Review of fish and fisheries research to inform ScotMER evidence gaps and future strategic research in the UK

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Review of fish and fisheries research to inform ScotMER evidence gaps and future strategic research in the UK

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Executive summary

This study provides a review of research of relevance to existing evidence gaps of the potential impacts of Marine Renewable Energy (MRE) developments on fish and commercial fishing in the UK, and identifies recommendations for future research to address them.

The broad evidence gaps categories on which the study is focused are based on those identified by the Scottish Marine Energy Research (ScotMER) programme's fish and fisheries evidence map. These are considered of relevance in an UK-wide context and include the following:

- FF.01: Accurate mapping of fishing effort and catches in space and time;
- FF.02: Accurate and validated method to predict fisheries displacement levels and locations;
- FF.03: Fisheries stakeholders integration and participation process;
- FF.04: Improvements in Environmental Impact Assessment methodologies;
- FF.05: Strategic fisheries management;
- FF.06: Underwater noise and vibrations;
- FF.07: Electromagnetic fields (EMF);
- FF:08: Collision risk (tidal turbines);

- FF.09: Accurate spatio-temporal patterns of spawning activity by marine fish species;
- FF.10: Essential fish habitat (EFH);
- FF.11: Reef/fish aggregation effect;
- FF.12: Inshore populations/distribution;
- FF.13: Cumulative pressures and impact pathways;
- FF.14: Co-existence with commercial fisheries: and
- FF.15: Chemical/toxicity effects.

Research of relevance to the above evidence gaps was reviewed using internet search engines. In addition, in parallel, targeted consultation via questionnaires was undertaken with a range of UK and international experts and stakeholders including research institutions and universities, fisheries stakeholders, nature conservation organisations, developers and research and industry groups.

Taking account of the findings of the literature review and the consultation exercise, next steps in research to address each evidence gap were identified. Following this, recommendations for future research were proposed.

Key recommendations identified in respect of fish receptors relate to improving our understanding of the impacts of offshore wind farms on fish and shellfish species through the implementation of strategic research in operational sites. Other key priority aspects in respect of fish and shellfish relate to improving the evidence base to facilitate the assessment of underwater noise impacts and the development of mapping tools on essential habitat (including spawning grounds).

In the case of commercial fisheries, key recommendations identified relate to improving access to fisheries data and the format in which data are made available, as well as the development of standard assessment guidelines and research to allow the assessment of the displacement effects at a strategic level. In addition, the undertaking of trials to demonstrate the viability of fishing within operational sites, as well as the development of technical guidance on wind farm design and its compatibility with fishing were also identified as critical aspects to reduce consenting risks and uncertainty in relation to commercial fisheries receptors.

The strong inter-dependence that exists between various evidence gaps was noted and it was recommended that when preparing future detailed research proposals to address evidence gaps, their inter-dependencies are given due consideration.

Introduction

Over the next decade a significant expansion is expected in the Marine Renewable Energy (MRE) sector around the world, particularly in the offshore wind industry.

In England and Wales, The Crown Estate's Offshore Wind Leasing Round 4 tender process concluded in February 2021, with six proposed new offshore wind projects. These projects together represent just under 8 GW of potential new offshore wind capacity and, subject to the conclusions of the plan level Habitats Regulation Assessment, will join the strong pipeline of UK offshore wind farms already in operation, construction and planning.

In Scotland, a new leasing round (ScotWind) launched in June 2020 by Crown Estate Scotland, will further help put the UK on track to meet the government's target for 40 GW of offshore wind capacity by 2030. The aim of the ScotWind leasing round is to deliver up to 10 GW of offshore wind energy in Scottish waters.

The development of offshore wind projects under these new leasing rounds, will be vital to meet the UK's Government current target of achieving net-zero carbon emissions by 2050 as well as the Scottish Government target of achieving net-zero by 2045.

To improve understanding and assess the environmental and socio-economic implications of existing and up-coming MRE projects, Marine Scotland has established the ScotMER programme, working closely with stakeholders to map out the research gaps in scientific knowledge when assessing the environmental and socio-economic impacts of MRE developments in Scottish waters.

Seven specialist groups of key experts and stakeholders were created under the ScotMER programme, each focussing on particular impact receptors, including the Fish and Fisheries Specialist Receptor Group (FFSRG). Similar to the other groups, the FFSRG has produced an “Evidence Map” that outlines and prioritises knowledge gaps in fish ecology and fisheries. However, there is a need to review current research on fish and fisheries interactions with offshore renewable developments to update this evidence map, and inform future strategic research projects.

In order to facilitate this process, this report provides a review of recent research undertaken in the UK and internationally of relevance to the assessment of potential impacts of MRE projects on fish and fisheries and makes recommendations with regards to future research. Whilst the report has been structured to align with the current contents of ScotMER’s fish and fisheries evidence map, its scope is aimed at addressing evidence gaps on a UK-wide basis.

In this context it is important to note that whilst an evidence map equivalent to that produced under the ScotMER programme for Scotland is not currently available for the rest of the UK, the broad evidence gaps categories identified in ScotMER’s fish and fisheries evidence map are also of relevance in a UK context. The Crown Estate has contributed to this review by funding the UK-wide elements to inform its Offshore Wind Evidence and Change Programme.

Background Information – ScotMER's Evidence Gaps

At present, the ScotMER's fish and fisheries evidence map includes the following 15 evidence gaps:

- FF.01: Accurate mapping of fishing effort and catches in space and time;
- FF.02: Accurate and validated method to predict fisheries displacement levels and locations;
- FF.03: Fisheries stakeholders integration and participation process;
- FF.04: Improvements in Environmental Impact Assessment methodologies;
- FF.05: Strategic fisheries management;
- FF.06: Underwater noise and vibrations;
- FF.07: Electromagnetic fields (EMF);
- FF:08: Collision risk (tidal turbines);
- FF.09: Accurate spatio-temporal patterns of spawning activity by marine fish species;
- FF.10: Essential fish habitat (EFH);
- FF.11: Reef/fish aggregation effect;
- FF.12: Inshore populations/distribution;
- FF.13: Cumulative pressures and impact pathways;
- FF.14: Co-existence with commercial fisheries: and
- FF.15: Chemical/toxicity effects.

Target species/groups, relevance and priority ratings identified in the current evidence map for each evidence gap are summarised in Table 1.

Further information on the ScotMER's programme and the evidence maps is available at: Science and research - Marine renewable energy - gov.scot (www.gov.scot)

Table 1: ScotMER's fish and fisheries evidence gaps, target species/group, relevance and priority ratings

Evidence Gap	Target Species/Group	Relevance	Priority
FF.01: Accurate mapping of fishing effort and catches in space and time	All < 12 m fisheries	Evidence of past fishing activity from vessels not currently fitted with Vessel monitoring System (VMS).	Medium
		Contribute to establishing historic fishing grounds in an area. May assist with spatial conflicts with other marine users, gear conflict resolution, as well as fisheries management.	Low
	Whole fleet (emphasis on scallop fisheries)	Important for seasonal management of marine activities. Easier access to International Council for the Exploration of the Sea (ICES) landings data for relevant impact area.	Medium
	Fisheries in the vicinity of offshore wind farms	Monitoring of commercial fishing activity adjacent to developments to aid with baseline characterisation.	High
	Creel fisheries targeting brown crab	Most creel vessels are not currently fitted with VMS. Contentious area during offshore wind farm construction.	Low
	Nomadic fleets (e.g. squid fishery)	Looking at historic data to determine patterns in nomadic fleet fishing activities (e.g. how often they return to areas and what time of the year)	Low
FF.02: Accurate and validated method to predict fisheries	Scottish king scallop dredge fishery	Estimate displacement levels in Environmental Impact Assessments (EIAs) and assist with more accurate disruption settlements.	High

Evidence Gap	Target Species/Group	Relevance	Priority
displacement levels and locations	Scottish *Nephrops* trawl fishery		High
	All Scottish vessels in harbours designated as operations based for offshore wind farm construction	Competition for onshore infrastructure in the licensing process – harbour and pier facilities and potential conflicts between fishing sector and offshore developers.	Low
	Static gear inshore fisheries	Concentration of fishing effort on smaller areas due to exclusion	-
	Whole fleet (emphasis on mobile gear for Floating Offshore Wind (FOW)	Minimum operating space requirements for fishing activities when conducting fishing activities (deploying and hauling gear)	-
FF.03: Fisheries stakeholder integration and participation process	Whole fleet (emphasis on interacting fisheries)	Review of consultation process to extract good practice and promote efficient consultation with the fishing industry.	Low

Evidence Gap	Target Species/Group	Relevance	Priority
FF.04: Improvement in Environmental Impact Assessment Methodologies	Whole fleet	Improve the quality of Environmental Impact Assessment (EIA) practice and assessments related to impacts on commercial fisheries.	Medium
		Address current data gaps on Cumulative Impact Assessment (CIA) guidance on fisheries. Studies will contribute to establishing the degree of co-existence possible between commercial fisheries and offshore renewables.	High
FF.05: Strategic fisheries management	Whole fleet	Promote potential synergies in Marine Spatial Planning (MSP)	Low
FF.06: Underwater noise and vibrations	Cod and herring	For most fish species the audiograms available are still extremely few and old, or reliant on proxies/surrogates. Audiograms, particularly for species sensitive to sound, would support better impact assessments. Improvement of the evidence base from which modelling methods and impact assessments arise. Hearing specialist species (cod and herring) are specifically mentioned due to existing licence conditions, however this need not be restricted to the two species.	High
	All species	The particle motion element of underwater noise has so far been largely excluded from consideration in EIAs. Existing modelling methods are not considered viable at depths of less than 100m.	High

