relevant to both wave and tidal projects** Priority is to first understand the potential acoustic output of operational devices and arrays (refer to outline project plan in Chapter 5 - **Project 5**). Await establishment of the 'evidence base' regarding operational noise levels from ongoing work by developers. This issue may be informed by monitoring of behaviour around single wave and tidal devices and first demonstration arrays (refer to outline project plan in Chapter 5 - **Project 1**) **Note:** Dose/response relationships are needed to understand the effects of any anthropogenic noise sources on marine life and thus determining these should not necessarily fall solely on the wave and tidal industries.

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
			Further development of noise propagation models to inform assessment of the potential impacts of operational noise on receptors from demonstration and commercial scale arrays.	**HOLD** **Relevant to both wave and tidal projects.** Await establishment of the 'evidence base' and the production/dissemination of device/array specific acoustic assessments. Priority is to first understand the potential acoustic output of operational devices (refer to outline project plan in Chapter 5 - **Project 5**).
1. Underwater noise	1.5: Knowledge regarding the possible effects of underwater noise from the construction and operation of wave and tidal arrays on marine mammals is incomplete	The noise levels capable of causing impacts of differing significance (e.g. lethal, sub lethal, permanent, temporary) for marine mammal species of concern.	Research on the sensory ecology of marine mammals (cetaceans and seals): • Expansion of range of species for which hearing capacities (i.e. audiograms) are available for key species in wave and tidal development areas. **Note:** ORJIP offshore wind priority (for porpoise, dolphin and seals) to determine: • The sound levels likely to cause Temporary Threshold Shift (TTS) and Permanent Threshold Shift (PTS). This information should, preferably, be in the form of a dose-response relationship, with associated uncertainty, for each priority species. **Note:** New projects planned through NERC RESPONSE doing playback of operational noise and monitoring of behavioural response of key species may inform this issue	**HOLD** **Relevant to both wave and tidal projects.** Priority is to first understand the potential acoustic output of operational devices (refer to outline project plan in Chapter 5 **- Project 5**). Await establishment of the 'evidence base' regarding operational noise levels from ongoing work by developers. **Note:** This is also an issue relevant to other marine industries (e.g. offshore wind) therefore may not be a priority for ORJIP Wave and Tide. Operational noise from wave and tidal devices is not likely to be at levels likely to cause injury or significant behavioural effects (Robinson and Lepper, 2013, Harland *et al.*, 2013).
		Effects of operational noise (behavioural changes, disturbance and displacement effects) from underwater devices and construction activities on marine mammals.	Further research / monitoring studies around single test devices and first demonstration arrays to gather information on the behaviour of marine mammals around operating devices to gather evidence to see whether noise is likely to be an issue or not for marine mammals. Dose/response relationships are needed to understand the amplitude and frequencies of sounds that elicit reactions in animals of concern. Determine if device noise is audible to marine mammals to elicit avoidance behaviour (may be linked to potential collision risk). Investigate if there are acoustic barrier effects of operational devices/arrays. Measuring noise doses on individuals around devices will be useful and can be integrated into studies of behavioural responses. An approach using computational acoustic models, based on anatomical data might be preferable.	**HOLD** **Relevant to both wave and tidal projects.** Priority is to first understand the potential acoustic output of operational devices and arrays (refer to outline project plan in Chapter 5 - **Project 5**). Await establishment of the 'evidence base' regarding operational noise levels from ongoing work by developers. This issue may be informed by monitoring of behaviour around single wave and tidal devices and first demonstration arrays (refer to outline project plan in Chapter 5 - **Project 1**). **Note:** Dose/response relationships are needed to understand the effects of any anthropogenic noise sources on marine life and thus determining these should not necessarily fall solely on the wave and tidal industries.
			Further development of noise propagation models to inform assessment of the potential impacts of operational noise on receptors from demonstration and commercial scale arrays.	**HOLD** **Relevant to both wave and tidal projects.** Await establishment of the 'evidence base' and the production/dissemination of device/array specific acoustic assessments. Priority is to first understand the potential acoustic output of operational devices (refer to outline project plan in Chapter 5 - **Project 5**).

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
2. Collision risk	2.1: The nature of any potential interactions between diving birds and tidal turbines is uncertain	Behaviour of diving birds (including avoidance and evasion behaviour and the attraction of species) around tidal turbines to better understand the real level of risk of collisions including: o Probability of occurrence o The extent to which devices, moorings and inter-array areas may act as fish aggregation devices and therefore increase potential for collision risk for predatory species of birds	Further research / monitoring studies around single test devices and first demonstration arrays to gather information on the behaviour of marine birds around operating devices and to quantify avoidance rates for input in Collision Risk Modelling (CRM). Need to build evidence base to assess whether collision is likely to be an issue or not for diving birds. It is important that data on avoidance and behaviour is collated and organised in a systematic manner so that data collected can feed into the development of Collision Risk Models (CRMs). Disseminate and appraise findings of monitoring studies around single test devices to inform need for studies around demonstration arrays. A review of results as they become available will inform whether further monitoring is required.	**Yes** **Relevant to tidal projects only** **Refer to outline project plan in Chapter 5 - Project 1 - Research and monitoring studies around single devices and first arrays to gather further information on the behaviour of marine mammals, birds and fish around operating wave and tidal devices**
			Further research to investigate probability of collisions occurring and factors affecting the likelihood of collision e.g. size of animal, swim speed, device speed, etc. o Laboratory based experimental research e.g. tank testing using animals or animal-sized objects to determine the proportion of individuals that are struck or otherwise injured o Hydrodynamic modelling o Computational Fluid Dynamics (CFD)	**Yes** **Relevant to tidal projects only** **Refer to outline project plan in Chapter 5 – Project 2 – Further investigation into the possible physical consequences of collision for marine mammals, diving birds and fish with operating tidal turbines**
			Individual Based Models (IBMs) can be used to investigate emergent behaviours of groups and flocks of animals. This type of model has the flexibility that allows a range of environmental parameters to be included allowing the response of the simulated animals to the environment to be investigated.	**HOLD** **Relevant to tidal projects only** ORJIP Wave and Tide priority is to understand the individual behavioural responses around operational devices (refer to outline project plan in Chapter 5 - **Project 1**). The outputs of the monitoring studies will provide useful inputs into this type of modelling process for determining population level impacts.
		Assessing collision risk for diving birds.	Need an agreed approach for Collision Risk Modelling for diving bird species.	**HOLD** **Relevant to tidal projects only** Collision risk models (CRMs) for diving birds are currently in preparation by SNH. There is a need for Regulators to agree which CRMs should be used and provide guidance on how to undertake collision risk modelling and how CRM fits into the consenting and decision making process. The findings of the monitoring studies of behaviour of diving birds around operating devices will help to inform avoidance rates and improve estimations/accuracy of CRMs (refer to outline project plan in Chapter 5 - **Project 1**).

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
		Use of tidal streams by diving birds: ○ Improved understanding of the functional importance of tidal stream areas ○ Improved understanding of the spatial and temporal patterns of site use of tidal stream areas (and relative importance of these areas), and ○ Improved understanding of behaviour (e.g. diving depth, dive profiles, and the proportion of time spent at the operating depth of tidal turbines is key information)	Further analysis of existing data to investigate species abundance and distribution against tidal cycle data to assess if key species are present in areas of greatest tidal flow to inform whether collision is likely to be a real issue (or not).	**No** **Relevant to tidal projects only** ORJIP Wave and Tide priority is to undertake direct observations around devices to understand individual behavioural responses around operational devices. The priority is to build an evidence base to assess whether collision is likely to be an issue or not for diving birds. Understanding use of high tidal energy areas by diving birds is more of a primary research project. May be more appropriate for Regulators or SNCBs to investigate this - not the responsibility of wave and tidal industries.
			Behavioural studies (including tagging) to look at diving behaviour to determine whether birds are at risk through their feeding ecology. Studies should focus on species identified by Furness *et al.* (2012) as being particularly sensitive to tidal energy developments.	**No** **Relevant to tidal projects only** ORJIP Wave and Tide priority is to undertake direct observations around devices to understand individual behavioural responses around operational devices. The priority is to build an evidence base to assess whether collision is likely to be an issue or not for diving birds. Understanding use of high tidal energy areas by diving birds is more of a primary research project. May be more appropriate for Regulators or SNCBs to investigate this - not the responsibility of wave and tidal industries.
2. Collision risk	2.2: The nature of any potential interactions between marine mammals and basking sharks and tidal turbines is uncertain	Behaviour of marine mammals and basking sharks (including avoidance and evasion behaviour and the attraction of inquisitive species e.g. bottlenose dolphin and minke whale) around tidal turbines to better understand the real level of risk of collisions including: ○ Probability of occurrence; ○ The extent to which devices, moorings and inter-array areas may act as fish aggregation devices and therefore increase potential for collision risk for marine mammals	Monitoring studies around single test devices and first demonstration arrays to gather information on the behaviour of marine mammals (cetaceans and seals) and basking sharks around operating devices and to quantify avoidance rates for input in Collision Risk Modelling. Need to build evidence base to assess whether collision is likely to be an issue or not for marine mammals and basking sharks. It is important that data on avoidance and behaviour is collated and organised in a systematic manner so that data collected can feed into the development of Collision Risk Models (CRMs). Disseminate and appraise findings of monitoring studies around single test devices to inform need for studies around demonstration arrays. A review of results as they become available will inform whether further monitoring is required.	**Yes** **Relevant to tidal projects only** **This will provide critical information to further inform demonstration scale EIA/HRA and environmental mitigation and monitoring plans for first array projects and the consenting of larger commercial scale projects.** **Refer to outline project plan in Chapter 5 - Project 1 - Research and monitoring studies around single devices and first arrays to gather further information on the behaviour of marine mammals, birds and fish around operating wave and tidal devices.**
			Further research to investigate probability of collision occurring and factors affecting the likelihood of collision e.g. size of animal, swim speed, device speed, responses to noise, etc. ○ Laboratory based experimental research e.g. tank testing using animals or animal-sized objects to determine the proportion of individuals that are struck or otherwise injured ○ Hydrodynamic modelling ○ Computational Fluid Dynamics (CFD)	**Yes** **Relevant to tidal projects only** **Refer to outline project plan in Chapter 5 – Project 2 – Further investigation into the possible physical consequences of collision for marine mammals, diving birds and fish with operating tidal turbines.**

