Ocean Energy

working to accelerate offshore consenting

ORJIP Ocean Energy

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Wave and Tidal Stream Critical Evidence Needs

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MarineSpace Making Sense of the Marine Environment™

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EXECUTIVE SUMMARY

The Offshore Renewables Joint industry Programme Ocean Energy (ORJIP Ocean Energy) is a UK-wide collaborative programme of environmental research with the aim of reducing consenting risks for wave, tidal stream and tidal range projects. The programme brings together industry, regulatory and advisory bodies, academia, and other key stakeholders to identify and address critical evidence gaps for the principal Environmental Impact Assessment (EIA) and Habitats Regulations Assessment (HRA) consenting risks for the wave and tidal sectors.

The ORJIP Ocean Energy Forward Look provides a list of outline project plans for research projects to address key EIA/HRA issues based around a series of prioritised consenting issues for the wave and tidal stream sectors. These consenting issues were identified and agreed in a gap analysis process carried out by industry, regulators, and other key stakeholders.

This Wave and Tidal Stream Critical Evidence Needs document has been aligned with the State of the Science 2020 report, which is produced under the Ocean Energy Systems (OES) Environmental initiative of 15 countries. These countries collaborate to evaluate scientific evidence on the potential environmental effects of marine renewable energy development, to assist with permitting, and allow increased and responsible deployment of devices. The State of the Science 2020 comprehensively reviews the scientific evidence derived from multiple field, laboratory, and modelling studies conducted around the world. It presents the best available scientific evidence on the potential environmental effects of marine renewable energy development.

This document complements and builds on the Forward Look and the growing body of evidence, knowledge and experience of wave and tidal stream consenting both in the UK and globally. It sets out the critical outstanding evidence needs for wave and tidal stream energy in the UK, grouped into ten strategic topics (see Section 3). The ten topics provide an overall perspective on research priorities and their importance for effective decision-making, by linking research needs to the practical application of outputs, to enable:

1. Sectoral planning that is underpinned by best available science and evidence-based impact assessments (environmental, climate change, social and economic assessments).
2. Pre-application development activity (including project planning and design, and baseline characterisation), that identifies and minimises negative impacts (to de-risk consenting) and maximises the benefits of development.
3. Consenting processes and decisions that are well-informed, evidence-based, proportionate and effective.
4. Post-consent activity (including environmental monitoring and management) that is realistic, effective and appropriately targeted.

The critical evidence needs are organised into ten strategic topics, as follows:

1. Methods and instruments to measure mobile species occupancy and behaviour in high energy environments and around marine energy devices.
2. Near-field interactions between mobile species and tidal stream turbines.
3. Occupancy patterns, fine-scale distribution and behaviour of mobile species in wave and tidal stream habitats.
4. Far-field responses of mobile species to wave and tidal stream devices and arrays.

5. Subsea acoustic profiles of wave and tidal stream sites and technologies.
6. Tools for assessing and managing risk to mobile species populations for large-scale wave and tidal stream development.
7. Tools for assessing effects of large-scale wave and tidal stream developments on physical processes.
8. Tools for assessing social and economic impacts of wave and tidal stream developments.
9. Tools for assessing climate change impacts of wave and tidal stream developments.
10. Tools and guidance for managing risk and uncertainty during the preparation of project environmental monitoring plans (PEMPs)

PRIORITY ACTIONS

STRATEGIC TOPICS	PRIORITY ACTIONS

1. Methods and instruments to measure mobile species occupancy and behaviour in high energy environments and around marine energy devices.	• Development of instrumentation to measure/determine:
	  ○ Distribution and individual behaviour around tidal stream turbines (including near-field responses).
	  ○ Collision events or avoidance of tidal stream turbines.
	  ○ Consequences of collisions.
	• Cooperation between regulatory bodies, industry and researchers to agree on a preferred suite of instruments and platforms to accelerate data collection and facilitate national and international cooperation on the development of an improved evidence base.
	• Improvement of the reliability and survivability of instruments in high energy waters, to address challenges including:
	  ○ Hydrodynamic forcing.
	  ○ Corrosion and biofouling.
	  ○ Pressure and sealing.
	• Development of solutions to reduce electronic interference between instruments on platforms.
	• Development of solutions to improve efficiencies in storing, processing and analysing large amounts of data generated by monitoring, including improved integration of algorithms and machine learning to recognise images of marine animals around turbines to reduce processing of large quantities of data generated by monitoring programmes.
	• Development of reliable approaches to powering monitoring equipment to achieve a balance between conserving power and carrying out observations over long periods of time (due to the rare probability of interactions).

2. Near-field interactions between mobile species and tidal stream turbines.	• Further monitoring around operational tidal stream turbines to describe the occurrence and behaviour of marine mammals, fish and diving birds at close range to devices (1–10s of metres).
	• Quantification of near-field responses (evasion) of marine mammals, fish and diving birds to devices.
	• Further research to understand the potential consequences of blade strikes and collisions including:
	  ○ Lethal effects.
	  ○ Occurrence and nature of the injuries.
	• Links between injury and an individual's ability to survive and reproduce.
	• Cooperation between government, regulatory bodies, industry and researchers to agree on a collaborative approach to gathering and sharing information on measurements of animal interactions with devices.

3. Occupancy patterns, fine-scale distribution and behaviour of mobile species in wave and tidal stream habitats.	• Further characterisation of marine mammal, seabird occupancy patterns and behaviour in marine energy sites including habitat use in relation to hydrodynamic features and conditions, to understand the likely degree of spatial and temporal overlap with deployed devices and arrays. • Baseline fish distribution to determine which species are in vicinity of potential tidal energy sites.
4. Far-field responses of mobile species to wave and tidal stream devices and arrays.	• Development of methods to relate specific marine animal behavioural responses to the range of frequencies and sound levels from single wave and tidal stream devices, or the physical presence of devices. • Development of a framework for studying the behavioural consequences of radiated noise from wave and tidal stream devices, to move beyond using audibility as a proxy for behavioural response.
5. Subsea acoustic profiles of wave and tidal stream sites and technologies.	• Further development of instrumentation to accurately measure the noise from a range of wave and tidal stream device types and distinguish from ambient noise. • Further measurements of radiated noise generated by a range of operational wave and tidal stream devices, distinguished from ambient noise, in particular across sound frequencies within the hearing range of sensitive marine animals. • Measurement of radiated noise around early arrays of wave and tidal stream devices.
6. Tools for assessing and managing risk to mobile species populations for large-scale wave and tidal stream development.	• Validation/revision of collision risk predictive models using empirical data and field measurements. • Development of models or frameworks for translating individual collision risk to population level risk, and to scale collision risk from single tidal stream turbine to arrays. • Development of models or frameworks to predict how the underwater noise from larger arrays of devices may affect marine animals.

7. Tools for assessing effects of large-scale wave and tidal stream developments on physical processes.	• Validation of predictive models for large-scale energy extraction, using empirical data and field measurements of high-resolution bathymetry and flow. • Field measurements before and after deployments of large arrays to validate oceanographic models (note there is limited value in gathering data from small-scale arrays). • Improved parameterisation of wave and tidal stream devices to represent specific designs at specific locations, to accurately model the effects they may have on oceanographic systems. • Research to connect physical change with its ecological implications for specific species and habitats, so that any change described by model results can be translated to real-world implications.
8. Tools for assessing social and economic impacts of wave and tidal stream developments.	• Development of tools and databases to classify key social and economic indicators. • Identification of key questions and data needs to guide data collection efforts. • Development of incentives to collect and share MRE data across the MRE industry. • Creation of flexible planning approaches to address uncertainty as projects move forward and learning increases. Appropriately scale MRE project impacts and data collection efforts to avoid unnecessary requirements for data and mitigation.
9. Tools for assessing climate change impacts of wave and tidal stream developments.	• Development of tools and databases to classify key climate change and carbon reduction indicators. • Identification of key questions and data needs to guide data collection efforts. • Development of incentives to collect and share MRE data across the MRE industry.
10. Tools and guidance for managing risk and uncertainty during the preparation of PEMPs	• Further development of Environmental Risk Management Measures Toolbox (OES Environmental and ORJIP Ocean Energy). • Undertake a comprehensive review of the approach taken to developing PEMPs and adaptive management strategies in the wave and tidal sector to date. • Produce guidance on how PEMPs can be best developed in the future, drawing on experience from other sectors where relevant. • Determine the transferability of data and experience regarding the applicability and effectiveness of management and mitigation measures applied to date.