Evidence Gap	Target Species/Group	Relevance	Priority
	All species	Of interest to other receptors too. Opportunistic particle motion monitoring could also be tied in to this work.	Medium
FF.07: Electromagnetic Fields (EMF)	NA	Calculating the strength and dissipation of iE and B fields from cables. If cable design become more standarised a study could have broad application.	Medium
	Various	Limited information regarding shellfish although there have been some studies with AC cables and a recent study looking at American lobster and HVDC cables.	Medium
	NA	To allow consideration of mitigative measures where required.	Low
FF.08: Collision risk (tidal turbines)	Various	To allow assessment of collision risk to marine fish species. If considering Computational Fluid Dynamic (CFD) this would be a cross receptor group project covering marine mammals, ornithology and diadromous fish species.	Medium
FF.09: Accurate spatial -temporal patterns of spawning activity by marine fish species	Various	Fundamental to EIAs and consideration of mitigation options.	Medium
FF.10: Essential Fish Habitat	Various	Currently used sensitivity maps provide indicative areas. Greater clarification on essential fish habitat would be useful when assessing effects from marine projects.	High

Evidence Gap	Target Species/Group	Relevance	Priority
FF.11: Reef/ fish aggregation effects	Various	Understanding potential positive effects – distinguishing between a simple aggregation effect and any benefits in terms of food availability	Medium
	Various	Understanding indirect or negative effects – predator prey-interactions and potential for increased collision for fish or their predators.	Medium
FF.12: Inshore populations/distribution	Various	There is a general paucity of data on fish close to shore, compared to deeper waters where fishery-dependent and IBTS data is plentiful. A better knowledge of fish populations close to shore would be useful when considering near shore activities. This has the potential to be relevant also to other areas such as seaweed harvesting.	Medium
FF.13: Cumulative pressures & impact pathways	Various	Contribute to CIA and overall ecosystem assessments	Low
FF.14: Co-existence with Commercial Fisheries	Mobile gear that comes into contact with the seabed	Understanding potential for demersal towed gear fisheries to resume in operational wind farm sites	High
	Whole fleet	Understanding minimum operating requirements for fishing activities (deploying and hauling gear).	High

Evidence Gap	Target Species/Group	Relevance	Priority
FF.15: Chemical/toxicity effects	Various	Understanding chemicals and heavy metal contents within sediments and the water column within offshore wind farms and potential bioaccumulation of heavy metals within the food chain from biofouling/filter feeding organisms to top predators	Low

Methodology

A total of 163 peer reviewed and grey literature publications were reviewed to help inform this report. These were primarily identified via internet search engines, using words included in the titles of the ScotMER fish and fisheries evidence gaps combined with the terms “marine renewable energy”, “offshore wind farm”, “fish” and “fisheries” as appropriate.

In parallel, targeted consultation via questionnaires was undertaken with a range of UK and international stakeholders including research institutions and universities, fisheries stakeholders, nature conservation organisations, developers and research and industry groups. This consultation was aimed at identifying recent, on-going and/or planned research which may be of relevance to the ScotMER’s fish and fisheries evidence gaps. In addition, the questionnaires provided an opportunity for consultees to identify any additional evidence gaps which they felt should be given consideration in the future. The consultation questionnaire used for the targeted consultation exercise in support of this report is provided in Appendix 01 for reference.

A total of 15 completed questionnaires were returned. A summary of the profiles of the organisations which responded to the consultation and an indication of their geographical location is provided in Table 2.

Table 2 Consultees’ Summary

Consultee	No. of responses	Location
Offshore Wind Developers	5	Scottish, UK-wide and international projects
Universities	2	Wales and Scotland
Other research institutions	1	Scotland
Fisheries federations/associations	1	England and Wales
Licensing bodies/government departments and agencies	4	England, Wales and Northern Ireland
SNCBs and Inshore Fisheries and Conservation Authorities (IFCAs)	2	England

Research papers and other relevant publications identified by consultees in the questionnaires have been referenced within the review of current knowledge on the evidence gaps as appropriate. In addition, reference has been made to high level information provided by consultees in relation to standard monitoring practices and other activities that they undertake which may provide useful data and information to address some of the existing evidence gaps.

As part of their consultation responses, some consultees, including various developers, fisheries organisations and research institutions, also provided feedback on additional aspects that they feel need to be addressed. Whilst these may not be directly addressed in this literature review, they should be given consideration in future strategic evidence gap mapping and/or research. These were the following:

- Fishing activity by under 15 m vessels engaged in lobster and whelk fisheries;
- Displacement of activity for the whole UK fleet;
- Guidance on how to improve relationships with fishermen and involve them in the consultation process at an early stage;
- Engagement with the EU fishing industry post-Brexit;
- Strategic approaches to larval surveys (in relation to the collection of evidence on fish spawning);
- The appropriate scale at which the data and knowledge are gathered needs to be addressed;
- The way that monitoring of effects is undertaken should be more targeted to address strategic and cumulative questions, rather than be set within the context of EIAs. In addition, there should be a stronger focus on ecosystem effects rather than on specific receptors;
- The current basis for fishing in the vicinity of cables and the legal protection of cables against willful or culpable negligence lacks clarity and is hindering the potential for co-existence. There is a risk that without intervention to provide a clearer legal basis for fishing in the vicinity of cables or arrangements for the appropriate management of liabilities, that changes in insurance provision will result in the future de-facto exclusion of fishing activities. Research is needed to review the current legal framework applying to fisheries-cable interactions, legal practice and case law, insurance market views, explore models for the future management of liabilities and make recommendations based on findings.

- Investigations on alternative fishing methods and potential development of new gear types that may be less damaging to the marine environment and more suited to operating inside the boundaries of offshore wind farms; and
- Additional research and guidance in relation to cable burial, burial techniques and target depth and facilitation of co-existence with other marine users. The development of an agreed approach on data presentation relating to “as laid” cables for other marine users would also be useful.

Evidence Gap FF.01: Accurate mapping of fishing effort and catches in space and time

Review of current knowledge

Commercial fisheries impact assessments are generally informed by the undertaking of desktop reviews of existing studies and datasets and complemented with the collection of data and information on fishing activities through direct consultation with fisheries stakeholders.

Standard fisheries data sources that are frequently used to characterise fishing activities spatially and temporally in UK waters include the following:

- Landings and Effort Statistics: These are primarily based on landings declarations and logbook data. To allow the identification of the broad sea areas where fish and shellfish have been caught, landings and effort data used to inform commercial fisheries assessments are generally analysed by International Council for the Exploration of the Sea (ICES) rectangle, the smallest spatial unit used in the collection of this type of data.
- Vessel Monitoring System (VMS) Data: VMS data are derived from position information reported by UK and EU Member States’ vessels carrying the EU mandated monitoring system. Since 2012 all commercial fishing vessels of 12 metres and over in length have been required to report their position, course and speed at regular intervals using VMS. Prior to 2012 this requirement only applied to commercial fishing vessels of 15 metres and over.

Fishing is not equally distributed across the area of ICES rectangles, hence, the overall landings and effort data recorded for a given rectangle may not be representative of the activity which occurs across different subsections of the rectangle. Whilst VMS data provides information at increased spatial resolution, in its raw format it does not provide quantitative information in respect of aspects such as catch weight, value and effort. In addition, this data does not identify whether vessels are actively fishing or simply in transit. Over the last ten years, however, data analysis methodologies have been developed to improve the characterisation of fishing activity using VMS data (i.e. Lee et al 2010, Gerritsen et al 2011, Bastardie et al 2010). In addition, the establishment of the ICES Working Group on Spatial Fisheries Data (WGSFD) has facilitated the implementation of standardised methods for the analysis of VMS data across countries.

At present, the combination of VMS data with logbook information is considered the most practical and cost-effective way to describe the spatial dynamics of fishing activities (ICES 2019). In the UK, data in this format is collated for UK registered vessels by aggregating the number of position plots by gear type in a 0.05 x 0.05 degree grid. This is then combined with landings values to provide effort, value (£) and weight (tonnes) outputs for each cell within the grid. The data is filtered by speed so that only activity of vessels deemed to be fishing is included in the dataset. It should be noted, however, that VMS combined with logbook data is provided separately by fishing method and in some cases a single method may encompass vessels from different fleet segments. For instance, data for bottom otter trawls amalgamates information from vessels engaged in squid, *Nephrops* and whitefish fisheries, whilst the beam trawl category would mostly include activity of Anglo-Dutch and UK beam trawlers targeting flatfish as well as vessels engaged in the shrimp fishery. This, together with the need to anonymise vessels in the dataset due to confidentiality issues means that the extent and level of activity of vessels engaged in a particular fishery may not always be accurately represented by this data. Approaches which allow the mapping of activity by fleet segment or fishery should be favoured where feasible (i.e. see Kafas et al 2013). In addition, as VMS data is currently only available for vessels of 12 metres and over, this type of data does not take account of fishing activity undertaken by vessels in the smaller length categories. Vessels under 12 metres in length tend to account for the majority of fishing in areas close to shore, therefore, VMS-based datasets provide little information of fishing activity in inshore waters.

The lack of accurate spatial data to describe fishing activity in inshore areas has resulted in various studies being commissioned in recent years to address this information gap. These have generally involved participatory mapping methods to spatially identify fishing grounds. Examples of these include:

- "FisherMap": The FisherMap study aimed to map the extent and intensity of fishing activities around the English coast to inform new Marine Conservation Zones (MCZs) recommendations under the UK's Marine and Coastal Access Act. Data were collected by interviewing 1,914 fishermen by four regional project teams across England ("Net Gain", "Balanced Seas", "Finding Sanctuary" and "Irish Sea Conservation Zone") undertaken between 2007 and 2010 (Enever et al 2016);
- "Understanding the distribution and trends in inshore fishing activities and the link to coastal communities": A Defra commissioned Cefas project to better understand trends in inshore fisheries around England and Wales, including collating and analysing fisheries sightings data from 2010 to 2012. These data were displayed as national layers of sightings (of certain fishing activities - trawling, potting, netting, etc) per unit effort (Vanstaen and Breen 2014); and
- "ScotMap": Fisheries mapping study undertaken by Marine Scotland to provide spatial information on the fishing activity of Scottish registered vessels under 15 metres in overall length. The dataset is based on interviews with 1,090 fishermen. The data is provided as data layers with information on monetary value, relative value, number of vessels and number of crew and is subdivided by fishing gear (Kafas et al 2014a).