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
			Individual Based Models (IBMs) can be used to investigate emergent behaviours of groups of animals.	**HOLD** **Relevant to tidal projects only** ORJIP Wave and Tide priority is to understand the individual behavioural responses around operational devices (refer to outline project plan in Chapter 5 - **Project 1**). The outputs of the monitoring studies will provide useful inputs into this type of modelling process for determining population level impacts.
		Assessing collision risk for marine mammals and basking sharks	Need an agreed approach for Collision Risk Modelling for marine mammals and basking sharks.	**HOLD** **Relevant to tidal projects only** Collision risk models (CRMs) for marine mammals are currently in preparation by SMRU/Marine Scotland. There is a need for Regulators to agree which CRMs should be used and provide guidance on how to undertake collision risk modelling and how CRM fits into the consenting and decision making process. The applicability of these CRMs for use in estimating collision risk for basking shark should be considered. The findings of the monitoring studies of behaviour around operating devices will help to inform avoidance rates and improve estimations/accuracy of CRMs (refer to outline project plan in Chapter 5 - **Project 1**).
		Use of tidal stream by marine mammals and basking sharks: ○ Improved understanding of the functional importance of tidal stream areas ○ Improved understanding of the spatial and temporal patterns of site use of tidal stream areas (and relative importance of these areas), ○ Improved understanding of routes used for movement and migration; and, ○ Improved understanding of behaviour (e.g. diving depth, dive profiles, and the proportion of time spent at the operating depth of tidal turbines is key information)	Studies to determine how marine mammals and basking sharks are using high tidal energy environments and the relative importance of these areas compared to surrounding (presumably less energetic) environments. Need to gather data prior to devices being installed to assess where areas or times of key overlap exist. If species do not occur in the highest tidal energy areas or at times of highest flow/energy then that is obviously important.	**No** **Relevant to tidal projects only** ORJIP Wave and Tide priority is to undertake direct observations around devices to understand individual behavioural responses around operational devices. The priority is to build an evidence base to assess whether collision is likely to be an issue or not for marine mammals and basking sharks. Understanding the use of high tidal energy areas by marine mammals and basking sharks is more of a primary research project. May be more appropriate for Regulators or SNCBs to investigate this - not the responsibility of wave and tidal industries.

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
			Further analysis of existing data (species abundance and distribution, seal tagging data) against tidal cycle data to assess if marine mammals are present in areas of greatest tidal flow to inform whether collision is likely to be a real issue (or not).	**No** **Relevant to tidal projects only** ORJIP Wave and Tide priority is to undertake direct observations around devices to understand individual behavioural responses around operational devices. The priority is to build an evidence base to assess whether collision is likely to be an issue or not for marine mammals and basking sharks. Understanding use of high tidal energy areas by marine mammals and basking sharks is more of a primary research project. May be more appropriate for Regulators or SNCBs to investigate this - not the responsibility of wave and tidal industries.
			Tagging work to help inform about behaviour of marine mammals in the water column (dive profiles, diving depth, swimming orientation of marine mammals and basking sharks in relation to tidal flow) for use in estimating collision risk but sample size issues present challenges.	**No** **Relevant to tidal projects only** ORJIP Wave and Tide priority is to undertake direct observations around devices to understand individual behavioural responses around operational devices. The priority is to build an evidence base to assess whether collision is likely to be an issue or not for marine mammals and basking sharks. Understanding behaviour of marine mammals and basking sharks in the water column is more of a primary research project. May be more appropriate for Regulators or SNCBs to investigate this - not the responsibility of wave and tidal industries.
2. Collision risk	2.3: The nature of any potential interactions between migratory fish and tidal turbines is uncertain	Behaviour of migratory fish (including avoidance and evasion behaviour)around tidal turbines to better understand the real level of risk of collisions including: ○ Probability of occurrence	Monitoring studies around single test devices and first demonstration arrays to gather information on the behaviour (e.g. aggregation or avoidance) of fish around operating devices and to quantify avoidance rates to help refine and validate (or otherwise) encounter risk models. Need to gather evidence to see whether collision is likely to be an issue or not for migratory fish. Disseminate and appraise/review of data /findings of monitoring studies around single test devices to inform need for studies around demonstration arrays. A review of results as they become available will inform whether further monitoring is required.	**Yes** **Relevant to tidal projects only** **This will provide critical information to further inform demonstration scale EIA/HRA and environmental mitigation and monitoring plans for first array projects and the consenting of larger commercial scale projects.** **Refer to outline project plan in Chapter 5 - Project 1 - Research and monitoring studies around single devices and first arrays to gather further information on the behaviour of marine mammals, birds and fish around operating wave and tidal devices.**
			Individual Based Models (IBMs) can be used to investigate emergent behaviours of groups of animals.	**HOLD** **Relevant to tidal projects only** ORJIP Wave and Tide priority is to understand the individual behavioural responses around operational devices (refer to outline project plan in Chapter 5 - **Project 1**). The outputs of the monitoring studies will provide useful inputs into this type of modelling process for determining population level impacts.

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
			Further research to investigate probability of collisions occurring and factors affecting the likelihood of collision e.g. size of animal, swim speed, device speed, etc. ○ Laboratory based experimental research e.g. tank testing using animals or animal-sized objects to determine the proportion of individuals that are struck or otherwise injured ○ In-water experimental research around operating turbines e.g. release of acoustically tagged fish to track movement past devices ○ Hydrodynamic modelling ○ Computational Fluid Dynamics (CFD)	**Yes** **Relevant to tidal projects only** **Refer to outline project plan in Chapter 5 – Project 2 – Further investigation into the possible physical consequences of collision for marine mammals, diving birds and fish with operating tidal turbines**
		Assessing collision risk for migratory fish	Need an agreed approach for Collision Risk Modelling for migratory fish species.	**HOLD** **Relevant to tidal projects only** There is a need for Regulators to agree which CRMs should be used and provide guidance on how to undertake collision risk modelling and how CRM fits into the consenting and decision making process. The findings of the monitoring studies of behaviour around operating devices will help to inform avoidance rates and improve estimations/accuracy of CRMs (refer to outline project plan in Chapter 5 - **Project 1**).
		Use of tidal stream areas by migratory fish (research gaps identified in (Slaski *et al*., 2013): 1. Migratory pathways / behaviour – to what extent are migratory salmonids likely to be geographically co-incident with the locations of wave and tidal energy projects 2. Swimming behaviour – if fish are geographically co-incident (in any significant numbers), to what extent are they likely to be physically co-incident. Swimming depth preference and avoidance capability appear to be the key questions 3. Mode of transport in high current speeds – the degree to which passive transportation through areas of high energy takes place, and potential implications 4. Encounter Effects – if some fish do make physical (or equivalent) contact with the wave or tidal energy device, what are the outcomes?	Monitoring studies to determine how migratory fish species are using high tidal energy environments and the relative importance of these areas compared to surrounding (presumably less energetic) environments. Need to gather data prior to devices being installed to assess where areas or times of key overlap exist. If species do not occur in the highest tidal energy areas or at times of highest flow/energy then that is obviously important.	**HOLD** **Relevant to tidal projects only** This is a High priority issue but need to await findings of work underway (e.g. ERI work on migratory fish – Funded by The Crown Estate, and Tagging work undertaken by MSS in 2013/2014). The findings of these studies may ascertain if more strategic baseline data is required or not (see Key Issue 13). The findings of the monitoring studies of behaviour around operating devices will help to inform avoidance rates and improve estimations/accuracy of CRMs (refer to outline project plan in Chapter 5 - **Project 1**). This issue is also relevant to other industries/bodies therefore the responsibility should not necessarily fall solely on the wave and tidal industries to undertake this work.

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
2. Collision risk	2.4: There is uncertainty as to the possible physical consequences of potential collision events for marine mammals, diving birds and fish and tidal turbines	Severity of injury should strike occur	The consequences of collision with a turbine (or passage through a turbine in the case of fish) can be investigated using computer modelling or laboratory studies (e.g. tank testing) to study the effects of rotational speed of the blade, distance along blade, etc. on severity of injury for a range of turbine designs and species. Computational Fluid Dynamics (CFD) studies to ascertain if some species may have 'protection' from collision through entrainment. CFD models of turbines and turbine arrays could be used to predict the pressure fluctuations experienced by species as they pass close to turbines. These pressure traces can be used to find effects on key marine species and their prey. NOTE: Based on preliminary flume and field studies, avoidance appears to be high and given the slow rate of rotation, impact on larger animals in the event strike should occur appears to be low. Though often compared, current evidence suggests that tidal turbine strike risk varies greatly from that of ship propellers and conventional hydropower turbines (US Dept. of Energy, 2012).	**Yes** **Relevant to tidal projects only** **Findings of experimental research into the consequences of collision may inform the issue of collision within shorter timescales. This may be a quicker way of identifying if collision is a real issue than in-water monitoring and may determine the level of in-water monitoring required around arrays.** **Refer to outline project plan in Chapter 5 - Project 2 – Further investigation into the possible physical consequences of collision for marine mammals, diving birds and fish with operating tidal turbines.**
2. Collision risk	2.5: Further development of suitable instrumentation and methodologies for monitoring wildlife behaviour around wave and tidal devices and arrays and for detection of any collision events is required	Further development of suitable technologies/tools and methods for use in high energy tidal environments to: ○ Monitor behaviour of wildlife in the vicinity of devices and support structures , and ○ Detect and record actual collision events to quantify the incidence/frequency of collisions	Further development of suitable instrumentation and methodologies may require an integrated approach utilising a number of different technologies running in parallel e.g. development of acoustic tag technology, active sonar automatic detection/tracking ability, development of automated 3D PAM tracking, development of collision detection technology. Trial/test monitoring technologies (potentially at e.g. EMEC, WaveHub, FaBTest and other test sites) to inform improvements in technologies and cost reductions Differentiation to species level may be required (Depending on technique, this may require a significant investment to make a reality – e.g. using PAM techniques – only some are distinguishable currently.)	**Yes** **Relevant to both wave and tidal projects only** **The development of monitoring methods is one of the priorities and one that generic industry funding could be well used to address. Enables the collection of empirical data on potential impacts.** **Some studies already underway – need to learn from these and advance.** **Refer to outline project plan in Chapter 5 - Project 3 - Further development of suitable instrumentation and methodologies for monitoring wildlife behaviour around wave and tidal devices and arrays and for detection of any collision events.**
			Comparison of methods for monitoring especially as scaling up from single devices to arrays.	**HOLD** **Relevant to both wave and tidal projects only** Await results of monitoring studies (refer to outline project plan in Chapter 5 - **Project 1**). Methods have to be developed first, and advantages / disadvantages in comparison with other methods could be a mandatory section in the corresponding project report.