Contents

1 INTRODUCTION

1.1 ORJIP OCEAN ENERGY AND THE FORWARD LOOK

The Offshore Renewables Joint industry Programme Ocean Energy (ORJIP Ocean Energy) is a UK-wide collaborative programme of environmental research with the aim of reducing consenting risks for wave, tidal stream and tidal range projects. The programme brings together industry, regulatory and advisory bodies, academia, and other key stakeholders to identify and address critical evidence gaps for the principal Environmental Impact Assessment (EIA) and Habitats Regulations Assessment (HRA) consenting risks for the wave and tidal sectors.

The ORJIP Ocean Energy Forward Look provides a list of outline project plans for research projects to address key EIA/HRA issues based around a series of prioritised consenting issues for the wave and tidal stream sectors. These consenting issues were identified and agreed in a gap analysis process carried out by industry, regulators, and other key stakeholders.

1.2 SCOPE AND PURPOSE OF DOCUMENT

This ORJIP Ocean Energy 'Wave and Tidal Stream Critical Evidence Needs' document has been produced to further refine the information in the Forward Look to take account of:

1. The increased body of evidence on the environmental effects of wave and tidal stream energy devices collated since the last issue of the Forward Look (2017).
2. Increased knowledge gained through recent experience of consenting wave and tidal stream projects in the UK, in particular understanding of those issues and evidence gaps that have exerted significant influence on decision-making and consenting outcomes.
3. Changes in the marine energy planning and consenting policy landscape and the growing need for decision-making to be informed by climate change, social and economic impact assessments.
4. Feedback from end-users of the Forward Look on its usefulness, format, accessibility, and functionality.

This document complements and builds on the Forward Look and the growing body of evidence, knowledge and experience of wave and tidal stream consenting both in the UK and globally. It sets out the critical outstanding evidence needs for wave and tidal stream energy in the UK, grouped into ten strategic topics (see Section 3). The ten topics provide an overall perspective on research priorities and their importance for effective decision-making, by linking research needs to the practical application of outputs, to enable:

1. Sectoral planning that is underpinned by best available science and evidence-based impact assessments (environmental, climate change, social and economic assessments).
2. Pre-application development activity (including project planning and design, and baseline characterisation), that identifies and minimises negative impacts (to de-risk consenting) and maximises the benefits of development.
3. Consenting processes and decisions that are well-informed, evidence-based, proportionate and effective.
4. Post-consent activity (including environmental monitoring and management) that is realistic, effective and appropriately targeted.

This document does not replace the Forward Look but sets out the key outstanding evidence needs in a succinct, focussed and user-friendly format that makes clear links between the evidence needs and their practical application to consenting and decision-making for wave and tidal stream energy. It signposts to information in the Forward Look but functions as a standalone document. Critical evidence needs for the tidal range sector have not been reviewed in this document, since the information in the Forward Look remains valid for this sector and its current status.

Four cross-cutting themes have also been identified, which further seek to ensure that any research to address the ten critical evidence needs delivers solutions-orientated outputs with high practical impact for more effective decision-making. These themes should be integrated into the development of research proposals (see Section 2).

The critical evidence needs identified in this document do not replace the requirement for project and site-specific data collection where this is needed to inform consent applications and decisions. However, even robust baseline environmental information cannot comprehensively address all pre-deployment evidence gaps. Addressing the identified critical needs will ensure that project-level evidence requirements for wave and tidal stream developments are appropriate and proportionate, recognising that some issues and evidence gaps can only be addressed with confidence through strategic research.

1.3 RELATIONSHIP WITH THE STATE OF THE SCIENCE 2020 REPORT

This document has been aligned with the State of the Science 2020 report, produced under the Ocean Energy Systems (OES) Environmental initiative of 15 countries that collaborate to evaluate scientific evidence on the potential environmental effects of marine renewable energy development, to assist with permitting, and allow increased and responsible deployment of devices. The State of the Science 2020 comprehensively reviews the scientific evidence derived from multiple field, laboratory, and modelling studies conducted around the world. It presents the best available scientific evidence on the potential environmental effects of marine renewable energy development.

The State of the Science 2020 has been fully taken into account in identifying the remaining critical evidence needs for wave and tidal stream energy in the UK set out in this document. Signposting to relevant information on each of the ten topics in the State of the Science 2020 is provided, along with an overview of the current status of key relevant knowledge, also derived from the State of the Science 2020. For each of the ten critical outstanding evidence needs, priority actions have been identified, based on key recommendations in the State of the Science 2020 to guide how the level of risk for each interaction might be further understood and lowered.

1.4 STRUCTURE AND CONTENT OF DOCUMENT

Table 1.1 details the structure of this document, including the wave and tidal stream critical evidence needs and cross-cutting themes. Details of how links are provided to the ORJIP Forward Look strategic consenting issues and outline project plans, as well as key evidence in the OES-Environmental State of the Science 2020 report are summarised.

Table 1.1 Structure and content of ORJIP Ocean Energy Critical Evidence Needs document

Content	Further detail and document signposting
Cross-cutting themes	○ Series of themes or principles aimed at ensuring research is solutions-orientated and delivers outputs that have high practical impact for more effective decision-making. ○ The cross-cutting themes are detailed in Section 2 of this document. ○ The cross-cutting themes have been integrated into the critical evidence needs tables in Section 3.
Critical evidence needs	○ Detail the outstanding critical evidence requirements for wave and tidal stream energy in the UK, grouped into ten strategic topics. ○ The critical evidence needs are detailed in a series of tables in Section 3.
Links to State of the Science 2020 report	○ Signposting to key relevant information in the State of the Science 2020 is provided in the critical evidence needs tables in Section 3. ○ Overviews of the current status of key relevant knowledge on each of the strategic topics, based on information in the State of the Science 2020 are provided in the critical evidence needs tables in Section 3.

Content	Further detail and document signposting
	○ Priority actions to address the evidence needs, based on recommendations in the State of the Science 2020 are highlighted in tables in Section 3.
Links to Forward Look key consenting issues	○ The relationship between the critical evidence needs and the key consenting issues in the Forward Look are provided in Appendix A of this document.
Links to Forward Look pre-scoped projects	○ The relationship between the critical evidence needs and the pre-scoped research projects in the Forward Look are provided in Appendix A of this document.

2 CROSS-CUTTING THEMES

A series of cross-cutting themes have been identified, that seek to ensure that any research to address the ten critical evidence needs identified in Section 3 delivers solutions-orientated outputs with high practical impact for more effective decision-making by Consenting Authorities. Opportunities should be sought to integrate these cross-cutting themes into research proposals.

Some consideration of the themes has been integrated into the critical evidence needs tables in Section 3, but further opportunities should be explored in the development of research proposals. The cross-cutting themes and some explanatory notes are detailed in Table 2.1.