It should be noted that approaches to the mapping of inshore activity based on qualitative information such as interviews, generally provide limited information on the intensity of the activity (i.e. information is limited to fishing location with no reference to frequency of fishing). In addition, these approaches may be limited in their ability to facilitate annual updates of information (Breen et al 2015). Furthermore, knowledge on fishing grounds and activities held by local fishermen and fisheries organisations, is generally difficult to standardise and quantify

(MMO, 2014) and, in some instances, fishermen may have concerns over data and information sharing and confidentiality issues (Rodwell et al 2013).

The improvement of the evidence base on which inshore fisheries management decisions can be made is an aspect being developed across the UK as part of initiatives such as the Future of Our Inshore Fisheries Project (Seafish 2019) and the Future of fisheries management strategy (2020 to 2030) for Scotland (The Scottish Government 2020b).

It is to be expected that with the introduction of Inshore Vessel Monitoring System (IVMS) solutions for vessels under 12 metres in length, constraints on the accurate mapping of inshore fishing activities will be significantly reduced in the future. Marine Scotland is currently undergoing an inshore fleet tracking programme where funding has been issued for the installation of remote electronic monitoring and VMS equipment for Scottish inshore vessels (under 12 m). The roll out of IVMS systems for the inshore fleet is also under way in the rest of the UK.

In Scotland, a three-year project (2017- 2020) project focused on improving the management of inshore fishing activities, involving industry, academia and government (the Scottish Inshore Fisheries Integrated Data System (SIFIDS) project)) has recently been completed (MASTS 2021). The project saw more than 130 vessel skippers in 43 ports around Scotland host research trips, test tracking and/or devices installed, undertake surveys and significantly contribute to equipment and software development relating to inshore fisheries management.

Key research undertaken as part of SIFIDS project included:

- Review and optimisation of shellfish data collection strategies for Scottish inshore waters;
- Development and pilot deployment of an autonomous fisheries data harvesting system;
- Investigation into the availability and adaptability of novel technological approaches to data collection;

- Development of a novel, automated mechanism for the collection of scallop stock data;
- Assessment of socio-economic and cultural characteristics of the Scottish Inshore Fishery;
- Capture and incorporation of experimental fisheries data;
- Development of a pilot recreational data resources for the collation and interpretation of inshore fisheries data;
- Development of a relational databased and user interface;
- Engagement with inshore sector to promote and inform;
- On board surveyors; and
- Identifying fishing activities and their associated drivers.

With increased availability of quantitative data for the under 12 metre fleet, consideration should be given to the development of methodologies to integrate this data with that available for vessels over 12 metres in length (i.e. VMS). The combination of spatial information from the two fleets would allow a comprehensive representation of all fishing activity in a given area (see Kafas et al 2014b).

Another aspect of importance to appropriately characterise fishing activities, both in inshore and offshore waters, relates to their seasonal and annual change. The latter is of particular importance to some fisheries such as scallop dredging, where the fishery shows a cyclical pattern, with good grounds rotating around the UK on a 7-8 year cycle (Cappell et al 2018). To date, spatial mapping of fishing activities used to inform marine spatial planning and impact assessments, tends to be presented as average data for various years or as annual data for a limited number of years (i.e. The Scottish Government 2019, DECC 2016, Vanstaen and Breen 2014, Kafas et al 2013; 2014a). In addition, it often includes little or no quantitative data to allow the identification of key fisheries seasonal constraints and long-term patterns and cycles. Guidelines for data acquisition to support marine environmental assessments of offshore renewable energy projects (Judd 2012) suggest that at least five years of fisheries data should be used to inform commercial fisheries assessments. However, the level of data ideally required to appropriately characterise seasonality and annual variations may vary significantly depending on the fishery and region under consideration and therefore may need to be considered on a case-by-case basis.

A summary of the key fisheries datasets currently available to inform commercial fisheries assessments is provided in Table 3.

Table 3 Summary of key fisheries data

Dataset	Data holder (s) and data collection	Data accessibility	Data Coverage
Landings data by ICES rectangle	The Marine Management Organisation (MMO) holds information on all landings into England, Wales and Northern Ireland and the Isle of Man by UK vessels and of landings abroad by vessels administered by MMO, Welsh Government, DAERA and Isle of Man Department of Environment, Food and Agriculture. Marine Scotland provides figures for landings into Scotland by all UK vessels and landings abroad by Scottish administered vessels. Once accepted as valid and complete, activity and landings data for the UK are compiled in a central	Data is available for direct download from the MMO and Marine Scotland's websites [2,3].	The landings data by ICES rectangle available for download from the MMO provide summaries of fishing activity for UK commercial fishing vessels that are deemed to have been fishing within a specified calendar year. These summaries have been aggregated by month of landing, the ICES division and rectangle fishing activity took place in, the length group of the vessel and the gear group used. For each aggregation the quantity (tonnes) of live weight fish landed, the actual landed weight (tonnes) and value (sterling) of live weight fish landed are given for specific species, with

[2] Marine Management Organisation Search Results - data.gov.uk
[3] Marine Scotland Open Data – Fisheries Group

Dataset	Data holder (s) and data collection	Data accessibility	Data Coverage
	database containing vital information from the systems managed by MMO and Marine Scotland1.		the remaining species combined into a composite group based on the species group they are classified to. The gear categories are comprised as follows; beam trawl; pelagic seine; demersal trawl & seine (includes all trawl gears (except beam trawl) and all seine gears (except purse seine); dredges; drift & fixed nets; gears using hooks; other mobile gears; other passive gears; and pots & traps. Similar landings by ICES rectangle annual data summaries are available for download from Marine Scotland separately by individual species, species group. month and vessel length category.
Annual VMS Data	MMO produces summaries of fishing activity for UK commercial	Dataset available for direct download	Whilst since 2012 vessels over 12 m have been required to have working

[1] Fishing data collection, coverage, processing and revisions - GOV.UK (www.gov.uk)

Dataset	Data holder (s) and data collection	Data accessibility	Data Coverage
combined with logbook data	fishing vessels of 15 m and over in length on an annual basis based on VMS data combined with logbook data.	from the MMO website [4].	VMS systems on board, the VMS combined with logbook datasets made publicly available to date, have only been compiled for vessels over 15 m in length and over. Data is filtered by speed so that only vessels deemed to have been fishing are included. Data is provided into aggregated gear groups. No information on individual vessels is disclosed. The dataset covers activity by UK vessels in UK waters and beyond.

[4] Marine Management Organisation Search Results - data.gov.uk

Dataset	Data holder (s) and data collection	Data accessibility	Data Coverage
	Marine Scotland has created aggregated VMS datasets based on ICES data. ICES collected relevant VMS and logbook data to produce, as a technical service to OSPAR, updated spatial data layers on fishing intensity/pressure.	Data layers are available from NMPi[5] Additional VMS data for Scottish waters held by Marine Scotland, may be obtained via data request.	These are available for bottom otter trawls, dredges and crustaceans caught by bottom trawl (i.e. *Nephrops*) and are provided as average fishing effort (hours) for the period 2009-2016). The dataset only provides information on activity by UK vessels within Scottish waters.
2009 – 2013 Amalgamated VMS data layers	Marine Scotland (Kafas et al 2013)	Data layers available for direct download from NMPi	These data layers only cover activity of UK vessels over 15 m in length. The spatial extent of the dataset is limited to Scottish waters. Data is provided separately by fishery (i.e. scallop fishery, *Nephrops* fishery, demersal (white fish fishery).

[5] Marine Scotland - National Marine Plan Interactive (atkinsgeospatial.com)

Dataset	Data holder (s) and data collection	Data accessibility	Data Coverage
			Only includes data for the period 2013 to 2019. The data layers provide a heat map of fishing activity (“displayed as fishing intensity”) rather than value or effort.
ScotMap	Marine Scotland	Data layers available for direct download from NMPi.	Inshore fisheries mapping data layers including spatial information on activity of Scottish-registered vessels of under 15 m in length. Only includes data for the period 2007 to 2011. The data is aggregated to provide information on the monetary value, relative importance and usage of seas around Scotland. Subsets are divided by gear.

Next steps in research
Aspects relating to the limitations of the existing fisheries data and their application for assessment of impacts from MRE projects have been and continue to be a key topic for discussion between regulators, researchers and fisheries stakeholders (Rodwell et al 2013, de Groot et al 2014). It appears that whilst currently available data allows the characterisation of fishing activity in a comprehensive way, the existing datasets are subject to various sensitivities and limitations, particularly when used to identify activity within localised, discrete, sea areas.

In addition, confidentiality and data privacy issues with regard to the activity of individual vessels and the use of broad gear categories not linked to specific fisheries/fleet segments in the VMS datasets, make the undertaking of assessments that accurately identify the relative importance of a given area to specific fisheries difficult. The limited quantitative data currently available for the under 12 metre fleet is also a key constraint to the accurate mapping of fishing activity. Whilst significant research and consultation has been undertaken to characterise the activities of the under 12 metre fleet around the UK, no specific guidance or standard methods have been developed to aid the integration of data from consultation in quantitative assessments or to facilitate the updating of data already collected on a regular basis.

With this in mind, the following next steps in research have been identified to address current knowledge gaps in respect of “Evidence Gap FF.01: Accurate mapping of fishing effort and catches in space and time”:

- Development of detailed guidance in respect of data requirements to inform commercial fisheries impact assessments, including recommendations to facilitate analysis of seasonal and annual variations for key UK fisheries.
- Development of data layers which allow mapping of fishing activity by fleet segment or fishery.
- Development of methodologies to facilitate the integration of data and information collected through consultation with fisheries stakeholders into quantitative assessments and the regular update of such information.

The above would allow standardisation of the impact assessment process and facilitate the undertaking of more robust impact assessments, both at project specific level and in a cumulative context.

Evidence Gap FF.02: Accurate and validated method to predict fisheries displacement levels and locations

Review of current knowledge

The potential for MRE projects, particularly offshore wind farms, to result in loss of fishing grounds or restrictions in access leading to displacement of fishing effort, is one of the key concerns of fisheries stakeholders since the development of projects started in the UK and in other countries (Mackinson et al 2006, Hooper et al 2015, Reilly et al 2015, Hagos 2007, ten Brink and Dalton 2018).