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
			Development of mitigation measures for novel wet renewable technologies may be required to ensure early deployments are compliant with the Habitats Regulations. While these can be developed on a project-specific basis, there would be merit in a more coordinated approach.	**HOLD** **Relevant to both wave and tidal projects only** ORJIP Wave and Tide priority is to undertake direct observations around devices to understand individual behavioural responses around operational devices. The priority is to build an evidence base to assess whether collision is likely to be an issue or not Await results of monitoring studies (refer to outline project plan in Chapter 5 - **Project 1**).
6. Displacement	6.1: Potential displacement of essential activities of marine mammals, basking sharks and birds	An agreed approach to assessing the potential effects of displacement from wave and tidal arrays	Undertake a review of findings of offshore wind research into displacement and the assessment of potential population level effects. Determine whether or not displacement from demonstration scale / commercial scale wave and tidal arrays is ever likely to result in biologically significant effects If necessary, develop a consistent approach to assessing/modelling the risk to populations from displacement form wave and tidal projects. To enable Regulators to assess the risk. If necessary, an agreed approach on how to measure/detect displacement is required. Can displacement be measured? What is a representative sample? How can potential significance of displacement be assessed?	**Yes** **Relevant to both wave and tidal projects** **Refer to outline project plan in Chapter 5 - Project 4- Development of an agreed approach to assessing the potential effects of displacement of marine mammals and birds from wave and tidal arrays**
		Potential for displacement to occur – research around demonstration scale arrays may provide an opportunity to gather data to inform commercial scale EIA/HRA.	If determined necessary, undertake research around first demonstration arrays to investigate if displacement occurs and to build an evidence base to inform our understanding of the behavioural response of animals to operational devices which may be used to inform commercial scale EIA/HRA.	**HOLD** **Relevant to both wave and tidal projects** Although not identified as a priority issue, the issue of displacement may be informed by **Project 1** (refer to outline project plan in Chapter 5 – **Project 1)**
13. General	13.1: Further strategic baseline data (distribution, abundance, seasonality, etc.) for marine mammals and basking sharks is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects	There is a requirement for: ○ Improved estimates of temporal and spatial variation in local density ○ Improved estimates of site fidelity ○ Improved information on population size and range ○ Improved information on routes used for movement and migration	Make better use of data already gathered for first projects (consented arrays and those near planning submission). Collation of information about priority species and priority areas (from existing installations and (potential) future installation areas around UK waters). Regular reviews of monitoring data (similar to the recent commissioned project by MMO (MMO 1031); reviewing post-consent monitoring collected from offshore wind farms in order to provide a synthesis of the evidence Make existing data available to other developers through the Regulators – this would build a longer term data set to be used in EIA/HRA.	**No** **Relevant to both wave and tidal projects** High priority issue but not a 'research project' for ORJIP Wave and Tide. More appropriate for Regulators and/or SNCBs and/or others to investigate this.
			Detailed statistical analysis of data already gathered from a number of sites to investigate any actual impacts occurring and ability to detect change to determine what can be learnt from data already gathered.	**No** **Relevant to both wave and tidal projects** High priority issue but not a 'research project' for ORJIP Wave and Tide.

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
			Development and update of sensitivity mapping for key species and the incorporation of this information into marine spatial planning.	**No** **Relevant to both wave and tidal projects** High priority issue but not a 'research project' for ORJIP Wave and Tide. More appropriate for Regulators and/or SNCBs and/or others to investigate this.
14. General	14.1: Further strategic baseline data (distribution, abundance, seasonality, etc.) for birds is required to allow better characterisation of high energy resource areas suitable for wave and tidal projects	There is a requirement for: ○ Improved estimates of local density ○ Improved estimates of site fidelity ○ Improved information on population size and range	Make better use of data already gathered for first projects (consented arrays and those near planning submission). Collation of information about priority species and priority areas (from existing installations and (potential) future installation areas around UK waters). Regular reviews of monitoring data (similar to the recent commissioned project by MMO (MMO 1031); reviewing post-consent monitoring collected from offshore wind farms in order to provide a synthesis of the evidence Make existing data available to other developers through the Regulators – this would build a longer term data set to be used in EIA/HRA.	**No** **Relevant to both wave and tidal projects** High priority issue but not one for ORJIP Wave and Tide. More appropriate for Regulators and/or SNCBs and/or others to investigate this.
			Detailed statistical analysis of data already gathered from a number of sites to investigate any actual impacts occurring and ability to detect change to determine what can be learnt from data already gathered.	**No** **Relevant to both wave and tidal projects** High priority issue but not one for ORJIP Wave and Tide.
17. General	17.1: Further data of mobile species populations (particularly qualifying species of Natura sites and EPS) for use in population modelling would improve confidence in EIA/HRA	Further data i.e. demographic parameters (e.g. adult survival, juvenile survival, productivity rates, etc.) for mobile species populations (particularly qualifying species of Natura sites and EPS) for use in population modelling. Current information on other sources of mortality and disturbance acting on marine mammal populations, such as fisheries by catch, is sparse.	Establish up-to date demographic parameters for key species to enable validation of models and to inform inputs to models. Lack of up-to-date data is a serious hindrance to research across the sector.	**No** **Relevant to both wave and tidal projects** High priority project/initiative for Regulators and/or SNCBs – Not ORJIP Wave and Tide ORJIP Wave and Tide priority issue is to see if there are any impacts from operating wave and tidal devices; as if there are no impacts, then no/less need to get into population modelling etc. An interim approach may be required as it may be several years before findings are available. High priority project/initiative for Regulators and/or SNCBs and/or others.
		Agreement on the reference populations (and current status and trends) against which changes are assessed. **NOTE**: Interagency Marine Mammal Working Group has agreed management units for the five species that are considered to be of greatest concern: grey seal, harbour seal, harbour porpoise, bottlenose dolphin, and minke whale for reporting Favourable Conservation Status (FCS) however there is some debate about their appropriateness for use in project assessment.	Establish consistent rationales for defining populations using the best available information. The definition of management units will be an adaptive process: when more evidence becomes available these units can be updated for following applications.	**No** **Relevant to both wave and tidal projects** High priority project/initiative for Regulators and/or SNCBs – Not ORJIP Wave and Tide
		Approaches to determining connectivity of mobile qualifying features.	**Connectivity (protected sites and species):** Understanding linkages between birds at sea and SPAs. Plug gaps in seabird tracking studies; improve our understanding of foraging areas associated with different breeding colonies.	**No** **Relevant to both wave and tidal projects** High priority project/initiative for Regulators and/or SNCBs – NOT ORJIP Wave and Tide

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
			Understanding linkages between migratory salmon (Natura species) and SACs. How to apportion populations to rivers and SAC sites.	**No** **Relevant to both wave and tidal projects** High priority project/initiative for Regulators and/or SNCBs – Not ORJIP Wave and Tide
18. General	18.1: Better understanding of population level impacts and methods to assess the significance of population level impacts would improve confidence in EIA/HRA	Improved understanding of population level impacts.	Review of existing modelling tools and of need for development of new tools to predict population level consequences of impacts on survival and reproductive success of individuals and hence population size. Establish an appropriate methodology e.g. such as using a modified version of PVA/PBR. Review of PBR approach to regulation including a consideration of alternatives. Briefing paper for Regulators and developers.	**No** **Relevant to both wave and tidal projects** High priority project/initiative for Regulators and/or SNCBs – Not ORJIP Wave and Tide ORJIP Wave and Tide priority issue is to see if there are any impacts from operating wave and tidal devices; as if there are no impacts, then there is no/less need to undertake population modelling etc. An interim approach may be required as it may be several years before findings are available. High priority project/initiative for Regulators and/or SNCBs
			Population modelling of the scaling up of impacts	**HOLD** **Relevant to both wave and tidal projects** Await findings of monitoring studies (refer to outline project plans in Chapter 5 – **Projects 1, 2, 4 and 5**)
		Establishing the limits of acceptable impact under the terms of the Habitats Regulations for both European Protected Species and qualifying species of SACs and SPAs.	The PCoD project and ORJIP offshore wind PCAD project should help to provide frameworks for determining thresholds for impacts in terms of disturbance or mortality levels, but there is likely to be a need for some additional work to ascertain thresholds that fully meet the requirements of the Habitat Regulations and which are relevant to wave and tidal projects. Develop a modelling and management framework appropriate for assessing the risks. Link results to the management of potential impacts on Favourable Conservation Status of protected sites/species.	**No** **Relevant to both wave and tidal projects** High priority project/initiative for Regulators and/or SNCBs – Not ORJIP Wave and Tide An interim approach may be required as it may be several years before findings are available. High priority project/initiative for Regulators and/or SNCBs
Human environment				
19. Impacts on commercial fisheries	19.1: Further baseline inshore fisheries activity data to inform CIA (Cumulative Impact Assessment)	There remains a gap in other UK waters, although the gap may only be related to areas where wave and/or tidal projects are clustered (i.e. less of a gap where individual projects are concerned).	Roll out of projects akin to ScotMap or tracking/plotter initiatives for key areas outside PFOWSA.	**No** **Relevant to both wave and tidal projects** This issue is not specific to the marine renewables industry and should therefore be done by the Regulator (Marine Scotland, MMO etc.). Issue also relevant to marine spatial planning.