Table 2.1 ORJIP OE cross-cutting themes

Cross-cutting theme	Detail
Better use of existing and new data	○ Optimise the value of research and environmental monitoring data and information to address critical evidence needs and support evidence-based management of the UK's marine energy resources. ○ Make better, more strategic use of data and information gathered from research projects, monitoring studies, and operational wave and tidal stream projects through meta-analysis, replication or building on existing information.
Sharing, dissemination and accessibility	○ Translate research outputs into problem-solving and consenting solutions (guidance, tools, protocols, etc). ○ Develop measures to overcome barriers to industry data sharing (e.g. Intellectual Property Rights, Commercial Confidentiality issues). ○ Ensure results and outputs are widely accessible to marine energy stakeholders.
Transferability, acceptance and uptake	○ Understand the transferability of key evidence, knowledge and information e.g. to other jurisdictions, locations, projects, technologies. ○ Work with stakeholders to ensure that the information and tools produced are used and embedded into guidance, regulations and decision-making. ○ Provide confidence to regulatory bodies in the results and outputs so they become an accepted and established part of the evidence base for decision-making.
Risk management	○ Produce solutions-focused outputs that help manage environmental risk proportionately and cost-effectively. ○ Identify opportunities to add value by gathering information and data or carrying out analyses of existing data to de-risk future up-scaling of the sector (larger projects, development clusters).

3 CRITICAL EVIDENCE NEEDS

The critical evidence needs presented in this section are organised into ten strategic topics, as follows:

1. Methods and instruments to measure mobile species occupancy and behaviour in high energy environments and around marine energy devices.
2. Near-field interactions between mobile species and tidal stream turbines.
3. Occupancy patterns, fine-scale distribution and behaviour of mobile species in wave and tidal stream habitats.
4. Far-field responses of mobile species to wave and tidal stream devices and arrays.
5. Subsea acoustic profiles of wave and tidal stream sites and technologies.
6. Tools for assessing and managing risk to mobile species populations for large-scale wave and tidal stream development.
7. Tools for assessing effects of large-scale wave and tidal stream developments on physical processes.
8. Tools for assessing social and economic impacts of wave and tidal stream developments.
9. Tools for assessing climate change impacts of wave and tidal stream developments.
10. Tools and guidance for managing risk and uncertainty during the preparation of PEMPs

For each of the ten topics, information is provided to facilitate research that is solutions-orientated with outputs that translate into knowledge for sectoral planning, consenting and risk management for industry, regulators, advisory bodies and other key stakeholders. This information for each topic is presented in the tabulated format set out in Table 3.1.

Table 3.1 Format for ORJIP Ocean Energy Critical Evidence Needs tables

Key research objectives	Solutions-focused research objectives, to ensure outputs translate into knowledge for effective decision-making.
Research focus	The priority receptors, theme or spatial focus of research (as appropriate).
Critical research outputs	Key deliverables and assimilated research outputs to deliver outputs that have high practical impact.
Practical application of outputs	Details how outputs will be used to improve strategic planning, consenting or post-consent commitments for wave and tidal projects.
Key evidence in State of the Science 2020	Signposting to key chapters of relevance to the topic in the State of the Science 2020 report.
Overview of knowledge status	Provides an overview of key evidence and knowledge of relevance to the topic, as set out in detail in the State of the Science 2020 report.
Priority actions	Details of the most critical actions of relevance to the topic, to help focus future funding and/or research activity.

3.1 METHODS AND INSTRUMENTS TO MEASURE MOBILE SPECIES OCCUPANCY AND BEHAVIOUR IN HIGH ENERGY ENVIRONMENTS AND AROUND MARINE ENERGY DEVICES

Key research objectives	Further development of methods, approaches and instruments to gather information on the occupancy patterns, fine-scale distribution and behaviour of mobile species in wave and tidal stream energy habitats.
	Further development of fit-for-purpose and reliable instrumentation for gathering data on the frequency, nature and consequences of near-field interactions between mobile species and tidal turbines.
	Further development of methods to store, share, and analyse data on interactions between mobile species and tidal turbines, including tools to streamline processing and management of data.
Research focus	Protected marine mammals, diving birds and migratory fish remain the priority taxa for research in this area in the UK.
	Developing methods and instruments to monitor near-field interactions between tidal stream turbines and mobile species is the current priority in the UK.
	Research should focus on the refinement of methods for gathering information on the occupancy patterns, fine-scale distribution and behaviour of mobile species in wave and tidal stream energy habitats to improve understanding for, and assessments of, impact risk and enable well-informed consent decisions.
	Research should focus on the further development of instrumentation and monitoring platforms that ensure information on near-field interactions between mobile species and tidal turbines can be gathered reliably and cost-effectively.
	Research should focus on developing solutions to the technical issues and challenges associated with gathering information on mobile species in high energy habitats and around tidal turbines.
	Research should focus on solutions to improve efficiencies in processing and management of data on interactions between mobile species and tidal turbines. In particular, integration of algorithms and machine learning to recognise video and acoustic images of marine animals around turbines to reduce processing of large quantities of data generated by monitoring programmes is required.
Critical research outputs	Guidance and protocols for cost-effective gathering of information on the occupancy, fine-scale distribution and behaviour of mobile species in wave and tidal stream energy habitats to enable more accurate assessments of impact risk.
	Fit for purpose, reliable and cost-effective instrumentation for detecting potential collision and/or avoidance events and to monitor wildlife interactions (e.g. trajectory, predator-prey interactions) with tidal turbines and arrays.
	Practical solutions to the technical issues and challenges associated with gathering information on mobile species in high energy habitats and around tidal turbines.
	Practical solutions to deliver efficiencies in processing and management of data gathered on interactions between mobile species and tidal turbines.
Practical application of outputs	More reliable and cost-effective methods to gathering field data in wave and tidal stream habitats to inform impact predictions for mobile species at a strategic level and in EIA and HRA.
	Development of consistent approaches to gathering field data to inform impact predictions for mobile species, to maximise transferability and strategic application of data.
	More reliable and cost-effective methods to gathering field data on interactions between mobile species and tidal turbines, to inform the development of project environmental monitoring plans.
	Improved efficiencies in processing and management of data on interactions between mobile species and tidal turbines, with reduction in data mortgages and accelerated reporting and use of data in refining understanding for collision risk.

Key evidence in State of the Science 2020	• Collision Risk for Animals around Turbines (Chapter 3) and Short Science Summary. • Environmental Monitoring Technologies and Techniques for Detecting Interactions of Marine Animals with Turbines (Chapter 10) and Short Science Summary. • Summary and Path Forward (Chapter 14) and Short Science Summary.

Overview of knowledge status	• The following instrumentation has been used successfully to measure animal interactions with devices at various locations globally:
	  ○ Passive acoustic instruments (hydrophones, sound traps and recorders).
	  ○ Active acoustic instruments (e.g. sonars, echosounders, acoustic cameras).
	  ○ Optical cameras (stills and video).
	• A number of combined instrument platforms have also been developed, or are under development, that can be fixed on the seabed or moved through the water to measure animal interactions with devices.

Priority actions	• Development of instrumentation to measure/determine:
	  ○ Distribution and individual behaviour around tidal stream turbine (including near-field responses).
	  ○ Collision events or avoidance of tidal stream turbines.
	  ○ Consequences of collisions.
	• Cooperation between regulatory bodies, industry and researchers to agree on a preferred suite of instruments and platforms to accelerate data collection and facilitate national and international cooperation on the development of an improved evidence base.
	• Improvement of the reliability and survivability of instruments in high energy waters, to address challenges including:
	  ○ Hydrodynamic forcing.
	  ○ Corrosion and biofouling.
	  ○ Pressure and sealing.
	• Development of solutions to reduce electronic interference between instruments on platforms.
	• Development of solutions to improve efficiencies in storing, processing and analysing large amounts of data generated by monitoring, including improved integration of algorithms and machine learning to recognise images of marine animals around turbines to reduce processing of large quantities of data generated by monitoring programmes.
	• Development of reliable approaches to powering monitoring equipment to achieve a balance between conserving power and carrying out observations over long periods of time (due to the rare probability of interactions).