Research and studies on fisheries displacement to date, however, have for the most part been focused on displacement effects associated with fisheries management measures such as closed areas (Dinmore et al 2003, Rijnsdorp et al 2001). In recent years this has been focused on displacement effects related to the implementation of management measures in Marine Protected Areas (MPAs) (ABPmer 2017, Vaughan 2017, Slijkerman and Tamis 2015, Goñi et al 2011, Greenstreet et al 2009).

Studies specifically focused on identifying displacement as a result of the introduction of MRE projects are limited. In the UK, Gray et al (2016) investigated the changes to fishing activity associated with six operational offshore wind farm projects in the Irish Sea (Robin Rigg, Walney 1 & 2, Ormonde, Barrow and Burbo Bank). This was undertaken through the analysis of available fisheries data (i.e. landings data, VMS, surveillance sightings, etc) and a consultation exercise via the circulation of questionnaires to local fishermen, fisheries managers and offshore wind developers. The study identified a large reduction in fishing effort and landings of demersal finfish in the area, most likely associated with reduced Total Allowance Catches (TACs) rather than as a result of offshore wind farm development. For the *Nephrops* fishery, it was found that landings had remained fairly stable before and after wind farm construction, however, the analysis of VMS data suggested a decline in trawling activity for *Nephrops* in Walney 2. In the other wind farms the decline in fishing activity appeared to be less obvious. The results suggest that there was a displacement of fishing effort to alternative grounds. The authors noted, however, that it was not known how much more effort, if any, was required to maintain landings.

In Belgium, trends in fishing effort and landings data from areas within and around various wind farms have been studied to help identify changes in fishing patterns (Degraer et al 2019). These investigations have found decreases in fishing effort within the wind farms (as expected given that fishing is not permitted within Belgian operational wind farms) and no significant changes in fishing effort and landings from the key fisheries in the area (Belgian and Dutch beam trawl fisheries). No clear avoidance or attraction towards the edges of the wind farm arrays was identified. In wind farms situated further offshore, however, deviation maps (comparing fishing prior and after the installation of the wind farms) suggested that fishermen may be slightly attracted to the wind farm edges. In addition, the results suggested that the presence of Belgian wind farms did not affect the efficiency of the beam trawl fleet in catching sole, one of key target species in the area. In the case of plaice, this study found indication of increased catch rates around wind farms.

The outcomes of a project recently commissioned by Marine Scotland, aimed at developing good practice guidance for assessing fisheries displacement (”Developing good practice guidance for assessing fisheries displacement by other licensed marine activities”) anticipated to be available in 2021, are expected to provide good practice guidance that facilitates the development of standard methodologies for the assessment of displacement effects consistently across marine licenced activities, including MRE projects. Earlier work commissioned by Natural England (ABPmer 2017) also provides a comprehensive framework to aid the development of methodologies for assessing fisheries displacement, including recommendations for monitoring and research (ABPmer 2017). Whilst Natural England’s study was focused on the effects of displacement associated with MPAs, its conclusions and recommendations are also of relevance with regard to potential displacement effects arising from MRE projects.

Key factors identified in Natural England's study in determining the potential displacement of fishing activities to other areas are outlined below (ABPMer 2017):

- Expectation or occurrence of localised 'spill over' effects;
- Availability of alternative fishing grounds (taking account of technical considerations of the gears used, etc);
- Knowledge of alternative fishing grounds;
- Distance from port (fishing range and steaming time);
- Individual fishermen strategies and preferences; and
- Availability of fishing rights and quota.

In the particular case of offshore wind farm projects in UK waters, however, as fishing within operational wind farms is permitted, the viability of fishing within them is also a key factor in determining potential fisheries displacement effects.

The level of compatibility that fishing can achieve with offshore wind farm projects is dependent on aspects such as project design parameters, fishing vessel and gear specifications, operational requirements, liabilities for damages to infrastructure and health and safety related issues. Key aspects of relevance in this context include:

- Minimum spacing and width of corridor clear of infrastructure between turbines;
- Windfarm design and configuration;
- Foundation type (floating vs. fixed foundations);
- Approach to cable burial, protection and monitoring;
- Fisheries liaison and communication strategy;
- Free-hanging dynamic cables in the water column (for floating offshore wind);
- Vessel manoeuvrability, operating patterns, and gear type (active vs. passive) and dimensions; and
- Level of contact of the fishing gear with the seabed (i.e. seabed penetration depths).

In this context it is important to note that comprehensive guidance with regard to fishing specific requirements and wind farm design compatibility is currently not available. Such technical guidance would be useful to enable accurate assessments of potential displacement effects associated with MRE projects in UK waters (see section on “Evidence Gap FF.14: Co-existence with commercial fishing”).

In addition, it should be acknowledged that whether fishing activity resumes within a wind farm or whether it is displaced elsewhere, and the level at which this takes place, would also be strongly influenced by behavioural aspects. Individual skippers may have differing views with regard to operating fishing gear within operational wind farms.

As described above, aspects requiring consideration to assess fisheries displacement are wide ranging, covering environmental, behavioural, technical and economic factors. The development of accurate and validated methods to predict displacement therefore requires the use of complex modelling tools. Significant research, studies and models have been developed in recent years to assess and predict displacement effects associated with MPAs (e.g. Chollet et al 2016, Bastardie et al 2015, Hynes et al 2016, Girardin et al 2015, Tidd et al 2012, Greenstreet et al 2009). Existing tools developed to assess displacement in relation to MPAs could be adapted to take account of wind farm specific parameters (e.g. viability of fishing within wind farms) and contribute to inform displacement assessments in respect of MRE projects.

Approaches which develop modelling scenarios able to integrate displacement effects from relevant licenced activities and management measures (i.e. closed areas associated with MPAs) and that allow incorporation in the strategic planning process, rather than focusing on the effect of displacement from individual projects alone, would provide more realistic outcomes. In this context it is important to note that fishing effort displaced from a specific MRE project may be relocated at considerable distances and can be influenced by displacement effects which occur elsewhere as a result of other marine projects and activities. As fisheries displacement effects tend to be cumulative in nature, their assessment requires a strategic approach which takes account of impacts from other marine activities rather than a project specific focus.

Next steps in research

As described above, limited studies have been undertaken to date to understand displacement effects on commercial fisheries and the majority of these have been predominantly focused on displacement effects associated with MPAs rather than MRE development. This knowledge gap limits our ability to undertake accurate assessments of the effect of MRE development on commercial fisheries at the project specific level but also in a cumulative context.

As displacement associated with a given project is influenced by a wide range of factors, including changes to fishing activities as a result of other projects/activities, complex modelling tools will likely be required to aid the undertaking of robust assessments. Such tools should allow the integration of relevant licenced activities and management measures with implications for fisheries displacement in addition to MRE developments.

Considering the above, the following next steps in research have been identified in respect of “Evidence Gap FF.02: Accurate and validated method to predict fisheries displacement levels and locations”:

- Undertaking of strategic studies and monitoring of changes to fishing activities and displacement associated with existing offshore wind farms in the UK; and
- Development of modelling approaches that allow the integration of relevant licenced activities and management measures with implications for fisheries displacement.

As the level of fisheries displacement that may occur in relation to MRE development is strongly dependent on the level of co-existence achieved between projects and commercial fishing, research recommendations under “Evidence Gap FF.15: Coexistence with commercial fisheries” are also of relevance to address current evidence gaps in respect of displacement effects.

Evidence Gap FF.03: Fisheries stakeholders integration and participation process

Review of current knowledge

The early stages of marine planning, whether integrated or sectoral, are considered crucial to prevent conflict with other activities, and particularly with fisheries (Dupont et al 2020). Ensuring that appropriate fisheries stakeholder participation takes place as part of the development process of MRE projects, is of critical importance to facilitate co-existence between the two sectors. The implementation of timely and effective communication, including engagement, consultation, coordination and information exchange, is widely acknowledged as being essential in promoting co-existence (Moura et al 2015, FLOWW 2014, BOEM 2020).

To facilitate the participation of fisheries stakeholders, however, consideration needs to be given to the arrangements that fishermen may need to engage in consultation. In many cases fishermen are based in remote locations and may need to take time off fishing to attend meetings. In addition, not all fishermen are part of local, regional or national fisheries organisations. Therefore, the interests of some fishermen may not be represented in certain consultation forums.

In the UK, early discussion of fisheries and offshore energy related matters is often undertaken in the context of marine spatial planning (MSP). The benefit of MSP associated processes to facilitate the identification of potential conflicts between planned activities and fisheries has been demonstrated in practice both in the UK and abroad (Haggett et al 2020). For instance, outputs of participatory fisheries mapping work sponsored by the Scottish Government (ScotMap) have been used to inform marine policy development in Scotland (see Kafas et al 2017). In addition, the recently developed Sectoral Marine Plan for Offshore Wind Energy in Scotland, includes reference to specific feedback from the fishing industry with regard to areas within Development Plan Options (DPOs) which could facilitate co-existence with fishing (The Scottish Government 2020a).

Similar approaches to participation and integration of fisheries stakeholders' views at an early stage in the planning process have also proved effective in the United States (Hagget et al 2020, Pol and Ford 2020).

In the UK, in addition to consultation as part of MSP, liaison between fisheries stakeholders and developers at a strategic level is further facilitated by the

Fisheries Liaison with Offshore Wind and Wet Renewables Group (FLOWW), established in 2002. Guidance developed by this group sets out good practice with regard to liaison and communication and guides the identification of potential effects and co-existence opportunities (FLOWW 2014, FLOWW 2015).

The establishment of Commercial Fisheries Working Groups (CFWG) has also played an important role in facilitating engagement between developers and fisheries stakeholders for many offshore wind farm projects across the UK.

In Scotland, this has been undertaken on a regional basis through the establishment of the Forth and Tay CFWG and the Moray Firth CFWG. For developers with projects in these two regions, participation in the relevant CFWG has generally been a requirement under consent conditions.

In the rest of the UK, participation in or establishment of CFWGs is not a standard requirement as part of individual project's licence conditions. In some instances, however, developers have voluntarily set up CFWGs to facilitate engagement with local fishermen. This has been undertaken on a project specific basis or to cover various projects located within a given region.