Topic	Key Issue	Gaps	Research areas	ORJIP Wave and Tide Priority?
21. Impacts on seascape	21.1: Lack of regional and local coastal landscape character assessments to inform Seascape, Landscape and Visual Impact Assessment	Baseline coastal landscape character assessments at a national level outside of Scotland and Wales.	Character-based coastal landscape assessment at national level.	**No** **Relevant to both wave and tidal projects** This issue is not specific to the marine renewables industry and should therefore be done by SNCBs/Local Planning Authorities, with input from developers as necessary.
		Baseline coastal landscape character assessments at a regional character level.	For areas where clusters for development are planned then a regional scale character based assessment should also be undertaken (or at a finer level than regional may be required on some complex areas of coast).	
		Baseline coastal landscape character assessments at a local character level.	Detailed assessment at a local scale is appropriate to impact assessment of specific coastal or marine based developments.	**No** **Relevant to both wave and tidal projects** Detailed local scale assessment is a site specific issue and therefore for the individual developer to undertake.
22. Social and economic impacts on local communities	22.1: Difficulty with identifying, assessing, mitigating and managing potential cumulative social and economic impacts from marine energy development and changes to existing maritime activity	It is unclear what level and type of employment will be required to support wave and tidal projects. This makes assessing key socio-economic impacts difficult.	Data collection in order to better understand the potential socio-economic impacts on local communities. Developers and supply chain should be engaged to provide predictions of the number and type of workers that will be required to support planned developments. This should include indicative timescales, consider project phasing etc. Although some work has already been done in this area by TCE this is several years old and now that some first demonstration projects have gained consent, those developers will be looking towards the construction phase and will have a better understanding of the level and type of employment that may be created.	**No** **Relevant to both wave and tidal projects** This is only really an issue at commercial scale however it should also be considered where there will be clusters of demonstration scale projects (e.g. PFOW) therefore is not a priority for ORJIP at the current time. It may be more of a priority for relevant local authorities and/or marine spatial planning bodies.
		The potential cumulative economic impacts on local communities resulting from increased employment opportunities, supply chain development, or changes to existing industries from multiple demonstration projects within a region.	The methodology and baseline produced by ABPmer could be used to undertake a cumulative socio economic impact assessment at a regional basis if determined necessary/beneficial by the local authority/regulator(s)/advisors.	**No** **Relevant to both wave and tidal projects** This is a high priority but one that should be considered at a regional/local level; possibly by the relevant local authority and/or marine spatial planning bodies in conjunction with regulator(s)/advisors and project developers.
		The potential cumulative social impacts on local communities resulting from development of the wave and tidal industry (such as the effects on local services from any change in population during construction and operation)	Socio-economic assessment as part of the EIA process is not a new topic but it is recognised that wave and tidal project will often happen in small rural communities, thus there is a potential for impacts to be magnified. A review of work underway in offshore wind ORJIP could be adapted / aligned with the needs of the wave and tidal industry. A cumulative social impact assessment similar to ABPmer's ongoing socio-economic case studies, but where the emphasis is on the potential social impacts and benefits from development of a wave and/or tidal industry, with particular emphasis on the impacts on small rural communities.	**No** **Relevant to both wave and tidal projects** This is a high priority but one that should be considered at a regional/local level; possibly by the relevant local authority and/or marine spatial planning bodies in conjunction with regulator(s)/advisors and project developers.

5 Task 4 – Outline 'Priority Research Project' plans

This chapter includes outline plans for the priority research projects identified during the previous task as those for any Joint Industry Programme to focus upon (refer to Table 4.1). These have been defined to specifically help address the priority EIA/HRA issues that are not currently being addressed through ongoing research and studies as well as those requiring further attention as a matter of urgency. A list of the priority research projects is provided below (in no particular order):

- **Project 1** - Research and monitoring studies around single devices and first arrays to gather further information on the behaviour of marine mammals, birds and fish around operating wave and tidal devices
- **Project 2** – Further investigation into the possible physical consequences of collision for marine mammals, diving birds and fish with operating tidal turbines
- **Project 3** - Further development of suitable instrumentation and methodologies for monitoring wildlife behaviour around wave and tidal devices and arrays and for detection of any collision events
- **Project 4** - Development of an agreed approach to assessing the potential effects of displacement of marine mammals and birds from wave and tidal arrays
- **Project 5** - Establishment of an acoustic 'evidence base' for operational wave and tidal devices and first arrays

The Draft Report including proposed outline project plans was circulated to attendees prior to the NERC workshop in Edinburgh in November 2013. The main objectives of the workshop's Session 2 working groups was to discuss the suitability of the projects in terms of addressing the key issues identified, provide further detail with regards to the possible scope of each and to suggest how each might be best delivered.

The outline plans presented in this chapter have been further developed following the workshop based on the discussions. Workshop discussion summaries are presented alongside each project plan (below). The Workshop Report with the original outline project plans is presented in full in Annex A.

Note: These projects have been developed to address specific key EIA/HRA issues. However, it is noted that a small number of integrated, 'whole-system' impact monitoring programmes around the first wave and tidal stream arrays to examine changes in all key anthropogenic influences and environmental parameters e.g. marine mammals, birds, benthos, physical processes etc., will provide further understanding as to what (if any) changes arise and importantly, why they do so. It will be important for work on the other research gaps identified to also be progressed, since these will also provide important improvements in knowledge, assessment techniques etc.

5.1 Project 1 - Research and monitoring studies around single devices and first arrays to gather further information on the behaviour of marine mammals, birds and fish around operating wave and tidal devices

Note: This project plan originally focused on monitoring the behaviour of marine mammals, diving birds and fish around operating tidal devices to assess whether collision is likely to be an issue or not for key species (see Annex A). At the workshop, it was recognised that further to informing the issue of collision risk and tidal devices, monitoring behaviour around tidal devices could provide valuable data to inform other issues potentially relevant at the commercial scale e.g. displacement and other changes in behaviour such as attraction. It was felt that monitoring behaviour around wave devices could also provide valuable data to inform issues potentially relevant at the commercial scale.

5.1.1 Overview

Monitoring studies are required to build an evidence base to record the behaviour of marine mammals, diving birds and fish around operating wave and tidal devices (particularly of array projects). Monitoring is needed at different states of tide and wave activity, and during periods when devices are generating and during periods when devices are not generating. This will improve understanding as to the potential effects of demonstration and commercial scale projects on key species.

5.1.2 Objectives

Primary objective

The primary objective is to monitor the behaviour of marine mammals, diving birds and fish around operational tidal devices. This will help inform collision risk assessments for tidal projects and will build an evidence base to help determine whether or not collision is ever likely to be an issue for key species.

Note: Risk of collision was **NOT** identified as being a priority issue for wave devices.

Secondary objective

Monitoring studies of marine mammal, bird and fish behaviour around operating wave and tidal devices (particularly array deployments) also have the potential to help inform what effects on behaviour, if any, the presence and operation of devices and arrays may have on key species to provide data to inform commercial scale EIA/HRA and future research and monitoring plans.

5.1.3 Outline scope of work

It is recommended that a comprehensive review of existing monitoring studies from wave and tidal deployments around the world is undertaken to inform the design, focus and extent of future environmental monitoring programmes.

Primary objective

Monitoring and research of marine mammal, diving bird and fish behaviour should be undertaken around operating tidal devices (particularly of first array demonstration tidal projects, and/or of single devices if necessary) to help:

- Determine the likelihood of collision / probability of occurrence
- Ascertain if there are any actual collisions with turbines
- Understand avoidance or attraction behaviour and ability to evade collisions
- Quantify avoidance rates for use in collision risk modelling

Monitoring should be focused on those species that are of key conservation interest identified as being potentially sensitive to potential impacts from wave or tidal developments to inform EIA/HRA.

Secondary objective

Monitoring and research of marine mammal, bird and fish behaviour around operating wave and tidal devices may provide data to help determine:

- what effect(s) on behaviour, if any, the presence of operating wave and tidal devices has on key species
- how key species interact with and around devices, e.g. whether displacement or other behavioural change (e.g. attraction of key species) occurs
- the extent to which devices, moorings and inter-array areas may act as fish aggregation devices
- the effects of operational noise on marine wildlife
- the potential for positive effects

In general, for this project to have strategic value, it is essential that data is gathered and reported in such a way that it helps build an evidence base that can inform commercial scale project EIA/HRA. Regular review of results as they become available will determine whether or not further monitoring is required.

Note: The first opportunities to monitor around early demonstration arrays in the UK will be; Sound of Islay, Inner Sound and Skerries (all consented projects but detail is yet to emerge about specifics of any monitoring plans). Other first array tidal projects in Europe should also be considered. Another option in the UK may be to use EMEC as an existing proxy for a demonstration scale tidal array, but this will depend on the level of operational activity at the test site and will need detailed consideration.

5.1.4 Workshop discussion summaries

Marine mammals and basking shark

The central issue of concern remains – how do animals interact with wave and tidal devices. If they collide we need to understand the consequences at the population level – if they are able to detect and avoid them, we need to understand the consequences of displacement or disturbance of 'normal' activity. By scaling up from single devices to arrays of devices, the consequences of this interaction, which may be species specific and even device specific, may well be more complex. There was a high degree of consensus associated with the need for continuation of research on this aspect, with focus on species at risk, their responses in the field and consequences of interactions. Technology innovation and development has a major role to play in designing appropriate field experiments, possibly requiring a different approach to single device trials to date. Similarly, continuation of efforts to develop improved collision risk models for the 'at risk' species and at appropriate scales is also needed.

It was suggested during the workshop that a critique of the technologies suitable for monitoring mammal and basking shark behaviour around tidal devices needs to be commissioned, in addition to progressing actual research/monitoring work on this issue (see later, Project 4). A different approach may be required as result of scaling up from single devices to arrays.