3.2 NEAR-FIELD INTERACTIONS BETWEEN MOBILE SPECIES AND TIDAL TURBINES

Priority research objectives	Improvement of knowledge on the frequency, nature and consequences of near-field interactions between mobile species and tidal turbines through monitoring of deployed devices.
	Improvement of knowledge on sensory perception of mobile species and near-field responses to tidal turbines, including development of a framework for studying the behavioural consequences of radiated noise from wave and tidal stream devices, to move beyond using audibility as a proxy for behavioural response.
	Quantification of key factors affecting mobile species collision risk around operational tidal turbines, including underwater turbine encounter rates and species densities, and evasion responses and rates.
	Improvement of knowledge on congruence, commonalities or differences in near-field interactions between tidal turbines and mobile species from multiple locations and technologies to better understand potential transfer of knowledge from one tidal energy site or technology to another.
Research focus	Protected marine mammals, diving birds and migratory fish remain the priority taxa for research in this area in the UK.
	Opportunities to add value to research proposals by also gathering information on other fish, particularly important forage fish species and those important for commercial, economic or social reasons, should be considered, to de-risk future larger-scale developments. Further, near-field interactions between fish and tidal turbines could affect the nature of interactions with piscivorous predators, other sea users and communities.
	Opportunities to add value to existing monitoring around operational tidal turbines either through expansion of monitoring activity or better strategic use of data gathered.
Critical research outputs	Estimates of key input parameters for collision risk models for use in impact risk assessments, or the development of alternative approaches or metrics to assess and evaluate collision risk (e.g. encounter or collision probability).
	Contextual and empirical evidence to inform the interpretation of assessments and predictions of collision risk for tidal stream development.
	Guidance and protocols for analysing data pertaining to collision risk assessment.
	Guidance and principles on the transfer of knowledge and information pertaining to collision risk from one tidal energy site or technology type to another.
	Provision of an evidence base to inform the development of measures to mitigate collision risk, including designing technologies or array configuration to minimise collision risk.
Practical application of outputs	Translation of data on near-field interactions between mobile species around tidal turbines into knowledge for impact risk assessment, to enable more accurate predictions of likely collision effects on protected mobile species in EIA and HRA.
	Provision of an evidence base that is widely accessible to marine energy stakeholders and reduces the consenting evidence burden placed on individual wave and tidal stream projects through transfer of knowledge from one tidal energy site or technology to another.
	Provision of an evidence base to inform the design of proportionate and effective measures for post-consent management of collision risk.
	Provision of an evidence base to inform project design and sectoral plans to minimise collision risk on mobile species.
Key evidence in State of the Science 2020	• Collision Risk for Animals around Turbines (Chapter 3) and Short Science Summary. • Environmental Monitoring Technologies and Techniques for Detecting Interactions of Marine Animals with Turbines (Chapter 10) and Short Science Summary. • Summary and Path Forward (Chapter 14) and Short Science Summary.

Overview of knowledge status	• No instances of marine mammals, diving seabirds, or other marine animals colliding with an operational tidal (or river) turbine have been observed to date. • Fish, birds and mammals have been observed interacting with turbines. • Laboratory and field studies have shown that marine mammals may exhibit some mid-range avoidance, and fish may exhibit local avoidance and fine-scale evasion behaviours, likely reducing their overall collision risk. • Research has also started to examine the consequences of collision for marine mammals and fish, some of which may be able to recover from many injuries, but this has yet to be explored for diving seabirds.

Priority actions	• Further monitoring around operational tidal stream turbines to describe the occurrence and behaviour of marine mammals, fish and diving birds at close range to devices (1–10s of metres).
	• Quantification of near-field responses (evasion) of marine mammals, fish and diving birds to devices.
	• Further research to understand the consequences of blade strikes and collisions including:
	  ○ Lethal effects.
	  ○ Occurrence and nature of the injuries.
	• Links between injury and an individual's ability to survive and reproduce.
	• Cooperation between government, regulatory bodies, industry and researchers to agree on a collaborative approach to gathering and sharing information on measurements of animal interactions with devices.

3.3 OCCUPANCY PATTERNS, FINE-SCALE DISTRIBUTION AND BEHAVIOUR OF MOBILE SPECIES IN WAVE AND TIDAL STREAM HABITATS

Priority research objectives	Further strategic characterisation of mobile species occupancy patterns, fine-scale distribution and behaviour in wave and tidal energy habitats, including underlying drivers and predictors.
	Improved accuracy of key parameters and metrics for evaluating mobile species impact risk based on occupancy patterns and behaviour in high energy habitats (exposure risk, at-risk density, flux and measures of key behaviours).
	Improvement of knowledge on congruence, commonalities or differences in occupancy patterns and fine-scale distribution of mobile species in high energy habitats to better understand potential transfer of knowledge from one site to another.
Research focus	Protected species (marine mammals and diving birds and migratory fish) remain the priority taxa for research in this area in the UK.
	Research in this area should focus on improving understanding in relation to collision, disturbance and displacement risk.
	Research on forage fish or underlying environmental drivers may lead to better ecosystems-based understanding for occupancy patterns of mobile species.
Critical research outputs	Characterisation of mobile species behaviour, occupancy patterns and fine-scale distribution in high energy habitats, and understanding for key drivers, including guidance or principles for the transfer of knowledge and information from one location to another. This includes the development of high energy habitat typologies.
	Further knowledge on the functional importance and uniqueness of high energy habitats for mobile species.
	Guidance and protocols for analysing data on fine-scale distribution and use of high energy habitats for use in impact risk assessments.
	Provision of an evidence base to inform the design of technologies, array configuration, or development clusters and other measures to manage collision and/or displacement risk.
Practical application of outputs	More accurate and reliable impact predictions for protected mobile species in EIA/HRA for wave and tidal stream developments, including the identification of potential impact pathways and sensitive or vulnerable species at EIA scoping stage.
	Improved knowledge about key factors affecting collision and displacement risk.
	Provision of an evidence base to inform the design of baseline surveys to provide the best possible evidence for project-level EIA and HRA (and identify where new data collection is not required).
	Provision of an evidence base to inform project design and sectoral plans to minimise impact risk on mobile species.
Key evidence in State of the Science 2020	• Collision Risk for Animals around Turbines (Chapter 3) and Short Science Summary. • Summary and Path Forward (Chapter 14) and Short Science Summary.

Overview of knowledge status	• Most research has focused on occupancy patterns, fine-scale distribution and behaviour of mobile species in tidal energy habitats, due to the pressing need to better understand likely spatial overlap in relation to collision risk. • Mammal and diving bird occupancy and use of tidal stream sites has been shown to vary at small spatial and temporal scales and often appear to be driven by underlying hydrodynamics. Highly energetic tidal sites may provide predictable foraging sites for a range of bird and mammal species, but the specific details of habitat use and therefore risk will be site-specific and may also vary within a site. • Evidence to date suggests that collision risk estimated on the basis of wide-scale average densities may not reflect actual risk at any one specific site. Alternative metrics to characterising risk, such as encounter probability have been explored. • Cormorants and auk species have been highlighted as the species most at risk from tidal stream projects, because of their diving behaviour and depth and the resulting potential for spatial overlap with operating devices. • Understanding for the depth distribution of marine mammal species in marine energy sites and how this influences impact risk is improving. For example, harbour porpoise in some tidal sites studied has been shown to be bimodal, with animals spending time foraging at the surface or at depth, and less time at intermediate depths. In contrast, studies of seal diving behaviour have shown a proportion of mid-water diving, in contrast to previous assumptions that most seal diving was thought to be to the seabed.
Priority actions	• Further characterisation of marine mammals and diving birds and migratory fish occupancy patterns and behaviour in marine energy sites including habitat use in relation to hydrodynamic features and conditions, to understand the likely degree of spatial and temporal overlap with deployed devices and arrays. • Baseline fish distribution to determine which species are in vicinity of potential tidal energy sites, and characterisation of occupancy patterns and behaviour as above.