Whilst CFWGs may be a useful as tool to facilitate engagement with fisheries stakeholders, their need and format should be considered on a case-by-case basis.

In addition to participation in relevant industry groups and as part of MSP, at project specific level, fisheries stakeholder engagement is facilitated as part of the planning application consultation process. Specific guidance on the requirements of the consultation process with fisheries stakeholders at this stage is however currently lacking, and therefore, the level of consultation undertaken and overall fisheries stakeholders' consultation strategy adopted by different projects may vary significantly. The establishment of clear guidelines on this topic may help the implementation of a consistent consultation framework across projects, reduce the potential for conflicts to arise and manage stakeholders' expectations from an early stage.

Following development consent, on-going engagement with fisheries stakeholders is facilitated through the implementation of Fisheries Liaison and Co-existence Plans (FLCP) (known as Fisheries Management and Mitigation Strategies (FMMSs) in Scotland).

At present, the development and implementation of FLCPs/FMMSs is normally included as a condition to consent for offshore wind farm projects across the UK. These documents outline the developers' approach to liaison with the fishing industry and the measures proposed to minimise and mitigate interference to fishing. FLCPs/FMMSs are developed with reference to relevant FLOWW guidance, with consideration of feedback from fisheries stakeholders and require approval by the regulator. FLCPs/FMMSs are also aimed at clearly identifying the role and responsibilities, in respect of fisheries related matters, of developers, Fisheries Liaison Officers (FLOs) and other relevant liaison roles (i.e. Offshore Fisheries Liaison Officers (OFLOs) and Fishing Industry Representatives (FIRs)) (FLOWW 2014, FLOWW 2015).

Guidance specific to the development of FLCPs/FMMSs is currently being developed by Marine Scotland (Draft Guidance on Producing a Fisheries Management and Mitigation Strategy ("FMMS") (Marine Scotland Science (draft) 2020). In addition, existing FLOWW guidance (FLOWW 2014, FLOWW 2015) is currently under review. These new guidelines will further assist in the production of future project-specific FLCPs/FMMSs.

Next steps in research

As described above, collaborative planning and appropriate engagement and communication with the fishing industry is key to reduce potential conflict and facilitate co-existence. Engagement and consultation with fisheries stakeholders are encouraged and facilitated at the various stages of MRE development in the UK, from early planning throughout the operational phase of the projects. There is a lack of detailed guidance, however, on the level of engagement and approach to consultation with the various fisheries stakeholders which needs to be implemented by individual projects during the planning application process.

Engagement with fisheries stakeholders at a strategic level (i.e. facilitated by FLOWW or other suitable industry wide forums) to discuss perceived shortfalls in the current consultation process with regard to integration and participation, as well as the need to develop specific guidelines on this matter, if appropriate, is strongly recommended.

Evidence Gap FF.04: Improvements in environmental impact assessment methodologies

Review of current knowledge

The commercial fisheries impact assessments methodologies used in EIAs for MRE developments in the UK normally use a generic EIA impact significance matrix approach based on the identification of receptor sensitivity and impact magnitude, similar to that used of other topics, and take account of relevant existing guidelines (i.e. BSI 2015, Seafish 2012, Cefas and MCEU 2004). Whilst the existing guidance documents include consideration of fisheries related aspects where appropriate, they do not establish standard criteria to aid in the evaluation of receptor sensitivity, impact magnitude and ultimately, impact significance.

In addition, as mentioned under "Evidence Gap FF.01: Accurate mapping of fishing effort and catches in space and time", the fisheries data and information currently available are subject to a range of sensitivities and limitations, including significant differences in the data collected for inshore and offshore fleets and difficulties to link spatial data to specific fleet segments or fisheries. As a result, the methodologies used for assessment of impacts from MRE developments on commercial fisheries to date, whilst supported by analysis of quantitative fisheries data and information, have been qualitative in nature.

In order to facilitate the identification of suitable quantitative thresholds that can be used to inform assessments, where appropriate, fisheries data available across relevant fleet segments require harmonisation, so that consistent criteria can be applied across fisheries receptors.

Furthermore, key parameters requiring consideration, particularly with regard to the assessment of loss of access to fishing grounds and associated displacement (i.e. operational range, availability of grounds, viability of fishing within operational sites, etc) need to be better defined by fleet segment (see "Evidence

Gap FF.01: Accurate mapping of fishing effort and catches in space and time", "Evidence Gap FF.02: Accurate and validated method to predict fisheries displacement levels and locations" and "Evidence Gap FF.15: Co-existence with commercial fisheries").This would facilitate the identification of suitable quantitative thresholds, where appropriate.

With regard to the assessment of loss of fishing grounds and associated displacement, it is anticipated that the outcomes of the project commissioned by Marine Scotland to develop good practice guidance for assessing fisheries displacement (see "Evidence Gap FF.02: Accurate and validated method to predict fisheries displacement levels and locations") will help inform the development of standard assessment methodologies.

Next steps in research

Guidance currently available to inform the undertaking of commercial fisheries assessments for MRE developments lacks detail on key methodological aspects such as receptor sensitivity and impact magnitude criteria. In addition, the limitations of the fisheries data that are available to inform assessments together with the existing uncertainty in respect of the degree of compatibility of the various fishing activities within operational MRE projects, make quantifying impacts in a standard manner difficult.

It is therefore recommended that standard commercial fisheries impact assessment methodologies are developed. This would allow the undertaking of assessments that are consistent across MRE projects for all fisheries receptors, increase the robustness of the assessments at the project specific level and improve the ability to undertake more detailed cumulative impact assessments.

The implementation of the recommendations proposed with regard to "Evidence Gap FF.01: Accurate mapping of fishing effort and catches in space and time", "Evidence Gap FF.02: Accurate and validated method to predict fisheries displacement levels" and "FF.14: Co-existence with commercial fisheries", would also contribute to the improvement of EIA methodologies and assessment outputs.

Evidence Gap FF.05: Strategic fisheries management

Review of current knowledge

UK fisheries management strategies and policies give due consideration to aspects relating to how the marine space can be best shared to ensure that the best decisions are made for the marine environment as a whole as well as for all those that depend on it (The Scottish Government 2020a, UK MPS 2011).

As competition for the marine space continues to increase, attention has been given in recent years to the potential for co-location of MRE with other activities and its potential role in fisheries management (Ashley et al 2014, Ashley et al 2018, Christie et al 2014, Roach et al 2018).

MRE projects may act as de facto MPAs or no-take areas, as the presence of infrastructure and associated works may limit the level of fishing activity that can be undertaken within their boundaries. Co-location of MRE projects and areas closed to fishing associated with management measures in MPAs could therefore minimise potential cumulative losses of fishing grounds to the fishing industry. This may be particularly the case for demersal towed gear fisheries as these are generally more constrained than static gear fisheries to operate within operational wind farms, and are more likely to be restricted in MPAs to protect qualifying habitats/species.

Furthermore, the presence of MRE infrastructure has potential to provide protection to fisheries resources, result in spill over effects and improve the productivity of some fisheries.

Studies where the impact of MRE development on fisheries resources and its potential role as a tool for fisheries management has been directly investigated are however limited to date. Roach et al (2018) investigated the ecological effect of a short-term closure of European lobster fishing grounds, associated with the construction of the Westermost Rough offshore wind farm, and found that the temporary closure offered some respite for adult animals and led to increases in abundance and size of the target species in the area. The findings of this study suggest that temporary closures of selected areas may be beneficial and offer a management option for lobster fisheries.

Robertson et al (2021) studied the potential for Gunfleet Sands wind farm to act as an oyster broodstock site for the Blackwater, Crouch, Roach and Colne Estuaries Marine Conservation Zone (MCZ), the only UK designation for native oyster beds. The study considered aspects such as environmental tolerance of native oyster, hydrodynamics, operational requirements and potential designs, and identified limited viability for a broodstock site at this location. It is understood that the findings of this study formed the foundation of a wider scoping analysis of over 50 UK offshore wind farms. Roberston et al (2021) reported that initial results from the wider scoping study identified several sites that may be suitable for restoration and habitat enhancement of native oysters and noted that the scoping is being extended to include other species and habitat enhancement opportunities. The results of this additional research are however yet to be published.

As described under “Evidence Gap FF.12: Reef/fish aggregation effect”, extensive monitoring of fish and benthic communities has been undertaken outside of the UK within European offshore wind farms. Fishing is not permitted in the majority of these wind farms and therefore they act as closed areas to fishing. Monitoring programmes in some of these sites have identified that the abundance of some species has increased in the vicinity of the foundations and in the wider area (van Hal et al 2017, Degraer et al 2018).

Similarly, recent research using modelling tools to predict the effect of the spatial closure of an offshore wind farm in the Bay of Seine, France (Halouani et al 2020) found an increase of catches and a slight increase in the proportion of high-trophic level fish species associated with the closure. The influence of the predicted spill over effect was localised to areas around the wind farm, within a 3 km radius.

In addition to research and data from existing wind farms, data and lessons learned from studies undertaken in relation to the effect of closed areas to fishing within MPAs, can aid future investigations on the potential role of MRE projects in fisheries management. These studies generally suggest potential for positive effects in nearby fishing grounds, however, whether or not the spill over effects identified result in direct benefits to fishermen and the fishing industry is still poorly understood (Russi et al 2016).

The potential for fishing closures to result in positive effects, through spill over effects, or other mechanisms, should be considered on a case-by-case basis. Buxton et al (2014) note that spill over effects associated with closures are more likely in areas where a fishery is highly depleted and/or where management controls are absent.

In addition, when considering the potential for offshore wind farms to act as MPAs and play a role in fisheries management, the dissimilar nature of assemblages on the structures themselves to natural communities needs to be carefully considered (Ashley et al 2014).

Furthermore, it may be difficult to distinguish impacts associated with the introduction of hard substrate (i.e. reef effects) from those associated with potential reductions in fishing activity or closures to fishing. Cause-effect relationships should therefore be investigated to understand the contribution of each factor to observed changes (Vandendriessche et al 2015).