Diving birds

The central issue for diving birds is how they interact with sub-sea and surface wave and tidal infrastructure, but generally the scope of the [original] proposed project was thought to be too narrow – as the consequences of collisions, disturbance and displacement all need to be considered. Concerns were also expressed about the quality of baseline data, and the interpretation of potential population scale effects, particularly at sites where populations were known to be declining. The presence of tidal or wave energy developments may in fact result in food resources recovering as a result of excluding other activities, with potential knock on beneficial effects for diving bird populations. However the possibility that this then exacerbates the potential for increased frequency of collisions with devices and possible mortality, cannot be excluded. It was noted in these discussions that primary lab testing and modelling research involving the computational fluid dynamicists, and multi-technology field experiments, may help to establish whether diving birds are EVER actually likely to be struck by turbine blades, and may well provide answers more quickly and cost effectively than monitoring around devices. The critical nature of establishing baseline conditions through tagging / acoustic moorings pre installation of arrays, was also emphasised as a significant factor in extracting useful outputs from the early demonstration array projects.

It was suggested during the workshop that the option for further primary research involving hydro-dynamicists and ornithologists in lab testing experiments should be explored, to attempt to establish whether diving birds are EVER likely to be struck by turbine blades. Ideally this work should be progressed in tandem with multi-technology monitoring at a tidal array deployment, as it has the potential to accelerate our understanding of interaction between diving birds and tidal devices.

Note: If the lab tests show birds never interact/will never get struck by blades, monitoring at sea may not be necessary.

Fish

At present this is regarded as an issue of concern especially for salmon and predominantly in Scotland, where it is possible that tidal array sites in development are located at or near to migratory routes of adult salmon. To date there have been no field experiments to establish whether salmon can avoid a single device or to what extent fish which are struck are irreversibly damaged. Acoustic tagging of salmon combined with underwater camera systems and use of flotation devices to recover fish to assess damage, have potential to yield the necessary outcomes – however, at present there does not appear to be a field site in development where trials could be initiated. In the mean time learning from modelling is likely to be the most useful approach, or alternatively, freshwater / estuarine systems with a large natural run of salmon may provide useful information on behaviour interactions with devices.

It was suggested during the workshop that the potential to learn from proxy sites such as estuarine / freshwater systems with large natural run of salmon should be explored in more detail, in addition to any opportunities arising at appropriate tidal projects.

5.2 Project 2 - Further investigation into the possible physical consequences of collision for marine mammals, diving birds and fish with operating tidal turbines

Note: This is a new project, included as a result of the discussions held during the NERC workshop in Edinburgh.

5.2.1 Overview

At present, due to a perceived risk that collision events with tidal turbines may occur, tidal developers are required to install highly precautionary collision risk monitoring systems to detect any potential events and to increase understanding as to the likelihood of collision events occurring. However, targeted lab-based research and modelling into the potential for collision events to occur and the possible consequences of any collision events may help to determine if collisions with tidal turbines are a real concern, or not, for key species within shorter timescales. Laboratory testing and modelling may also be a more cost effective mechanism for investigating the likelihood and consequences of collision risk with tidal turbines than monitoring at sea.

5.2.2 Objective

To establish whether key species are ever actually likely to be struck by turbine blades and if so, determine the possible physical consequences of collision with tidal turbines i.e. extent of injury for key species.

5.2.3 Outline scope of work

Monitoring around a device is unlikely to inform the assessment of severity of injury due to collision unless a carcass is found. The consequences of collision with a turbine (or passage through a turbine in the case of fish) can instead be investigated using computer modelling or laboratory studies (e.g. tank testing) to study the effects of rotational speed of the blade, distance along blade, etc. on severity of injury for a range of turbine designs and species.

Computational Fluid Dynamics (CFD) studies to ascertain if some species may have 'protection' from collision through entrainment. CFD models of turbines and turbine arrays could be used to predict the pressure fluctuations experienced by species as they pass close to turbines. These pressure traces can be used to find effects on key marine species and their prey.

Note: based on preliminary flume and field studies, avoidance appears to be high and given the slow rate of rotation, impact on larger animals in the event strike should occur appears to be low. Though often compared, current evidence suggests that tidal turbine strike risk varies greatly from that of ship propellers and conventional hydropower turbines (US Dept. Energy, 2012).

It is recommended that the following tasks are undertaken as part of this research project:

- Review of existing information regarding the possible consequences of collision events for key species
- Laboratory experiments to investigate the potential likelihood and consequences of collision events with different turbine designs for key species
- Further modelling to investigate the potential likelihood and consequences of collision events with different turbine designs for key species

5.3 Project 3 - Further development of suitable instrumentation and methodologies for monitoring wildlife behaviour around wave and tidal devices and arrays and for detection of any collision events

5.3.1 Overview

The development and success of a 'deploy and monitor' approach to early deployments of wet renewables will require (and benefit from) the ability of technologies to accurately detect and identify wildlife in the vicinity of operating devices, monitor behaviour around devices and detect and record any collision events.

5.3.2 Objective

To support the development of technologies and agreed approaches for monitoring detection and identification of wildlife, and their behaviour, interaction and collision risk with devices and support structures in high energy environments to inform EIA/HRA.

5.3.3 Outline scope of work

It is recommended that the following tasks are undertaken as part of this research project:

- Undertake a critique of the capabilities of existing technologies including the suitability, quality, reliability, durability, limitations, etc. for use in high energy marine environments
- Development/trialling of suitable cost-effective instruments and methodologies for use in high wave energy environments to monitor wildlife behaviour. Differentiation to species level may be required to inform EIA/HRA. This may be challenging for non-vocalising species.
- Development/trialling of suitable cost-effective instruments and methodologies for use in high tidal energy environments to detect and quantify incidence of collisions during operation of single test devices. Differentiation to species level may be required to inform EIA/HRA. This may be challenging for non-vocalising species.
- Explore use of EMEC, WaveHub, FaBTest and other test sites to trial instruments and methodologies to inform design improvements and cost reductions.

This project may require an integrated approach involving a number of organisations and utilising a number of different technologies running in parallel; e.g. development of acoustic tag technology, active sonar automatic detection/tracking ability, development of automated 3D PAM tracking, development of collision detection technology. Consideration should be given to how best to integrate instruments into infrastructure (including power and communication systems) provided by devices and support structures.

5.3.1 Workshop discussion summary

Despite the rapid pace of technology innovation and development it was recognised that deployment of combinations of existing technologies (active / passive acoustics, sonar, radar etc.) are likely to result in much more significant progress than attempts to innovate from scratch. In addition, use of systems which have already been developed has not been exploited optimally because of lack of funding and this particularly applies to the ReDAPT (now EMEC) pod. Nevertheless, there are significant challenges regarding use of existing technology which currently undermine our ability to monitor at the scale of arrays, and over timescales needed to obtain useful data. Hence, powering up, marinisation and ease of deployment / recovery are all considerations, which need to be urgently addressed, as is the potential to deploy monitoring technology in tandem with devices / foundations. It is also clear that some of the existing technologies do not collect data at appropriate spatial scales to be of use, and development of appropriate software / data transfer systems often lags behind the development of the hardware. Development of GPS tagging technology has proceeded apace and there is much to gain from use of telemetry and tagging at array deployment sites.

It was suggested at the workshop that there is a need to commission a critique of existing technologies suitable for monitoring, combined with an analysis of the specific development / innovation needs to allowing detection and monitoring at the scale of arrays.

Note: This has been included in the revised outline scope.

5.4 Project 4 - Development of an agreed approach to assessing the potential effects of displacement of marine mammals and birds from wave and tidal arrays

5.4.1 Overview

At present, wave and tidal developers are required to consider the potential effects of displacement on marine mammals and birds in relation to first arrays. It is essential at this time, to consider whether or not displacement from wave and tidal arrays is ever likely to result in a biologically significant population effect and if determined necessary, carry out further research/monitoring to ascertain any actual displacement effects from operating array projects.

5.4.2 Objective

To determine whether or not displacement is an issue for the wave and tidal sectors and to establish an agreed approach to assessing the potential effects of displacement in project EIA/HRA.

5.4.3 Scope of work

- Undertake a review of findings of research into displacement and any potential population level effects of other sectors, including but not limited to offshore wind.
- Determine whether or not displacement from demonstration scale wave and tidal arrays is ever likely to result in biologically significant effects.
- Determine whether or not displacement from commercial scale wave and tidal arrays is ever likely to result in biologically significant effects.
- If necessary, develop a consistent approach to assessing/modelling any potential risk to populations from displacement from wave and tidal arrays.
- If necessary, develop an agreed approach on how to measure/detect displacement and potentially carry out some research/monitoring studies to ascertain what if any displacement occurs from array projects.

Monitoring should be focused on those species that are of key conservation interest identified as being potentially sensitive to potential impacts from wave or tidal developments to inform EIA/HRA. Bird monitoring

should focus on species identified by Furness *et al*. (2012) as being most vulnerable to wave and tidal devices i.e. high vulnerability or medium vulnerability species.

Note: results from monitoring studies and research in relation to other potential impacts e.g. noise, behaviour around devices, etc. will help to determine whether or not displacement occurs (refer to Project 1)

5.4.1 Workshop discussion summary

It was generally agreed that considering 'displacement' per se was too narrow an approach, given that there is some evidence emerging to suggest that animals may be attracted to feeding around wave and tidal devices e.g. Arctic terns foraging in [the] wake of wave devices. Hence reference to 'behavioural change' of animals was regarded as more inclusive, as it captures the possibility that 'reverse' displacement or attraction into an energy development site also occurs. The main difficulty with delivering a robust prediction on this aspect is generally the absence of good quality baseline data, and the absence of models to allow extrapolation to biologically significant population level effects i.e. adult survival, breeding success. Although it would always be preferable to design surveys which have the power to detect change, these are often prohibitive in terms of cost and timescales. It was noted that observations of behavioural change for some species is subject of active research projects in the offshore wind sector at present and preliminary results indicate the effect is temporary and confined to the construction phase of projects. Consequently it was generally agreed that whilst the development of predictive models progresses, communication and cross sectoral learning for the 'at risk' species is essential. Better use of existing monitoring data, including using outcomes from EMEC as a proxy array development site, needs to be encouraged - however, it may be difficult to separate disturbance from vessel movements at EMEC and thus we need to await the outcome of data analysis underway.