3.4 FAR-FIELD RESPONSES OF MOBILE SPECIES TO WAVE AND TIDAL STREAM DEVICES AND ARRAYS

Priority research objectives	Improvement of knowledge on the sensory perception of mobile species and far-field responses to wave and tidal stream devices and arrays, including methods to relate specific marine animal behavioural responses to the range of frequencies and sound levels from single wave and tidal stream devices.
	Development of methods to accelerate translation of data on far-field responses of mobile species to devices and arrays into knowledge for collision risk and displacement impact assessment (including the development of models).
	Improvement of knowledge on congruence, commonalities or differences in far-field responses of mobile species to devices and arrays between locations or technologies to better understand potential transfer of knowledge from one location or technology type to another.
Research focus	Protected species (marine mammals and diving birds and migratory fish) remain the priority taxa for research in this area in the UK.
	Research in this area should focus on improving understanding for disturbance and displacement in spatially constricted locations such as narrow channels or areas of critical habitat.
	Research in this area should focus on methods to measure discernible behavioural responses to devices and arrays. Proposals in this area should be aware of previous studies that have demonstrated the limited statistical power to detect changes in mobile species distribution before and after installation of marine energy developments[1]. This has often been due to limitations of the survey design itself and future planned surveys should take this into account.
Critical research outputs	Characterisation and quantification of mobile species mid-field behavioural responses to devices and arrays, including key input parameters for encounter/collision risk models for use in impact risk assessments such as avoidance rates.
	Guidance and protocols for processing and analysing data on mid-field responses by mobile species to devices and arrays for use in collision risk and displacement impact assessments.
	Guidance and principles on the transfer of knowledge and information on the mid-field responses by mobile species to devices and arrays from one location or technology type to another.
Practical application of outputs	More accurate and reliable predictions of disturbance and displacement effects on protected mobile species in EIA and HRA, including at EIA scoping to understand when more detailed assessment is (and is not) required.
	More accurate and reliable predictions of collision risk for mobile species in EIA and HRA for tidal stream projects through incorporation of knowledge on disturbance and avoidance responses.
	Provision of an evidence base that is widely accessible to marine energy stakeholders and reduces the consenting evidence burden placed on individual wave and tidal stream projects, as an issue that will be difficult to address at project-level.
	Provision of an evidence base to inform project design and sectoral plans to minimise impact risk on mobile species.
Key evidence in State of the Science 2020	• Collision Risk for Animals around Turbines (Chapter 3) and Short Science Summary. • Risk to Marine Animals from Underwater Noise Generated by Marine Renewable Energy Devices (Chapter 4) and Short Science Summary. • Summary and Path Forward (Chapter 14) and Short Science Summary.

[1] E.g. Marine Management Organisation (2014).Review of environmental data associated with post-consent monitoring of licensing conditions of offshore windfarms (MMO 1031) https://www.gov.uk/government/publications/review-of-environmental-data-mmo-1031

Overview of knowledge status	• This remains an area of uncertainty in the absence of a broader evidence base. • Knowledge gained to date is mainly based on field studies of responses of marine mammals and fish to single devices, simulations of device noise, or assumptions about likely behavioural responses to the range of frequencies and sound levels from devices using audibility as a proxy for behavioural response. • Laboratory and field studies have shown that marine mammals and fish may exhibit some far-field avoidance of operating tidal stream devices and arrays (at the scale of 10s of metres), likely reducing their overall collision risk. • Understanding for possible far-field responses of birds to marine energy devices remains limited. Long-term monitoring at test sites such as EMEC suggest some short-term displacement of birds from marine energy development areas during construction and installation activities, but with no discernible effects during device operation.
Priority actions	• Development of methods to relate specific marine animal behavioural responses to the range of frequencies and sound levels from single wave and tidal stream devices, or the physical presence of devices. • Development of a framework for studying the behavioural consequences of radiated noise from wave and tidal stream devices, to move beyond using audibility as a proxy for behavioural response.

3.5 SUBSEA ACOUSTIC PROFILES OF WAVE AND TIDAL STREAM HABITATS AND TECHNOLOGIES

Priority research objectives	Development of cost-effective and reliable methods for measuring ambient and device operational noise in high energy habitats (and distinguishing between the two).
	Characterisation of ambient noise at high wave and tidal energy marine habitats and development of noise propagation models in the context of potential marine energy development and based on standardised approaches.
	Characterisation of operational noise (acoustic profiles) of wave and tidal devices and arrays, based on standardised approaches (e.g. IEC 62600-40: 2019[2]).
	Development of models for predicting the noise profile of multi-device arrays, based on standardised approaches.
	Improvement of knowledge on congruence, commonalities or differences in ambient noise between wave and tidal energy locations to better understand potential transfer of knowledge from one location or technology type to another.
Research focus	Research should focus on opportunities to gather data from single devices or small arrays to de-risk future larger-scale developments and opportunities to maximise knowledge transferability and the development of an acoustic evidence base.
	Opportunities should be explored to align measurements of device noise profiles with studies to better understand near-field and mid-field responses of protected mobile species to operational devices.
Critical research outputs	Acoustic profiles for operational devices and arrays and wave and tidal energy sites for use in impact risk assessments.
	Models for predicting noise profiles of single devices and multi-device arrays for use in impact risk assessments.
	Guidance and principles on the transfer of knowledge and information pertaining to operational noise and its ecological effects from one tidal energy site or technology type to another.
Practical application of outputs	More accurate and reliable impact assessments and predictions of the ecological effects of device and array noise in EIA and HRA, including at EIA scoping stage to determine when more detailed assessment is (and is not) required.
	Provision of a standardised acoustic evidence base for wave and tidal energy technologies and high energy sites for use in impact assessments, to reduce the consenting evidence burden placed on individual wave and tidal stream projects.
	Provision of an evidence base to inform project design and sectoral plans to minimise impact risk on mobile species.
Key evidence in State of the Science 2020	• Risk to Marine Animals from Underwater Noise Generated by Marine Renewable Energy Devices (Chapter 4) and Short Science Summary. • Summary and Path Forward (Chapter 14) and Short Science Summary.

[2] International Electrotechnical Commission – IEC (2019). Marine energy - Wave, tidal and other water current converters - Part 40: Acoustic characterization of marine energy converters (IEC TS 62600-40:2019).

Overview of knowledge status	• Measurements have been made of ambient noise in wave and tidal habitats and of radiated noise generated by a range of operational wave and tidal stream devices. • To date, the sound levels measured from wave and tidal stream devices are considerably below those that might be expected to cause physical harm to animal tissues, including those associated with hearing. • Evidence to date suggests that underwater noise generated by wave and tidal devices is considered most likely to affect the behaviour of marine animals, while acoustic pressure is most likely to affect marine mammals and seabirds, while fish are more sensitive to acoustic particle velocities. • In addition to existing thresholds for underwater noise likely to result in injury or death to marine mammals, additional thresholds have now been developed that consider lower levels of noise that may disturb or harass marine mammals. • An internationally accepted standard has now been published for measuring underwater noise from marine renewable energy devices, including instrument calibration, measurement methods, methods for data processing, and uniform presentation of results.
Priority actions	• Development of instrumentation to accurately measure the noise from a range of wave and tidal stream device types and distinguish from ambient noise. • Further measurements of radiated noise generated by a range of operational wave and tidal stream devices, distinguished from ambient noise, in particular across sound frequencies within the hearing range of marine animals. • Measurement of radiated noise around early arrays of wave and tidal stream devices.