Next steps in research

As identified in the literature review above, limited research has been undertaken to date to assess the impact of MRE development on fisheries resources and its potential role as a tool for fisheries management. In order to address this evidence gap the following recommendations are proposed:

- Research within offshore wind farms where fishing is restricted to better understand if there is a recovery of habitats and species, timescales of such recovery and potential for spill over effects and associated benefits to fishermen;
- Research on the potential of MRE installations for stock enhancement and development of pilot studies at suitable individual sites.
- Research on the feasibility of co-location of MPAs and offshore wind farms in the UK context.
- Development of modelling tools to identify potential effects of fishing closures in wind farms to inform management decisions (i.e. see Holouani et al 2020).

Recommendations under “Evidence Gap FF.11: Reef/fish aggregation effect”, would also be of relevance to inform strategic fisheries management options.

Evidence Gap FF.06: Underwater noise and vibrations

Review of current knowledge

The majority of fish and invertebrates use sound for vital life functions (communication, detection of prey and predators, mating, orientation and migration, habitat selection, etc) (Spiga et al 2012, Hawkins and Popper 2017, Weilgart, 2018, Popper and Hawkins 2019) and there is growing evidence that the introduction of man-made sound in aquatic environments has the potential to affect (Hawkins and Popper 2018) the ability of fish to detect and use the biologically relevant sounds that are important for their survival. Furthermore, it is well established that intense sounds not only affect fish sound detection and behaviour but also have the potential to have physiological and physical effects that could result in reduced fitness and in some cases death (Hawkins and Popper 2018). Behavioural responses are of particular concern if fish become more exposed to predators, are displaced from key habitats such as feeding and spawning grounds, their migrations are affected or experience disruption of communication between individuals (Hawkins et al 2020).

Concerns on underwater noise related effects on marine fauna associated with MRE development tend to be primarily focused on the potential impact of intense sounds such as those associated with unexploded ordnance (UXO) detonations and impact pile driving during construction works.

Noise associated with wind turbine vibration during operation, and other sources of continuous noise such as engine noise from survey, construction and operation and maintenance vessels, and drilling and dredging activities, however, can also contribute to increased ambient noise levels.

Whilst general effects of noise on fish and invertebrates have been reviewed extensively in recent years (e.g. Popper et al 2014, Radford et al 2014, Williams et al 2015, Kunc et al 2016, Hawkins and Popper 2017, Popper and Hawkins 2019), there are still significant gaps in our current knowledge.

Particle Motion

Sound waves have both a sound pressure and a particle motion component, however, most fish and invertebrates primarily sense sound using particle motion rather than sound pressure. Yet, despite its relevance to fish and invertebrates, few studies have measured the particle motion component of sound (Mueller-Blenkle 2010) and the role of particle motion in the biology and ecology of fish and invertebrates is largely unknown (Nedelec et al 2016). In addition, even for species that only sense particle motion, existing noise exposure criteria, based on current best practice guidelines (Popper et al 2014), are fully based on sound pressure.

There is therefore a need to better describe the characteristics of sound propagation in terms of particle motion, and in particular the propagation of sound and vibration through the seabed as this is especially relevant for benthic fish species and invertebrates. The monitoring of particle motion along with sound pressure and the development of instrumentation and software for this purpose has been identified as a high research priority in this field (Hawkins et al 2015). As identified in the current ScotMER fish and fisheries evidence map, best practice guidance on measuring particle motion is currently being developed by Exeter University and partners (publication expected in 2021).

In order to update current exposure criteria and guidelines for fish, taking account of the particle motion component of sound in addition to sound pressure, it is important that data on fish hearing sensitivity to particle motion is also collected (Popper and Howkins 2019). Much of the current data has been obtained either under unsatisfactory acoustic conditions or by means of physiological measurements and do not give an accurate indication of the detection ability of the animals. More detailed knowledge of the hearing abilities of fish and invertebrates is required, including the development of audiograms based on behavioural analysis (Hawkins et al 2015, Popper and Howkins 2019).

Behavioural impacts in fish

Quantitative criteria to address behavioural responses in fish are yet to be developed. Current noise exposure criteria (Popper et al 2014) only provide thresholds for the onset of Temporary Threshold Shifts (TTS), recoverable injury and mortality, in response to various impulsive sound sources (including pile driving), and for shipping and continuous sounds. As behavioural effects are strongly dependent on behavioural context and responses may not scale with sound level, there is considerable uncertainty in assessing risk of behavioural responses (Faulkner et al 2018). The use of experiments using new technologies, such as active acoustics tagging, to gather detailed observations on the behaviour of animals in the natural environment should therefore be encouraged (Hawkins et al 2015).

Impact on invertebrates

In recent years, studies of the effect of underwater noise effects on marine fauna have been increasingly focused on invertebrates, including crustaceans, and molluscs (Tidau and Briffa 2016, Edmonds et al 2016, Solan et al 2016, Jones et al 2020). The existing available data, however, is not considered sufficient to allow the definition of noise exposure criteria for invertebrates (Popper et al 2014). As a result, in the absence of specific criteria, assessments of the impact of noise on invertebrates have to draw on the evidence collected in existing studies (Faulkner et al 2018) and cannot be informed by detailed project specific noise modelling.

Mitigation options

In addition to improving the existing knowledge on the effect on noise on fish and invertebrates, suitable approaches to minimise potential impacts also need to be developed and implemented. These require consideration of the use of biological information to minimise impacts as well as of potential changes to the sound sources to minimise noise levels.

Hawkins et al (2015) highlights the need to improve our knowledge on identification of critical habitats, migration routes and reproductive periods so that exposures during these sensitive phases can be avoided. The development of suitable mitigation strategies in relation to underwater noise on fish is therefore closely linked to “Evidence Gap FF.09: Accurate spatio-temporal patterns of spawning activity” and “Evidence Gap FF.10: Essential fish habitat”. In this context it is important to note that standard noise mitigation measures implemented in the UK are generally focused on marine mammals (i.e. soft start piling, acoustic deterrent devices (ADDs), Marine Mammal Observers (MMOs)) rather than specifically designed to minimise impacts on fish. To date, where there has been a requirement to mitigate potential noise impacts on specific fish species, this has been generally addressed via consent conditions which impose restrictions over noise generating activities during specific periods of time and/or in specific areas. In some instances, initial restrictions have been lifted or reduced following the provision of additional evidence by developers (i.e. through survey work, additional noise modelling, etc).

With regard to potential mitigation measures in respect the reduction of sound sources to minimise noise levels, Merchant and Robinson (2020) and Verfuss et al (2019) provide comprehensive reviews of the current state of knowledge on the feasibility of different noise abatement options, including detailed information on the following technologies (see Table 4):

- Bubble curtains;
- Casings;
- Resonators; and
- Alternative hammers (i.e. Vibratory Hammer and Blue Hammer).

Table 4 Noise abatement technology summary (Merchant and Robinson (2020), Verfuss et al (2019))

Technology	Feasibility
Percussive pile driving	• Bubble curtains: demonstrated to be effective in waters up to 45 m (less effective as water depth increased due to dispersion of bubbles). • Casing-based systems: demonstrated in waters up to 45 m. Constrained by the availability of large enough systems for the water depth. • Encapsulated resonator systems: unlimited by water depth in principle.
Alternative turbine foundations and piling methods	• Vibratory hammer (used in combination with pile driving in Germany but can also be used in isolation). • Blue Hammer (under development). • Gravity base foundations, suction buckets and floating foundations.
UXO clearance	• Bubble curtains: already being deployed in UK waters for this purpose.

Technology	Feasibility
	• Low-order detonation via deflagration: viable option to avoid explosive detonation altogether. Logistical implications of deploying this method during UXO clearance need to be better understood.

Merchant and Robinson (2020) noted that no new policy would be needed to implement noise abatement in UK waters for offshore wind farm installation or detonation of UXO and conclude that their deployment would be feasible at locations where offshore wind farms are proposed in UK waters.

The above technologies have been successfully deployed in other parts of the North Sea to reduce the risk of impact on marine life. However, abatement measures are generally implemented to specifically address potential impacts on marine mammals, with fish being of secondary focus in this respect, and tend to be more effective at reducing risks for marine mammals and fish species that are sensitive to high frequencies sounds (>100 Hz) (Verfuss et al 2019).

In many countries, including the UK, it is rare for such technologies to be required by regulators, and the effect zones that would be achieved through their use are generally not modelled as part of the assessment process for MRE projects. The incorporation of noise abatement options in the noise modelling exercise together with the use of standard methods and metrics across EIAs, would help the undertaking of assessments at the project level that can feed into consistent cumulative assessments (Faulkner et al 2018).

Next steps in research

As identified above, there are significant data gaps in our understanding of how underwater noise affects fish and invertebrates and existing tools to help assessments need improving. In order to address the identified knowledge gaps, the following next steps in research are recommended:

- Collection and measurement of noise data, including measurements of particle-motion.
- Development of updated noise exposure criteria for fish to take account of the particle motion component of noise.

- Development of audiograms for key species using behavioural analysis.
- Strategic research to investigate the scale of the effect of noise exposure on fish and invertebrates that may result in population level impact or economic impact to fisheries.
- Development of detailed guidance to help the assessment of behavioural effects on fish.
- Provision of guidance on the approach to be taken for assessment of impacts on invertebrates in the absence of standard noise exposure criteria for this group.
- Collection of improved data and information on the behavioural effect of noise on fish and invertebrates
- Testing of noise abatement methods at wind farms during construction and their effectiveness in mitigating impacts on fish.

Evidence Gap FF.07: Electromagnetic fields (EMF)

Review of current knowledge

Sources of MRE related EMFs include inter array cables between devices (fixed foundations and floating) and substations, and export cables. AC power transmission cables are more commonly used for offshore renewable projects, however, DC cables are also currently used and are expected to become more widely used as the siting of projects moves further offshore (Hutchinson et al 2020b).

Magnetic or electric senses have been reported for a wide range of marine animals, including many groups of fish and several invertebrate groups. The ability to detect electric fields is well documented for elasmobranch species. These are generally considered to be the most electro sensitive species group as they possess a highly sensitive electrosensory system (ampullae of Lorenzini). In addition, species such as lampreys, sturgeons and a few teleost fish also have advanced electro-sensory systems. Few invertebrates have been tested for an electric sense, however, there is evidence of a response to EMFs from various species, including crustaceans such as crabs, shrimp and lobsters (Normandeau et al 2011).