It was suggested at the workshop that a short review should be undertaken to establish whether work underway in the offshore wind ORJIP can be utilised for wave and tidal.

Note: Although behavioural change is of interest, it is not the key priority in terms of consenting risk.

5.5 Project 5 - Establishment of an acoustic 'evidence base' for operational wave and tidal devices and first arrays

5.5.1 Overview

Acoustic signature data from operational devices and first arrays could be used to increase understanding of potential array effects to inform EIA/HRA for commercial scale wave and tidal energy projects. This might be particularly valuable in assessing potential collision risk i.e. building an understanding of the ability of key species to detect and avoid tidal turbines.

5.5.2 Objective

To build and maintain an evidence base of acoustic monitoring data and any modelling results relating to operational wave and tidal devices and arrays to inform commercial scale EIA/HRA in particular, collision risk assessments and noise propagation modelling.

5.5.3 Outline scope of work

Wave and tidal developers are gathering acoustic data from test deployments around the world. Currently, there is limited available operational acoustic data to inform impact assessments and research into the potential impacts of underwater noise generated by wave and tidal projects on marine wildlife. Such data could also inform the development of noise propagation models which can help predict the potential impacts of underwater noise on marine wildlife.

It is proposed that the following is undertaken as part of this project:

- Collate available device specific acoustic signature data and results from relevant modelling studies and research including available ambient acoustic data
- Create a (or use an appropriate existing) shared platform providing access to collated available acoustic monitoring data. This platform could also provide access to ambient noise data for use in assessments and research.
- Maintain the database to ensure that all data and information is up to date; providing an ongoing resource for regulators, advisors, developers and researchers. This will build an evidence base which, along with the latest research findings around the possible effects of operational noise on marine wildlife, will help determine whether this potential issue should remain a focus for the wave and tidal sectors.
- This could be enhanced by a regular review of key datasets and information by an expert panel to ensure that the best possible information regarding operational noise and the possible effects on marine wildlife is available to inform assessments and research.

Note: The usefulness of this database will be dependent on the establishment of an agreed approach to measuring, analysing and reporting of ambient acoustic data and operational device acoustic data (refer to Section 3.3, Key Issue 1.1 and Key Issue 1.2).

5.5.4 Workshop discussion summary

Measuring and understanding underwater noise in relation to wave and tidal devices is not generally regarded as an issue which will inhibit the progress of deployment in either tidal or wave energy – although this depends partly on the assumption that drilling is the main method for fixation of piles. However, understanding operational noise at the scale of arrays is highly significant, as collision risk may depend at least partly on acoustic cues. Also at present, because of the technical difficulties of measuring noise at wave and tidal development sites, there is no standardised approach / method for measurement of noise or protocols for data handling / analysis. Theoretical modelling has potential to reduce costly field measurements, but current modelling approaches need experimental validation before they can be widely adopted. It was recognised that a major barrier to progress however, is the commercial sensitivities of developers and technology providers. It was suggested that perhaps technology providers could be asked to provide noise data for their operating devices - this would facilitate discussions with the regulator and reduce pressure on developers. Also if data collected at test sites could be made publically available, this aspect of scaling up to arrays would proceed much more rapidly, and from a position of collective engagement with the most recent information.

It was suggested during the workshop that the option for extending The Crown Estate Marine Data Exchange (MDE) to include the specific needs highlighted in these discussions should be explored going forward.

6 Annex A – Workshop Report

Workshop to discuss the 'Consolidation of wave and tidal EIA / HRA issues and research priorities' report by Aquatera Ltd.

13th November 2013

6.1 Background

A workshop to discuss the key strategic EIA/HRA issues and research needs for wave and tidal stream arrays, was recently arranged by NERC in conjunction with The Crown Estate, to potentially inform the development of a Wave and Tidal Offshore Renewables Joint Industry Programme (or similar).

In preparation for this event, The Crown Estate commissioned Aquatera Ltd. to produce a consolidated, up-to-date list identifying the key strategic EIA/HRA issues/uncertainties in the wave and tidal stream sectors, and the research priorities on which any Joint Industry Programme for wave and tidal should focus. Aquatera also identified potential approaches for filling the gaps by designing a series of research / monitoring projects which would directly address the current issues. The draft final report from this work was circulated to workshop attendees on the 5th November 2013 and used as a basis for workshops discussions.

The purpose of the workshop was threefold: to review the gap analysis and the priority projects identified in the draft Aquatera report; work towards a consensus across the organisations present on the key strategic EIA/HRA research priorities for demonstration arrays in the near term; add detail (and if necessary) suggest revisions to the proposed priority research projects.

Following the workshop, Aquatera updated and finalised the report. The final report – of which this workshop summary has been included as an annex – therefore reflects the workshop discussions.

6.2 Overview of the workshop agenda

The workshop involved the following activities:

1. **Industry presentations** – Joseph Kidd of Siemens and Marc Murray of Aquamarine –set the scene by providing perspectives from a tidal and wave developer respectively.
2. **Presentation of the results of the Aquatera review** – **Ian Hutchison –** which identified the key EIA/HRA issues, gap analysis, prioritisation of issues and research gaps.
3. **Session 1: group discussions to review the gap analysis and EIA/HRA priorities** – discussions led by six facilitators – with the objective of thoroughly reviewing the analysis, identifying gaps or inconsistencies in Aquatera report.
4. **Presentation of the proposed priority R&D projects – Ian Hutchison** – these were the projects to emerge from systematic analysis of the existing research landscape, as priorities for future R&D investment focused on EIA / HRA priorities.
5. **Session 2: group discussions re. the proposed priority strategic R&D projects** – led by seven facilitators – the purpose being to discuss the objectives of the projects and to add details/fill out the project scopes where possible (including e.g. possible methods / approaches (including alternative approaches), which organisations would need to be involved etc.).
6. **Discussion of potential UK and European funding opportunities** and actions arising from workshop – including specific funding calls, collaboration opportunities and advice on the processes necessary to optimise outcomes from funding sources / calls.

6.3 Workshop attendees

Representatives from the following stakeholder groups were invited to participate:

- wave and tidal developers with consented/planned first array development sites, together with their respective consultants,
- regulators and their SNCB advisors,
- research scientists actively involved in wave and tidal R&D,
- prospective partner organisations from European centres with complementary R&D needs.

A full list of participants appears in the Appendix 1.

6.4 Workshop outcomes

The complete notes of all discussions held during facilitated round table sessions are available in '**Workshop to discuss the consolidation of wave and tidal EIA / HRA issues and research priorities' *held at Edinburgh conference and training centre, on Nov 13th, 2013.'*** available as a separate document (see www.mrekep.net) and will serve as reference for the development of any future strategic wave and/or tidal R&D programme.

The following is a short synthesis of workshop discussions, with an overview of the main points to emerge and where appropriate, identification of further recommended actions.

(1)Session 1 discussions: Review of gap analysis and identification of priority issues for R&D

Discussions in all groups point to a general consensus that the Aquatera report was comprehensive, and that a systematic analysis of the research landscape allowed the correct priorities to be identified. The group identified some areas needing refinement/additional references. The draft report has therefore been updated to reflect these, mainly relating to tables 2.1 and 3.1. However, the following wider issues cropped up at several points during the workshop. Whilst they are not directly relevant to any strategic research programme created to tackle wave and tidal's priority R&D issues, they are of wider relevance and have therefore been included here for reference:

i. Data management and the means to share data / optimise use of existing data resources across different stakeholder organisations is one which attendees want to be addressed as a priority (n.b. any research projects initiated through any strategic, coordinated research programme would include wide data sharing, so this issue relates to use and sharing of data from existing/other sources). There was a general consensus that all possible means need to be implemented to promote data sharing whether through anonymising data sets or through proactive collation and curation of data by a designated agency. This is regarded as a very high priority activity still needed to facilitate acceleration of learning across the sector. In addition, development of improved skills and understanding in appropriate application of data and analytical tools is also needed in many organisations.

ii. Discussions also highlighted the inadequacy of current tools and methods for management of risk and uncertainty. There is generally a poor understanding of the processes of applying risk assessment, and

the difference between the perceived risk of an impact and the reality are often confused, as is the correct application of uncertainty analyses, statistical analytical tools and interpretation of results. It is clear that action to address this and drive up standards generally from regulator / SNCB and industry perspectives would be very welcome. This issue is beyond the focus of any strategic R&D programme which may be created, but is a relevant topic needing further consideration via other forums.

(2)Session 2 discussions: Synthesis of discussions regarding the priority R&D projects outlined in the draft Aquatera report

The following paragraphs précis the discussions in the session 2 groups, and draw out some of the essential points. In general attendees commented favourably on the scope of work for each of the projects presented in the Aquatera report, but agreed that the scopes would need to be reviewed and updated when a funding opportunity arose. High level actions arising from the discussions are noted at the end of each Workshop discussion.

(i) Project 1: Project 1 - Establishment of an 'acoustic database' for wave and tidal devices and first arrays – facilitated by Steve Robinson

Original proposed outline project (which was discussed at the workshop)

Overview

Acoustic signature data from operational devices and first arrays could be used to increase understanding of potential array effects, including informing noise propagation models, to inform EIA/HRA for commercial scale wave and tidal energy projects.

Objective

To build and maintain an evidence base of acoustic monitoring data and any modelling results relating to operational wave and tidal devices and arrays to inform commercial scale EIA/HRA.

Outline scope of work

Wave and tidal developers are gathering acoustic data from test deployments around the world. Currently, there is limited available operational acoustic data to inform impact assessments and research into the potential impacts of underwater noise generated by wave and tidal projects on marine wildlife. Such data could also inform the development of noise propagation models which can help predict the potential impacts of underwater noise on marine wildlife.