3.6 TOOLS FOR ASSESSING AND MANAGING RISK TO MOBILE SPECIES POPULATIONS FOR LARGE-SCALE WAVE AND TIDAL STREAM DEVELOPMENT

Priority research objectives	Development of frameworks or tools to translate knowledge on the effects of single devices or small arrays on mobile species into predictions of the effects of larger-scale developments.
	Improvement of the availability and accuracy of knowledge on the size, geographic range, status and key demographic information for populations of protected mobile species.
	Development of tools or models for predicting and quantifying impacts on populations of protected mobile species.
Research focus	Protected mobile species (marine mammals, seabirds and migratory fish) remain the priority taxa for research in this area in the UK.
	Research in this area should identify opportunities to assimilate outputs from monitoring of single devices or small arrays in a systematic and standardised way to maximise knowledge transfer for more effective decision-making for larger-scale developments and sectoral planning.
	Research should provide information to enable decision- and policymakers to reach well-informed decisions about thresholds of acceptable impact risk for populations of protected species.
Critical research outputs	Guidance, protocols and empirical evidence for translating predictions of effects on mobile species from single devices and arrays into assessments of the consequences of larger-scale developments or clusters.
	Frameworks and tools for predicting the effects of large-scale developments or geographic clusters of development, on key mobile species for use in impact risk assessments. For collision risk, this might include the further development of encounter/collision risk models, or the development of alternative approaches or metrics to assess and evaluate risk (e.g. encounter or collision probability).
	Estimates of key population demographics and metrics for populations of protected mobile species.
Practical application of outputs	More accurate and reliable assessments and predictions of impacts of arrays and large-scale developments on populations of protected mobile species in EIA and HRA, including at EIA scoping to understand when more detailed assessment is (and is not) required.
	Provision of tools and models to translate predictions on the nature and magnitude of potential effects on mobile species to assessments of impacts on population viability in EIA and HRA.
	Provision of an evidence base to enable well-informed decisions about thresholds of acceptable impact risk for populations of protected species.
	Provision of an evidence base to inform project design and sectoral plans to minimise impact risk on mobile species.
Key evidence in State of the Science 2020	• Collision Risk for Animals around Turbines (Chapter 3) and Short Science Summary. • Risk to Marine Animals from Underwater Noise Generated by Marine Renewable Energy Devices (Chapter 4) and Short Science Summary. • Summary and Path Forward (Chapter 14) and Short Science Summary.

Overview of knowledge status	• Evidence suggests that wave and tidal stream devices deployed to date have not resulted in any negative consequences for marine mammal, bird or fish populations. • Considerable modelling efforts have been carried out to estimate the risk of collision of marine mammals, birds and fish around turbines and to predict the possible effects on species populations. Approaches have generally been based on encounter/collision risk modelling, with linear scaling from single to multiple devices. Data from post-installation monitoring are starting to provide information to challenge and verify the degree to which the models emulate real risk. • Alternative approaches to assessing risk have also been explored, including the use of metrics such as encounter probability, in recognition of the likelihood that collision risk modelling based on wide-scale average densities may not reflect actual risk at any one specific site (see 3.3 above). • Improvements in evidence about near-field interactions and far-field responses between marine animals and devices (see 3.2 and 3.4) and occupancy patterns in marine energy habitats (see 3.3) are all improving understanding for possible population effects of larger arrays.
Priority actions	• Validation of collision risk predictive models using empirical data and field measurements. • Development of models or frameworks for translating individual collision risk to population level risk, and to scale collision risk from single tidal stream turbine to arrays. • Development of models or frameworks to predict how the underwater noise from larger arrays of devices may affect marine animals.

3.7 TOOLS FOR ASSESSING EFFECTS OF LARGE-SCALE WAVE AND TIDAL STREAM DEVELOPMENTS ON PHYSICAL PROCESSES

Priority research objectives	Further information on changes in energy regime (hydrodynamic features and metrics) as a result of deployed wave and tidal devices and arrays.
	Development of tools for predicting the nature and scale of any changes to physical processes caused by large wave and tidal stream arrays or development clusters and any ecological consequences.
Research focus	Research should focus on opportunities to gather resource data (wave/tidal) around single devices or small arrays to build knowledge and evidence on the potential effects of future larger-scale arrays or development clusters.
	Research focus includes the development of tools for modelling or predicting the effects of large arrays or development clusters on physical process and any ecological consequences. Research should therefore also consider standardisation of the methodology and data configuration/parameter settings in any field measurements to maximise potential of knowledge transfer and application to model development.
Critical research outputs	Guidance, protocols and evidence on potential changes in energy regime or hydrodynamic features and variables around operational wave and tidal devices and arrays.
	Models and tools to predict changes to physical processes from larger-scale developments or development clusters for use in impact risk assessments.
	Models and tools to predict the likely scale of development at which changes to physical processes might lead to significant ecological consequences.
Practical application of outputs	Improvement of the accuracy of predictions of changes to physical processes, such as changes in water flow or energy removal in EIA and HRA, including at EIA scoping stage to understand when more detailed assessment is (and is not) required.
	Provision of an evidence base to inform the location and design of large-scale arrays and other mitigation measures to minimise changes to physical processes and ecological consequences.
	Provision of an evidence base to reduce the consenting evidence burden placed on individual wave and tidal stream developers, as an issue that will be difficult to fully address at project-level, in particular for development clusters.
Key evidence in State of the Science 2020	• Changes in Benthic and Pelagic Habitats Caused by Marine Renewable Energy Devices (Chapter 6) and Short Science Summary. • Changes in Oceanographic Systems Associated with Marine Renewable Energy Devices (Chapter 7) and Short Science Summary. • Summary and Path Forward (Chapter 14) and Short Science Summary.
Overview of knowledge status	• Evidence to date indicates that changes in physical processes and oceanographic systems (circulation, wave height, and subsequent changes to sediment transport patterns, water quality, and marine food webs) caused by wave and tidal stream arrays of ~20 MW or less are likely to be small compared to the natural variability of oceanographic systems. • Field studies to date have measured some changes in flow close to devices, but these fade into the background water movement quickly and are not biologically significant. • To date, the changes resulting from larger arrays estimated using models indicate that they are likely to be localised and revert to background levels within short distances from the devices. The number of devices used in these models to demonstrate change in the environment often exceeds the realistic number that are likely to be consented, based on other concerns such as underwater noise and collision risk. • A range of numerical models has been used to predict the effects of future large-scale wave and tidal stream energy extraction, but these have generally focused on the determination of the potential for power generation and device survivability and efficiency, rather than on environmental questions.

Priority actions	• Validation of predictive models for large-scale energy extraction, using empirical data and field measurements of high-resolution bathymetry and flow. • Field measurements before and after deployments of large arrays to validate oceanographic models (note there is limited value in gathering data from small-scale arrays). • Improved parameterisation of wave and tidal stream devices to represent specific designs at specific locations, to accurately model the effects they may have on oceanographic systems. • Research to connect physical change with its ecological implications for specific species and habitats, so that any change described by model results can be translated to real-world implications. • Consideration of the longer-term impacts on morphodynamics (nearshore and coastal), which could also impact on ecological receptors caused by energy extraction and physical alteration of the currents, waves, and sediment transport regime.