Given the expansion of the MRE industry across Europe and internationally, interest has grown in recent years in improving our understanding of the potential impact of EMF on marine organisms.

In the UK, early studies on the effect of EMFs associated with MRE projects were undertaken by COWRIE (Collaborative Offshore Wind Research into the Environment), an independent body set up by The Crown Estate, and were focused on fish species, particularly elasmobranchs (Gill et al 2005; 2009).

Elasmobranchs naturally detect bioelectric emissions from prey, conspecifics and potential predators and competitors (Gill et al 2005). In addition, they are known to detect magnetic fields (Normandeau et al 2011).

Gill et al (2009) studied whether elasmobranchs responded to controlled EMF with the characteristics and magnitude of EMF associated with offshore wind farm power cables. The study took an experimental research approach where sections of subsea cables were enclosed (mesocosm study) to allow assessment of the responses of elasmobranchs in a semi-natural setting. The research found that the benthic elasmobranchs studied (thornback ray and lesser spotted catshark) can respond to the presence of EMF of the type and intensity associated with subsea cables. However, their response was found not to be predictable and appeared to be species and individual specific. Thornback rays were found to be more likely to move around within the EMF zone whilst some catsharks were found nearer to the cable and restricted their movement within the EMF area. From this study, however, there was no evidence to suggest any positive or negative effect on elasmobranchs as a result of encountering the EMF.

Further research on lesser spotted catsharks (i.e. Kimber et al (2011)) found that this species are able to distinguish some types of electric fields but are either unable to distinguish between or at least show no preference for other types. They showed a significant preference for the stronger DC electric field and a less pronounced, but still significant, preference for an AC electric field. No preference was demonstrated between an artificial and natural DC electric field. These findings suggest that these predators could potentially confuse prey bioelectric fields with artificial electric fields during foraging.

In recent years, there has been an increasing focus and research effort, in improving our knowledge of the impact of EMF on invertebrates, particularly species of commercial importance, and on early life stages.

Some examples of recent and planned future research on EMFs, including existing research on invertebrates and early life stages, are provided below:

- Love et al (2016) studied the effect on marine organisms of EMFs from subsea cables based on in situ observation around energised and unenergised cables in the Pacific Region. This study found no evidence that there were significant differences in fish communities or in invertebrate assemblages between energised and unenergised cables. Similarly, it found no evidence to suggest that electro-sensitive species such as elasmobranchs, were either attracted or repelled by the EMFs emitted from the energised power cables. The study also found that EMFs produced by the energised cables were similar over the three years of the study and along the cables and that the strength of the EMF dissipated quickly with distance from the cables (i.e. approached background levels at about one metre).
- Love et al (2017) studied the potential for energised cables off southern California to impact the Dungeness crab (*Metacarcinus magister* and other commercially important crab species in the area (*Cancer productus*). The research found no evidence that the EMF emitted by energised submarine power cables influenced the catchability of these two species. In addition, it found no difference in the responses of crabs to lightly buried versus unburied cables.
- Scott et al (2018) investigated the effect of simulated EMFs emitted from sub-sea power cables on edible crabs in the laboratory and identified a clear attraction to shelters that had a relatively high B-field and a decrease in roaming behaviour. In addition, the daily behavioural and physiological rhythmic processes of the haemolymph L-Lactate and D-Glucose levels were disrupted. The EMF did not however appear to affect stress related parameters (i.e. hemocyanin concentrations, respiration rate, activity level or the antennular flicking rate).
- Hutchison et al (2018; 2020a) quantified biologically relevant behavioural responses of American lobster (*Homarus americanus)* and the Little skate

(*Leucoraja erinacea),* to EMFs from a subsea high voltage direct current (HVDC) transmission cable. The study found an increase in exploratory/foraging behaviour in skates in response to EMF and a more subtle exploratory response in lobsters. In addition, through direct measurements of the magnetic field and electric field components of the EMF emitted by the cable, it was found that there were DC and, unexpectedly, AC components.

- Cresci et al (2019) studied the orientation mechanisms in haddock larvae through observations of 59 and 102 haddock larvae swimming in the Norwegian Sea and in a magnetic laboratory, respectively. The findings of the research in both settings identified that haddock larvae orientation at sea is guided by a magnetic compass mechanism. A similar study by Cresci et al (2020) focused on herring larvae, found no evidence of magnetic compass orientation for this species, indicating that the orientation direction of herring larvae is not magnetic during this early life stage.
- Taormina et al (2020) studied the potential impact of EMF on the behaviour of recently settled juvenile European lobster and found that juvenile lobsters did not exhibit any change of behaviour when submitted to an artificial magnetic field gradient (maximum intensity of 200 μT) compared to non-exposed lobsters in the ambient magnetic field. In addition, no influence was noted on either the lobsters' ability to find shelter or modified their exploratory behaviour after one week of exposure to anthropogenic magnetic fields (225 ± 5 μT) which remained similar to those observed in control individuals.
- Scott et al (2021) investigated the effects of different strength Electromagnetic Field (EMF) exposure (250 μT, 500 μT, 1000 μT) on the commercially important decapod, edible crab (*Cancer pagurus*). Stress related parameters were measured (L-Lactate, D-Glucose, Total Haemocyte Count (THC)) in addition to behavioural and response parameters (shelter preference and time spent resting/roaming) over 24 h periods. Exposure to 250 μT was found to have limited impacts, however exposure to 500 and 1000 μT was found to disrupt the L-Lactate and D-Glucose circadian rhythm and alter THC. The findings were that crabs showed clear attraction to EMF exposed shelters with significant reduction in time spent roaming. The study recommended the need for in-situ

measurements of EMF from existing cables and suggested that a working limit of a maximum of 250 μT could result in minimal physiological and behavioural changes within this species and should be considered during MRED design and implementation.

- Research is planned to be undertaken in 2021 at St Abbs Marine Station in Scotland, on the effects of EMF from renewable subsea power cables on coastal invertebrates (MASTS 2020). The objective of the research is to investigate the adaptation and resilience of coastal species by testing whether the simulated EMFs from MRE subsea power cables affect the post-disturbance recovery times, as an indicator of stress of coastal invertebrates. Experiments will be undertaken in tanks where various species of invertebrates (including various species of echinoderms, crustaceans and molluscs) will be exposed for 24 hours to either a control set-up or an active Helmholtz-coil used to general EMFs that will simulate those expected around a cable landing site. Individual animals will then be placed in tanks and their behaviour will be recorded using a CCTV system.

In addition to the specific studies outlined above, a number of comprehensive reviews on various key EMF related topics have been recently published covering magnetoreception and electroreception in fish (Formicki et al 2019, Newton et al 2019, respectively) and environmental impacts and interactions with marine organisms (Taormima et al 2018, Hutchison et al 2020b). In addition, the updated State of the Science report published in 2020, includes detailed consideration of the potential risk to fish and invertebrates from EMF associated with MRE projects (Gill and Desender 2020). The State of the Science report identified the following key aspects in relation to future research needs on the impact of EMF on these receptors:

- Cable characteristics and power transmitted determine the sources and intensity of the EMFs emitted. Therefore, quantifying these parameters in the aquatic environment would aid characterising emissions and accurate modelling.
- Field measurements of EMF intensity and its variability within the environment. This requires the development of affordable methods and equipment for measuring EMFs so that measurements taken at MRE project sites can be compared to power outputs of the devices.

- Further research on sensitive life stages (i.e. early embryonic and juvenile phases) of key receptors such as elasmobranchs, crustaceans and molluscs.
- Laboratory studies which consider EMF exposure at different intensities and durations, to determine species-specific thresholds and life stage-specific dose responses.
- Field studies using tagging and tracking systems to gather behavioural, and where appropriate, physiological evidence, for determining potential effects on mobile receptors of encountering multiple cables.
- The undertaking of field studies to address data gaps on the interaction of pelagic species and dynamic cables (cables in the water column).
- Long terms in situ studies to assess the effects of chronic EMF exposures on egg development, hatching success and larval fitness and potential implications of potential attraction of species to hard substrate associated with MRE projects (i.e. reef effect); and
- Demonstration of effects at the relevant biological unit of the species population (i.e. through replicated studies that show evidence of a consistent response).

Next steps in research

From the literature review undertaken it is apparent that our understanding of how marine species interact with EMFs has grown in recent years, however, evidence available to inform assessments and management is still limited and improved knowledge is required in relation to both, pressures and receptors.

The evidence available to date suggests that ecological impacts associated with MRE subsea power cables may be weak or moderate. However, this is based on evidence from a small number of studies and limited data, as a result uncertainty remains in relation to how EMF may affect fish and invertebrates (Gill and Desender 2020).

Taking account of the findings of the literature review presented above in respect of "Evidence Gap FF.07: Electromagnetic fields", the following next steps in research have been identified to address current knowledge gaps:

- Improvement of knowledge and increased facilitation of data sharing with regard to technical information on cable characteristics, cable transmission and measurements of EMFs from existing cables (both AC and DC), including information on cable burial status/location (i.e. buried, surface laid, dynamic).

- Additional research to establish species specific thresholds and further consideration of potential effects on early life stages (eggs and larvae).
- Development of pilot studies in UK operational MRE projects to identify EMF related impacts on fish species and other key receptors, including consideration of species of importance to the fishing industry. Such research could be combined with wider research initiatives to investigate other MRE operational related effects (i.e. reef effects).
- For mobile species, consideration should be given to studies which allow the collection of evidence on repeated exposure due to the encounter of multiple cables. This would facilitate the development of evidence in respect of cumulative impacts which is currently lacking.
- Strategic research to investigate the scale of the effect of EMF exposure on fish and invertebrates that may result in population level impact or economic impact to fisheries.
- Investigation on potential mitigation measures which may reduce potential effects on fish and invertebrates.