It is proposed that the following is undertaken as part of this project:

- Collate available device specific acoustic signature data and results from relevant modelling studies and research including available ambient acoustic data
- Create a (or use an appropriate existing) shared platform providing access to collated available acoustic monitoring data. This platform could also provide access to ambient noise data for use in assessments and research.
- Maintain the database to ensure that all data and information is up to date; providing an ongoing resource for regulators, advisors, developers and researchers. This will build an evidence base which, along with the latest research findings around the possible effects of operational noise on marine wildlife, will help determine whether this potential issue should remain a key consideration for the wave and tidal sectors.
- This could be enhanced by a regular review of key datasets and information by an expert panel to ensure that the best possible information regarding operational noise and the possible effects on marine wildlife is available to inform assessments and research.

Note: The usefulness of this database will be dependent on the establishment of an agreed approach to measuring, analysing and reporting of ambient acoustic data and operational device acoustic data (refer to Table 3.1, Key Issue 1.1 and Key Issue 1.2).

Workshop discussion

Measuring and understanding underwater noise in relation to wave and tidal devices is not generally regarded as an issue which will inhibit the progress of deployment in either tidal or wave energy – although this depends partly on the assumption that drilling is the main method for fixation of piles. However, understanding operational noise at the scale of arrays is highly significant, as collision risk may depend at least partly on acoustic cues. Also at present, because of the technical difficulties of measuring noise at wave and tidal development sites, there is no standardised approach / method for measurement of noise or protocols for data handling / analysis. Theoretical modelling has potential to reduce costly field measurements, but current modelling approaches need experimental validation before they can be widely adopted. It was recognised that a

major barrier to progress however, is the commercial sensitivities of developers and technology providers. It was suggested that perhaps technology providers could be asked to provide noise data for their operating devices - this would facilitate discussions with the regulator and reduce pressure on developers. Also if data collected at test sites could be made publically available, this aspect of scaling up to arrays would proceed much more rapidly, and from a position of collective engagement with the most recent information.

Action: it was suggested that the option for extending The Crown Estate Marine Data Exchange (MDE) to include the specific needs highlighted in these discussions should be explored going forward.

(ii)Project 2: Research and monitoring studies around single devices and first arrays to gather further information on the behaviour of marine mammals and basking sharks around operating tidal devices – facilitated by Ben Wilson

Original proposed outline project (which was discussed at the workshop)

Overview

Monitoring studies are required to build an evidence base to record the behaviour of marine mammals around operating tidal devices (particularly of tidal array projects) at different states of tide and during periods when devices are generating and during periods when devices are not generating.

Objective

To monitor the behaviour of marine mammals and basking sharks around operational tidal turbines to help inform collision risk assessments for tidal projects and to build an evidence base to help determine whether or not collision is likely to be an issue for marine mammals and basking sharks.

Outline scope of work

Monitoring and research of marine mammal and basking shark behaviour should be undertaken around operating tidal devices (particularly of first array demonstration tidal projects, and/or of single devices if necessary) to help:

- Determine the likelihood of collision / probability of occurrence
- Ascertain if there are any actual collisions with turbines
- Understand avoidance or attraction behaviour and ability to evade collisions
- Quantify avoidance rates for use in collision risk modelling

For this project to have strategic value, it is essential that data is gathered and reported in such a way that it helps build an evidence base that can inform commercial scale project EIA/HRA. Regular review of results as they become available will determine whether or not further monitoring is required.

Note: The first opportunities to monitor around early demonstration arrays in the UK will be; Sound of Islay, Inner Sound and Skerries (all consented projects but detail is yet to emerge about specifics of any monitoring plans). Other first array tidal projects in Europe should also be considered. Another option in the UK may be to use EMEC as a proxy for a demonstration scale tidal array, but this will depend on the level of operational activity at the test site and will need detailed consideration.

Workshop discussion

The central issue of concern remains – how do animals interact with wave and tidal devices? If they collide we need to understand the consequences at the population level – if they are able to detect and avoid them, we need to understand the consequences of displacement or disturbance of 'normal' activity. By scaling up from single devices to arrays of devices, the consequences of this interaction, which may be species specific and even device specific, may well be more complex. There was a high degree of consensus associated with the need for continuation of research on this aspect, with focus on species at risk, their responses in the field and consequences of interactions. Technology innovation and development has a major role to play in designing appropriate field experiments, possibly requiring a different approach to single device trials to date. Similarly, continuation of efforts to develop improved collision risk models for the 'at risk' species and at appropriate scales is also needed.

Action: a critique of the technologies suitable for monitoring mammal and basking shark behaviour around tidal devices needs to be commissioned, in addition to progressing actual research/monitoring work on this issue (see later, Project 5). A different approach may be required as result of scaling up from single devices to arrays.

(iii)Project 3: Research and monitoring studies around single devices and first arrays to gather further information on the behaviour of diving birds around operating tidal devices – facilitated by Beth Scott

Original proposed outline project (which was discussed at the workshop)

Objective

To monitor the behaviour of diving birds around operational tidal devices (particularly of tidal array projects) to help inform collision risk assessments for tidal projects and to build an evidence base to help determine whether or not collision is likely to be an issue for diving birds.

Outline scope of work

Bird monitoring should focus on species identified by Furness *et al*. (2012) as being most vulnerable to tidal devices i.e. high vulnerability species: black guillemot, razorbill, European shag, common guillemot, great cormorant and medium vulnerability species: great northern diver, red-throated diver, Atlantic puffin, black-throated diver, little auk.

Monitoring and research of diving bird behaviour should be undertaken around operating tidal devices (particularly of first array demonstration tidal projects, and/or single devices if necessary) to help:

- Determine the likelihood of collision / probability of occurrence
- Ascertain if there are any actual collisions with turbines
- Understand avoidance or attraction behaviour and ability to evade collisions
- Quantify avoidance rates for use in collision risk modelling

For this project to have strategic value, it is essential that data is gathered and reported in such a way that it helps build an evidence base that can inform commercial scale EIA/HRA. Regular review of results as they become available will determine whether or not further monitoring is required.

Note: The first opportunities to monitor around early demonstration arrays in the UK will be; Sound of Islay, Inner Sound and Skerries (all consented projects but detail is yet to emerge about specifics of any monitoring plans). Other first array tidal projects in Europe should also be considered. Another option in the UK may be to use EMEC as a proxy for a demonstration scale tidal array, but this will depend on the level of operational activity at the test site and will need detailed consideration.

Workshop discussion

The central issue for diving birds is how they interact with sub-sea and surface wave and tidal infrastructure, but generally the scope of the proposed project was thought to be too narrow – as the consequences of collisions, disturbance and displacement all need to be considered. Concerns were also expressed about the quality of baseline data, and the interpretation of potential population scale effects, particularly at sites where populations were known to be declining. The presence of tidal or wave energy development may in fact result in food resources recovering as a result of excluding other activities, with potential knock on beneficial effects for diving bird populations. However the possibility that this then exacerbates the potential for increased frequency of collisions with devices and possible mortality cannot be excluded. It was noted in these discussions that primary lab testing and modelling research involving the computational fluid dynamicists, and multi-technology field experiments, may help to establish whether diving birds are EVER actually likely to be struck by turbine blades, and may well provide answers more quickly and cost effectively than monitoring around devices. The critical nature of establishing baseline conditions through tagging / acoustic moorings pre installation of arrays was also emphasised as a significant factor in extracting useful outputs from the early demonstration array projects.

Action: It was suggested that the option for further primary research involving hydro-dynamicists and ornithologists in lab testing experiments should be explored, to attempt to establish whether diving birds are EVER likely to be struck by turbine blades. Ideally this work should be progressed in tandem with multi-technology monitoring at a tidal array deployment, as it has the potential to accelerate our understanding of interaction between diving birds and tidal devices.

(iv) Project 4: Research and monitoring studies around single devices and first arrays to gather further information on the behaviour of fish around operating tidal devices – facilitated by John Armstrong

Original proposed outline project (which was discussed at the workshop)

Objective

Monitoring the behaviour of fish around operational tidal devices (particularly tidal array projects) will help inform collision risk assessments for tidal projects and to build an evidence base to help determine whether or not collision risk is likely to be an issue for fish.

Note: basking sharks are included along with marine mammals in Project 2

Outline scope of work

Monitoring and research of fish behaviour should be undertaken around operating tidal devices (particularly of first array demonstration tidal projects, and/or of single devices if necessary) to help:

- Determine the likelihood of collision / probability of occurrence
- Ascertain if there are any actual collisions with turbines
- Understand avoidance or attraction behaviour and ability to evade collisions
- Quantify avoidance rates for use in collision risk modelling

The extent to which devices, moorings and inter-array areas may act as fish aggregation devices and therefore increase potential for collision risk for predatory species such as marine mammals and birds is also uncertain. Direct observations could therefore also be used to investigate whether there is evidence of attraction of fish species into the vicinity of tidal devices and how this varies temporally and with respect to state of tide.

For this project to have strategic value, it is essential that data is gathered and reported in such a way that it helps build an evidence base that can inform commercial scale EIA/HRA. Regular review of results as they become available will determine whether or not further monitoring is required.

Note: The first opportunities to monitor around early demonstration arrays in the UK will be; Sound of Islay, Inner Sound and Skerries (all consented projects but detail is yet to emerge about specifics of any monitoring plans). Other first array tidal projects in Europe should also be considered. Another option in the UK may be to use EMEC as a proxy for a demonstration scale tidal array, but this will depend on the level of operational activity at the test site and will need detailed consideration.

Workshop discussion

At present this is regarded as an issue of concern especially for salmon and predominantly in Scotland, where it is possible that tidal array sites in development are located at or near to migratory routes of adult salmon. To date there have been no field experiments to establish whether salmon can avoid a single device or to what extent fish which are struck are irreversibly damaged. Acoustic tagging of salmon combined with underwater camera systems and use of flotation devices to recover fish to assess damage, have potential to yield the necessary outcomes – however, at present there does not appear to be a field site in development where trials could be initiated. In the mean time learning from modelling is likely to be the most useful approach, or alternatively, freshwater / estuarine systems with a large natural run of salmon may provide useful information on behaviour interactions with devices.