3.8 TOOLS FOR ASSESSING SOCIAL AND ECONOMIC IMPACTS OF WAVE AND TIDAL STREAM DEVELOPMENTS

Priority research objectives	Development of tools and frameworks for assessing social and economic impacts (positive and negative) of wave and tidal stream developments, including impacts on other sectors and activities. Includes identifying key evidence and data requirements to develop standardised methods.
	Development of tools and frameworks for assessing opportunities and impacts for local communities from wave and tidal stream developments.
	Improvement of information on interactions and effects of deployed wave and tidal stream developments on other sectors and activities.
	Further knowledge about the effectiveness of measures to mitigate negative effects, or to maximise benefits on other sectors and activities.
Research focus	Impacts on commercial fisheries, recreational users (e.g. sea kayakers), shipping and navigation, tourism and local communities are the priorities for research in this area.
	Research in this area should focus on opportunities to gather data from existing deployed and consented wave and tidal projects to build knowledge and evidence on the potential effects of future larger-scale arrays or development clusters.
Critical research outputs	Better evidence on the social and economic effects of wave and tidal stream development, including the validation of predictions made in EIA.
	Models and tools to predict social and economic effects of wave and tidal stream developments for use in impact risk assessments.
	Development of best practice and standardised approaches for gathering information and assessing social and economic impacts of wave and tidal stream development.
Practical application of outputs	More accurate and reliable predictions of social and economic effects (positive and negative), of wave and tidal stream developments.
	Provision of an evidence base to inform the development of measures to minimise negative social and economic effects and maximise benefits of wave and tidal steam developments.
	Improved transparency, consistency and the development of good practice in social and economic impact assessment within EIA and sectoral planning.
Key evidence in State of the Science 2020	• Social and Economic Data Collection for Marine Renewable Energy (Chapter 9) and Short Science Summary. • Marine Spatial Planning and Marine Renewable Energy (Chapter 11) and Short Science Summary. • Summary and Path Forward (Chapter 14) and Short Science Summary.
Overview of knowledge status	• A number of studies have shown that the wave and tidal stream sector has the potential to create significant social and economic benefits, including benefits for rural and coastal communities and economies that other sectors cannot reach. • Some wave and tidal stream projects to date have provided insight into potential effects and their extents, which include low visual impacts, engagement of the local population and an increase in employment opportunities. • OES-Environmental has produced a set of good practices, based on qualitative experiences, to improve consistency in the collection of social and economic data and foster a better understating of long-term impacts and changes.
Priority actions	• Development of tools and databases to classify key social and economic indicators. • Identification of key questions and data needs to guide data collection efforts. • Development of incentives to collect and share MRE data across the MRE industry. • Creation of flexible planning approaches to address uncertainty as projects move forward and learning increases. • Appropriately scale MRE project impacts and data collection efforts to avoid unnecessary requirements for data and mitigation.

3.9 TOOLS FOR ASSESSING CLIMATE CHANGE IMPACTS OF WAVE AND TIDAL STREAM DEVELOPMENTS

Research objectives	Improvement of the accuracy of information and evidence on carbon reduction benefits of wave and tidal developments and their contribution to net zero targets (including at a local scale).
	Development of tools for assessing the climate change benefits of wave and tidal stream developments.
Research focus	The carbon reduction benefits of large-scale wave and tidal stream development, as well as the contribution of smaller-scale developments, such as through diesel displacement or off-grid end-users are the priorities for research.
Critical research outputs	Contextual and empirical evidence to inform the assessment of climate change benefits of large- and small-scale wave and tidal stream developments.
	Guidance and protocols for assessing climate change benefits of wave and tidal stream developments.
	Development of good practice in the assessment of climate change benefits of wave and tidal developments.
Practical application of outputs	Improve the transparency, consistency, accuracy and reliability of predictions of climate change benefits in EIA.
	Provision of an evidence base to inform assessment of climate change benefits in EIA to reduce the evidence burden on individual developers, as a strategic issue that will be difficult to address effectively at project-level.
Key evidence in the State of the Science 2020	This topic is not specifically covered in the State of the Science 2020.
Overview of knowledge status	Current knowledge on this topic is limited.
Priority actions	• Development of tools and databases to classify key climate change and carbon reduction indicators. • Identification of key questions and data needs to guide data collection efforts. • Development of incentives to collect and share MRE data across the MRE industry.

3.10 TOOLS AND GUIDANCE FOR MANAGING RISK AND UNCERTAINTY DURING THE PREPARATION OF PEMPS

Key research objectives	To review and improve the existing approach to risk management within the consenting process so as to ensure that project specific requirements are proportionate to the potential risks posed by a specific development. To develop a "toolbox" of possible management, mitigation and optimisation measures for use in EIA/HRA and the development of Project Environmental Management Plans. To provide methods and procedures for developing PEMPs for demonstration projects and large-scale wave and tidal arrays.
Research focus	Protected marine mammals, diving birds and migratory fish remain the priority taxa for research in this area in the UK.
	Methods/processes/tools required to help manage perceived and identified environmental risks that may arise from wave and tidal developments to ensure that project level requirements are proportionate and fit for purpose.
Critical research outputs	Review of approach to developing Project Environmental Monitoring Plans, incorporating adaptive management strategies for single device deployments, demonstration arrays and larger arrays to date, drawing on experience from other sectors where appropriate. Guidance/tools/processes for developing, consulting on and implementing project specific PEMPs including; stakeholder engagement plans, reporting timescales and requirements, feedback mechanisms, etc. Review of effectiveness/success of management and mitigation measures to date. Review of potential for transferability between different developments/locations.
Practical application of outputs	Robust and transparent frameworks for managing risk and uncertainty during the consenting process and post consent monitoring activities.
	Toolbox of management and mitigation measures that are applied in PEMPs and associated adaptive management plans.
	More reliable and cost-effective methods of managing collision risk for mobile species.
Key evidence in State of the Science 2020	• Evaluating the success of adaptive management at selected MRE development sites (Chapter 12). • Mitigation of Risk (Chapter 12).
Overview of knowledge status	• A number of tools, methods and processes for managing environmental risks associated with marine energy developments have been developed in recent years. • Project Environmental Monitoring Plans, incorporating adaptive management strategies have been required for majority of projects to date. • A broad range of management and mitigation measures have been used across all marine industries. • Environmental Risk Management Measures Toolbox has been developed by OES Environmental and ORJIP Ocean Energy.
Priority actions	• Further development of Environmental Risk Management Measures Toolbox (OES Environmental and ORJIP Ocean Energy). • Undertake a comprehensive review of the approach taken to developing PEMPs and adaptive management strategies in the wave and tidal sector to date. • Produce guidance on how PEMPs can be best developed in the future, drawing on experience from other sectors where relevant. • Determine the transferability of data and experience regarding the applicability and effectiveness of management and mitigation measures applied to date. • Review of 'lessons learned' related to development of PEMP's across jurisdictions.

4 USING THIS DOCUMENT

The critical wave and tidal stream evidence needs and cross-cutting themes identified in this document complement and build on the Forward Look and the growing body of evidence, knowledge and experience of wave and tidal stream consenting. They set out the key outstanding evidence needs for wave and tidal stream energy in the UK and provide an overall perspective on research priorities and their importance for effective decision-making, by linking research needs to their practical application. Presenting the critical evidence needs in this way is intended to help deliver solutions-orientated research with high practical impact for more effective decision-making by Consenting Authorities.

ORJIP Ocean Energy would like to actively encourage Network participants to express their interest in progressing research or studies to address any of the critical evidence needs identified. Whilst ORJIP Ocean Energy cannot directly fund research, the Secretariat works actively to identify and influence funding opportunities and can support and facilitate interested organisations or consortia in developing research proposals. Any updates regarding recently completed, ongoing or planned research relevant to the critical evidence needs would be welcomed at any time.

ORJIP Ocean Energy would also encourage opportunities to develop strategic evidence plans and programmes at a local, regional or UK level to collaboratively address the critical evidence gaps. This may involve the identification of specific research objectives under the ten strategic topics, for example relating to mobile species of particular regional importance or value, or to take advantage of opportunities presented by wave and tidal stream deployments including regional development clusters.