Action: It was suggested that the potential to learn from proxy sites such as estuarine / FW systems with large natural run of salmon should be explored in more detail, in addition to any opportunities arising at appropriate tidal projects.

(v)Project 5: Further development of suitable instrumentation and methodologies for monitoring wildlife behaviour around tidal devices and arrays and for detection of any collision events – facilitated by Paul Bell

Original proposed outline project (which was discussed at the workshop)

Overview

The development and success of a 'deploy and monitor' approach to early deployments of wet renewables will require (and benefit from) the ability of technologies to accurately detect and identify wildlife in the vicinity of operating devices, monitor behaviour around devices and detect and record any collision events.

Objective

To support the development of technologies and agreed approaches for monitoring detection and identification of wildlife, and their behaviour, interaction and collision risk with devices and support structures in high energy environments to inform EIA/HRA.

Outline scope of work

It is recommended that the following tasks are undertaken as part of this research project:

- Investigation/study into the suitability (quality, reliability, etc) of existing technology.
- Development/trialling of suitable cost-effective instruments and methodologies for use in high tidal energy environments to monitor wildlife behaviour. Differentiation to species level may be required to inform EIA/HRA. This may be challenging for non-vocalising species.
- Development/trialling of suitable cost-effective instruments and methodologies for use in high tidal energy environments to detect and quantify incidence of collisions during operation of single test devices. Differentiation to species level may be required to inform EIA/HRA. This may be challenging for non-vocalising species.
- Explore use of EMEC and other test sites to trial instruments and methodologies to inform design improvements and cost reductions.

This project may require an integrated approach involving a number of organisations and utilising a number of different technologies running in parallel; e.g. development of acoustic tag technology, active sonar automatic detection/tracking ability, development of automated 3D PAM tracking, development of collision detection technology. Consideration should be given to how best to integrate instruments into infrastructure (including power and communication systems) provided by devices and support structures.

Workshop discussion

Despite the rapid pace of technology innovation and development it was recognised that deployment of combinations of existing technologies (active / passive acoustics, sonar, radar etc.) are likely to result in much more significant progress, than attempts to innovate from scratch. In addition, use of systems which have already been developed has not been exploited optimally because of lack of funding and this particularly applies to the ReDAPT (now EMEC) pod. Nevertheless, there are significant challenges regarding use of existing technology which currently undermine our ability to monitor at the scale of arrays, and over timescales needed to obtain useful data. Hence, powering up, marinisation and ease of deployment / recovery are all considerations, which need to be urgently addressed, as is the potential to deploy monitoring technology in tandem with devices / foundations. It is also clear that some of the existing technologies do not collect data at appropriate spatial scales to be of use, and development of appropriate software / data transfer systems often lags behind the development of the hardware. Development of GPS tagging technology has proceeded apace and there is much to gain from use of telemetry and tagging at array deployment sites.

Action: The main conclusion to emerge from these discussions was the need to commission a critique of existing technologies suitable for monitoring, combined with an analysis of the specific development / innovation needs to allowing detection and monitoring at the scale of arrays.

(vi)Project 6: Development of an agreed approach to assessing the potential effects of displacement from wave and tidal arrays **– facilitated by John Harwood**

Original proposed outline project (which was discussed at the workshop)

Overview

At present, wave and tidal developers are required to consider the potential effects of displacement on marine birds and mammals in relation to first arrays. It is essential at this time, to consider whether or not displacement from wave and tidal arrays is ever likely to result in a biologically significant population effect and if determined necessary, carry out further research/monitoring to ascertain any actual displacement effects from operating array projects.

Objective

To determine whether or not displacement is an issue for the wave and tidal sectors and to establish an agreed approach to assessing the potential effects of displacement in project EIA/HRA.

Scope of work

- Undertake a review of findings of research into displacement and any potential population level effects of other sectors, including but not limited to offshore wind.
- Determine whether or not displacement from demonstration scale wave and tidal arrays is ever likely to result in biologically significant effects.
- Determine whether or not displacement from commercial scale wave and tidal arrays is ever likely to result in biologically significant effects.
- If necessary, develop a consistent approach to assessing/modelling any potential risk to populations from displacement from wave and tidal arrays.
- If necessary, develop an agreed approach on how to measure/detect displacementand potentially carry out some research/monitoring studies to ascertain what if any displacement occurs from array projects.

Note: results from monitoring studies and research in relation to other potential impacts e.g. noise, behaviour around devices will help to determine whether or not displacement occurs.

Workshop discussion

It was generally agreed that considering 'displacement' *per se* was too narrow an approach, given that there is some evidence emerging to suggest that animals may be attracted to feeding around wave and tidal devices. E.g. Arctic terns foraging in wake of wave devices. Hence reference to 'behavioural change' of animals was regarded as more inclusive, as it captures the possibility that 'reverse' displacement or attraction into an energy development site also occurs. The main difficulty with delivering a robust prediction on this aspect is generally the absence of good quality baseline data, and the absence of models to allow extrapolation to biologically significant population level effects i.e. adult survival, breeding success. Although it would always be preferable to design surveys which have the power to detect change, these are often prohibitive in terms of cost and timescales. It was noted that observations of behavioural change for some species is subject of active research

projects in the offshore wind sector at present and preliminary results indicate the effect is temporary and confined to the construction phase of projects. Consequently it was generally agreed that whilst the development of predictive models progresses, communication and cross sectoral learning for the 'at risk' species is essential. Better use of existing monitoring data, including using outcomes from EMEC as a proxy array development site, needs to be encouraged - however, it may be difficult to separate disturbance from vessel movements at EMEC and thus we need to await the outcome of data analysis underway.

Action Undertake a short review to establish whether work underway in the offshore wind ORJIP can be utilised for wave and tidal.

(vii)Project 7: Socio-economic impacts of wave and tidal energy development – facilitated by Toby Gethin

This aspect was not identified as a high priority R&D issue in the draft Aquatera report, but it was raised in workshop session 1 and therefore an additional table was created to discuss the topic. The resulting discussion resulted in agreement that the main area to focus on is the social aspect, since the economic aspect is being well covered by existing work. It was recognised that potential social impact may be limited given the current scale of wave and tidal development, but with projects often located in remote communities, there is the potential for social impacts to be proportionally greater. This highlights the need to identify improved mitigation strategies at an early stage, whilst also encouraging research which captures the potential benefits for affected communities. It was agreed that the topic was not currently a priority research project for any strategic R&D programme. Consequently a 'watching brief' needs to be maintained on the existing research landscape, and outputs / case studies shared as widely as possible. Marine (and terrestrial) spatial planning was also identified as one potentially suitable route for further investigation of social impacts arising from wave and tidal development.

(viii)General conclusions and specific actions

The most significant conclusion to emerge from the workshop after a full day of discussions was the degree to which a consensus had been achieved, across all the organisations represented at the workshop regarding the highest priority EIA / HRA issues. This was mainly because of the very thorough and systematic approach adopted by Aquatera to produce the gap analysis, and subsequent identification of R&D priorities. This provided a very solid basis on which discussions at the workshop could progress.

It also became clear the extent to which the proposed R&D projects were interdependent, and that cost and efficiency benefits could be achieved from designing a coordinated and fully integrated programme, focused on the first array deployments. In addition, in order to maximise production of useful information which will move industry forward it is clear that:

i. a plan which secures the necessary funding for a strategic, coordinated research programme covering the pre installation / operational / post deployment period (i.e. about five years) will be essential and
ii. involvement in the programme will need to predicated on the basis that participating organisations agree to share data, and so measures which allow data sharing, and optimise the flow of information between all parties will be required.

Finally, although it was recognised that any future strategic R&D programme will need to be carefully scoped to reflect the fast moving R&D landscape, a step change in learning from the deployment of the first arrays will only be realised if organisations represented at the workshop proactively seek out funding to undertake the essential R&D. A robust justification for investment in R&D which deepens and broadens our understanding, and delivers greater confidence to investors, regulators and their advisors, is essential to securing the future of the industry.

APPENDIX 1: Attendee List

Facilitators of discussion group sessions are indicated in **bold text**:

Organisation	Name	Surname
Marine Scotland	**John**	**Armstrong**
NERC	Eleanor	Ashton
Open Hydro	Sue	Barr
NOC	Paul	Bell
Marine Scotland	**Finlay**	**Bennet**
SMRU	Cormac	Booth
The Crown Estate	Annie	Breaden
Pelamis	Laura	Carse
Natural England	Victoria	Copley
The Crown Estate	**Mike**	**Cowling**
Scottish Environment Link	Sarah	Dolman
ERI, UHI	Jeremy	Evans
Univ. Edinburgh (EERA)	Laura	Finlay
Royal Haskoning	Frank	Fortune
Xodus	Liz	Foubister
The Crown Estate	**Toby**	**Gethin**
Aquatera	Jude	Hamilton
Univ. St Andrews	**John**	**Harwood**
Univ. St Andrews	Gordon	Hastie
Defra	Debbie	Hembury
MMO	**Ross**	**Hodson**
Aquatera	Ian	Hutchinson
MCT	Joseph	Kidd
SNH	George	Lees
Univ. Loughborough	Paul	Lepper
NERC	Annie	Linley
MAREMAP	Fraser	Macdonald
ORE Catapult	Andy	Macdonald
LCRI	**Ian**	**Masters**
Marine Scotland	Roger	May
Scottish Environment Link	Aly	McCluskie
The Carbon Trust	Kate	McWilliam
REA	Stephanie	Merry
Aquamarine Power Ltd	Marc	Murray
EMEC	Jenny	Norris
CEFAS	Jon	Rees
The Carbon Trust	Emilie	Reeve
NPL	**Stephen**	**Robinson**
Meygen	Ed	Rollings
Univ. Aberdeen	**Beth**	**Scott**
ScottishPower Renewables	Kirstie	Shearer
NRW Advisory	Kate	Smith
Univ. Exeter	Helen	Smith
SMRU	Carol	Sparling
ScottishPower Renewables	Douglas	Watson
SAMS	**Ben**	**Wilson**
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