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Appendix A Relationship between Critical Evidence Needs and Forward Look key strategic consenting issues and outline project plans

Table A1 **Relationship between the critical evidence needs identified in this document, and the strategic consenting issues and outline project plans in the ORJIP Ocean Energy Forward Look. Relevant codes from the Forward Look are provided for ease of reference. Strategic consenting issues are taken from Table 2.1 in the Forward Look and outline project plans from Section 4.**

Critical Evidence Need	Forward Look strategic consenting issue(s)	Forward Look pre-scoped project(s)
1. Methods and instruments to measure mobile species occupancy and behaviour in high energy environments and around tidal turbines	1.5 Further development of suitable instrumentation and methodologies for reducing collision risk, monitoring wildlife behaviour around devices and arrays and for detection of any collision events is required	A3 Further development of instrumentation and methodologies for detecting potential collision events around tidal turbines and arrays E3 Further development of instrumentation and methodologies for monitoring wildlife behaviour around tidal turbines and arrays
2. Near-field interactions between mobile species and tidal stream turbines	1.1 The nature of any potential interactions between marine mammals and basking sharks and tidal turbines is uncertain	A1 Near-field monitoring of marine mammals around operational tidal turbines and first arrays to inform collision risk assessment A2 Further research to help understand the possible likelihood, probability and consequence of collision with tidal turbines for marine mammals E1 Monitoring around operational tidal turbines and first arrays to gather information on the behaviour of diving birds, marine mammals, basking shark and migratory fish around operating tidal turbines E2 Development of mitigation measures for identified and potential impacts of wave and tidal developments
	1.2 The nature of any potential interactions between diving birds and tidal turbines is uncertain	
	1.3 The nature of any potential interactions between migratory fish and tidal turbines is uncertain	
	1.4 There is uncertainty as to the possible physical consequences of potential collision events for marine mammals, diving birds and fish and tidal turbines	
	10.1 Methods/processes are required to help manage perceived and identified environmental risks that may arise from wave and tidal developments to ensure that project level requirements are proportionate	
3. Occupancy patterns, fine-scale distribution and behaviour of mobile species in wave and tidal stream habitats	4.1 Potential displacement of essential activities of marine mammals, basking sharks and birds	A2 Further research to help understand the possible likelihood, probability and consequence of collision with tidal turbines for marine mammals C1 Development of an agreed approach to assessing the potential effects and consequences of displacement from wave and tidal arrays
	5.1 Further strategic baseline data (distribution, abundance, seasonality, etc.) for marine mammals and basking sharks is required to better understand use of potential development areas	
	5.2 Further strategic baseline data (distribution, abundance, seasonality, etc.) for birds is required to better understand use of potential development areas	

Critical Evidence Need	Forward Look strategic consenting issue(s)	Forward Look pre-scoped project(s)
	5.3 Further strategic baseline data (distribution, abundance, seasonality, etc.) for migratory fish is required to better understand use of potential development areas	E2 Development of mitigation measures for identified and potential impacts of wave and tidal developments
	5.4 An agreed approach to undertaking site characterisation and baseline surveys for marine mammals and birds to inform EIA and HRA is required	
	10.1 Methods/processes are required to help manage perceived and identified environmental risks that may arise from wave and tidal developments to ensure that project level requirements are proportionate	
4. Mid-field responses of mobile species to wave and tidal stream devices and arrays	4.1 Potential displacement of essential activities of marine mammals, basking sharks and birds	A2 Further research to help understand the possible likelihood, probability and consequence of collision with tidal turbines for marine mammals C1 Development of an agreed approach to assessing the potential effects and consequences of displacement from wave and tidal arrays E1 Monitoring around operational tidal turbines and first arrays to gather information on the behaviour of diving birds, marine mammals, basking shark and migratory fish around operating tidal turbines E2 Development of mitigation measures for identified and potential impacts of wave and tidal developments
	10.1 Methods/processes are required to help manage perceived and identified environmental risks that may arise from wave and tidal developments to ensure that project level requirements are proportionate	
5. Subsea acoustic profiles of wave and tidal stream sites and technologies	2.1 Lack of available acoustic data from operational devices and arrays	B1 Establishment of an acoustic 'evidence base' for operational devices and arrays B2 Development of noise propagation models to further reduce uncertainty regarding the potential impacts of commercial scale arrays
	2.2 Knowledge regarding the possible effects of underwater noise from the construction and operation of arrays on marine mammals is incomplete	
	10.1 Methods/processes are required to help manage perceived and identified environmental risks that may arise from wave and tidal developments to ensure that project level requirements are proportionate	
6. Tools for assessing and managing risk to mobile species populations for large-scale wave and tidal stream development	1.4 There is uncertainty as to the possible physical consequences of potential collision events for marine mammals, diving birds and fish and tidal turbines	A2 Further research to help understand the possible likelihood, probability and consequence of collision with tidal turbines for marine mammals
	4.1 Potential displacement of essential activities of marine mammals, basking sharks and birds	

Critical Evidence Need	Forward Look strategic consenting issue(s)	Forward Look pre-scoped project(s)
	5.5 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	E4 Further research to improve understanding of the potential population level effects of protected mobile species from commercial scale wave and tidal current projects F1 Review of Potential Biological Removal (PBR) approach to regulation including consideration of alternatives
	5.6 Better understanding of population level impacts and methods to assess the significance of population level impacts would improve confidence in EIA/HRA	
	10.1 Methods/processes are required to help manage perceived and identified environmental risks that may arise from wave and tidal developments to ensure that project level requirements are proportionate	
	10.2 Methods/processes are required to predict and measure potential cumulative impacts around clusters of lease areas	
7. Tools for assessing effects of large-scale wave and tidal stream developments on physical processes	9.1 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	No pre-scoped projects for these key consenting risks identified in Forward Look
	9.2 Validation of hydrographic models to help predict the effects of changes in water flow and energy removal at commercial scale	
	10.1 Methods/processes are required to help manage perceived and identified environmental risks that may arise from wave and tidal developments to ensure that project level requirements are proportionate	
	10.2 Methods/processes are required to predict and measure potential cumulative impacts around clusters of lease areas	
8. Tools for assessing social and economic impacts of wave and tidal stream developments	6.1 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	D1 Further studies and research to understand the potential social and economic opportunities and impacts from the development of marine energy projects in rural communities G1 Development of agreed methods/processes for assessing, mitigating and managing potential impacts on shipping and navigation
	7.1 Difficulties with assessing and mitigating the potential cumulative impacts on shipping and navigation due to uncertainty around risks that may arise from a number of projects	
	8.1 Difficulty with identifying, assessing, mitigating and managing potential cumulative social and economic impacts from marine energy developments and changes to existing maritime activity	

Critical Evidence Need	Forward Look strategic consenting issue(s)	Forward Look pre-scoped project(s)
	10.2 Methods/processes are required to predict and measure potential cumulative impacts around clusters of lease areas	
9. Tools for assessing climate change impacts of wave and tidal stream developments	No corresponding key consenting issues or pre-scoped projects in the Forward Look. This area of consenting and planning policy has emerged since the release of the 2017 Forward Look	
10. Tools and guidance for managing risk and uncertainty during preparation of PEMPs	1.5 Further development of suitable instrumentation and methodologies for reducing collision risk, monitoring wildlife behaviour around devices and arrays and for detection of any collision events is required 10.1 Methods/processes are required to help manage perceived and identified environmental risks that may arise from wave and tidal developments to ensure that project level requirements are proportionate 10.4 Agreement is required on the approach to developing Project Environmental Monitoring Plans, incorporating adaptive management strategies, for commercial scale wave and tidal arrays	A.3 Further development of instrumentation and methodologies for detecting potential collision events around tidal turbines and arrays E.2 Development of mitigation measures for identified and potential impacts of wave and tidal developments F.2 Development of methods/processes for identifying and managing environmental risks associated with wave and tidal energy developments within the consenting process F.4 Development and agreement of methods/processes for developing Project Environmental Management Plans, incorporating mitigation measures and adaptive management strategies, for demonstration

Table A2 **Pre-scoped projects and strategic consenting issues in the ORJIP Ocean Energy Forward Look not directly covered within the Critical Evidence Needs. Relevant codes from the Forward Look are provided for ease of reference. Strategic consenting issues are taken from Table 2.1 in the Forward Look and outline project plans from Section 4.**

Forward Look strategic consenting issues and risks	Further comments
E5 Review and dissemination of findings of environmental monitoring studies	Addressed within the cross-cutting themes
3.1 Further data and information regarding the possible effects of EMF from transmission cables on fish would improve confidence in EIA and HRA	The information and evidence provided in the State of the Science 2020, indicates that this is no longer a key consenting issue for wave and tidal stream projects
10.3 Agreement is required on the approach to applying a design envelope approach to consenting wave and tidal arrays	Addressed within the cross-cutting themes
10.5 Further guidance is required as to how best to consider decommissioning in the consenting process	This is a policy issue that cannot be addressed through research