Evidence Gap FF.08: Collision risk (tidal turbines)

Review of current knowledge

Tidal energy devices are located in energetic and tidally dynamic sites which are often important to protected species. There is concern, therefore, with regard to the potential for tidal devices such as rotors to represent and obstacle and collision risk to marine animals. Whilst concerns in respect to collision risk relate more obviously to marine mammals and diving birds, there are also concerns on fish, particularly on large fish of conservation importance such as Atlantic salmon and basking sharks (SNH 2016).

As observing animal behaviour around tidal devices is challenging, limited field data on the interactions between tidal turbines and fish is currently available. To date only few observations have shown fish in contact with turbines or other MRE infrastructure, resulting in no obvious damage to fish. As such collision or even close encounters between fish and turbines are considered to be rare (Copping et al 2020).

Matzner et al (2017) analysed video data collected around a marine renewable energy device deployed in the Kvichak River in Alaska, to test underwater video cameras as a fish monitoring technique. Only on one occasion was an actual contact confirmed, and this was an adult fish making contact with the camera, rather than the turbine itself. Bevelhimer et al (2017) used multibeam hydro-acoustics to monitor fish passage at a tidal turbine in the East River, New York. The study found the density of fish in the sampled area when the turbine was absent was roughly twice the density observed when the turbine was in place, suggesting large-scale avoidance behaviour. Viehman and Zydlewski (2015) used acoustic cameras to observe fish interaction with a commercial-scale turbine in Cobscook Bay, Maine. The study found that fish were less likely to enter the turbine when it was rotating than when it was not. In addition, the probability of fish entering the turbine was higher at night than during the day and this difference was greater for small fish than larger fish. Similarly, studies on fish behaviour around a vertical axis hydrokinetic rotor (Hammar et al 2013) found that fish reduced their movement through the area when the rotor was present. In addition, fish that passed the rotor avoided the near-field area, with larger fish particularly cautious of the rotor. Berry et al (2019) studied the response of juvenile Atlantic salmon and sea trout to a hydrokinetic turbine in an experimental set up. No direct collisions were observed in the study and it was found that sea trout were less likely to pass the turbine than salmon. In addition, both species preferentially passed around the turbine rather than passing through the turbine.

In order to help inform and improve encounter probability and collision risk models, to better understand potential interactions between fish and tidal devices, further information on the behaviour of fish around devices needs to be collected. Recently (or yet to be) developed echosounder and camera data processing algorithms and suitable software and process to automate data analysis are expected to facilitate progress in this context (Fraser et al 2017, Viehman et al 2020, Sparling et al 2020, Hutchison et al 2020c).

It should be noted that to date the majority of research has been focused on the effects on individual fish and individual turbines. Future studies should examine the impacts of MRE arrays, as these may have implications substantially different from those of single devices (Sparling et al 2020). For example, arrays comprising multiple turbines may restrict fish movements, particularly for large species, with possible effects on habitat connectivity (Hammer et al 2013).

In addition, as the industry develops there is a need to consider potential community-level effects. The distribution of fish is likely to drive the foraging behaviour of larger predators and will likely influence risks to other species (Fraser et al 2018, Williamson et al 2019, Whitton et al 2020).

Next steps in research

The literature review presented above indicates that only few observations have shown fish in contact with turbines, and collisions or even close encounters are considered to be rare. However, only limited monitoring and field data have been collected to date. Furthermore, the majority of existing studies have been focused on the effects of individual devices rather than on the impact from arrays and little attention has been given to potential community level effects. With this in mind, the following steps are recommended to address current knowledge gaps:

- Monitoring and collection of field data and improvement of existing data analysis tools (i.e. processing algorithms and software and tools to automate data analysis).
- Development of fish collision risk models which incorporates relevant behavioural information as information becomes available.
- Strategic research to investigate the impact of MRE arrays both at population and community level.

FF.09: Accurate spatial -temporal patterns of spawning activity by marine fish species

Review of current knowledge

The importance of spawning areas and the need to minimise impacts on fish species during this key period of their life cycle is widely recognised as part of marine policy and marine plans developed in the UK (UK MPS 2011, The Scottish Government 2015, MMO 2014c, Welsh Government 2019 and DAERA 2018).

Existing knowledge on fish spawning around the UK has been compiled into key publications which consolidate data from various surveys and cover a comprehensive range of species:

- Fisheries Sensitivity Maps in British Waters (Coull et al 1998); and
- Spawning and nursery grounds of selected fish species in UK waters (Ellis et al 2012).

These publications provide a comprehensive review of the broad distribution of grounds and timing of spawning for a range of fish species and are widely used to inform impact assessments in support of MRE projects and other offshore activities.

As the spawning grounds identified in Coull et al (1998) are based on historic research, in some instances they may not be representative of recent trends in the distribution of fish species and preferred spawning grounds. Similarly, the information in Ellis et al (2012), whilst based on more recent data, is also subject to limitations due to the variable amount of ichthyoplankton (fish egg and larvae) data available for different regions and different species. Therefore, where available, for species for which regular survey work is undertaken in key spawning areas (e.g. International Herring Larvae Survey (IHLS)), data from more recent survey results is often analysed and used to further inform impact assessments. It should be noted, however, that limitations associated with survey coverage, annual variability and the wide survey grid used for sampling in the IHLS and other surveys which inform Coull et al (1998) and Ellis et al (2012), mean that it is not always possible to characterise the relative importance of discrete, localised sea areas as spawning grounds for fish species.

The difficulty in ascertaining the level of spawning activity and key spawning periods at the spatial scale of individual MRE projects, has resulted in the need to implement broad temporal and/or spatial restrictions during the construction phase (i.e. piling restrictions) and monitoring requirements as part of consent conditions for many projects. In addition, in some cases, fish spawning surveys have been undertaken as part of the EIA baseline characterisation with a view to reducing uncertainty prior to consent.

Piling restrictions and conditions on monitoring with regard to fish spawning have often being focused on herring. In a recent study, Boyle et al (2018) reviewed licence conditions across offshore wind farm projects in the UK and identified 19 offshore wind farm projects with conditions related to spawning herring. Other species of particular concern with regard to impacts on spawning associated with MRE projects in the UK to date, include gadoids, particularly cod, and flatfish species (Dover sole, plaice).

In order to minimise consenting risks and current uncertainty in the assessment of potential impacts of MRE projects on fish, there is a need to improve our understanding of the distribution and timing of spawning for key fish species. Whist information gathered through survey work will continue to improve the evidence base in this respect, additional approaches, including the use of modelling tools to predict spawning distribution and intensity should be given due consideration. More detailed information on this topic is provided below under "Evidence Gap FF.10: Essential fish habitat".

In addition, for species with high substrate specificity such as sandeels or spawning herring, the potential to develop detailed sediment maps identifying the extent of suitable areas to support these species during critical periods should be explored. Standard sediment suitability criteria for these species have been developed for the marine aggregate sector (Reach et al 2013, Latto et al 2013), and are increasingly used to inform assessments for other industries, including in EIAs for MRE projects. Spatial information on sediment suitability in combination with data on the distribution of early life stages would facilitate the mapping of more accurate spawning grounds for these species.

Next steps in research

As described above, whilst broad information on the spatial distribution and timing of spawning for key fish species is already available, this is often not sufficient to accurately identify the relative importance of areas occupied by MRE projects as spawning grounds and the timing when spawning may take place in these areas. This has resulted in the need to implement wide restrictions during the construction phase and monitoring requirements as part of consent conditions for many MRE projects.

In order to address this knowledge gap and assist in reducing uncertainty, the development of spawning mapping tools which take account of up-to-date data and that allow higher resolution mapping, both in spatial and temporal terms, is strongly recommended. For species with specific seabed suitability requirements for spawning (i.e herring, sandeels), these mapping tools would benefit from the integration of information on sediment characteristics.

Evidence Gap FF.10: Essential fish habitat (EFH)

Review of current knowledge

Essential Fish Habitats (EFH) are those necessary to support critical fish life stages, such as spawning, feeding or growing to maturity. These habitats are of key importance to ensuring the viability of fish populations and the provision of associated ecosystem services. As a result, EFH are of interest when considering the potential impacts of marine activities, including MRE projects.

Early information on the distribution of sensitive fish habitats around the UK (i.e. spawning and nursery grounds identified in Coull et al 1998, Ellis et al 2012) is considered insufficiently resolved for the use in marine planning (MMO 2013a). The lack of high-resolution data on EFH constitute a major limitation for the reliable identification of high value habitats and their practical consideration in the marine planning process (MMO 2016). In order to address this data gap and develop methodologies to improve the resolution of EFH, significant research has been undertaken in recent years.

For instance, the MMO developed spatial models of EFH in respect of the South Inshore and Offshore Marine Plan areas in 2013 (MMO 2013a). Under this project models were produced to identify the environmental conditions associated to the presence of adult foraging habitats, nursery habitats and spawning grounds for selected fish species. These models informed the production of maps showing the spatial distribution of EFH, illustrating probability of occurrence of adult, juvenile and eggs/larval stages. In 2016 a follow up study was undertaken to validate the EFH maps produced in 2013 against new data and expert judgement. In addition, the follow up study aimed to identify additional data from fish surveys and environmental data layers and assess the acceptability of the MMO (2013a) approach as a tool to support marine planning (MMO 2016).

EFH maps have also been produced for key commercial fish species in the Irish Sea by the Agri-Food and Biosciences Institute (AFBI 2021) and various models to predict spawning across the North Sea have been recently developed for species such as cod (González-Irusta and Wright 2015), haddock (González-Irusta and Wright 2016) and whiting (González-Irusta and Wright 2017). In addition, existing UK fisheries sensitivity maps were updated in 2014, based on models which combine observations of species occurrence with environmental data, to provide information on the most likely locations for aggregations of fish during their first year (Aires et al 2014).

Research is currently on-going to develop new spatially predictive EFH models nationally under project “Essential Fish Habitat Validation (MMO1133)” (MMO, 2021). Whilst this is expected to continue development of previous MMO commissions (MMO 2013a, MMO 2016) it is also considering other models. In addition to fish, future research should give consideration to the possibility of modelling shellfish species, particularly species of commercial importance (MMO 2016).

In the particular case of inshore waters, it should be noted that their inclusion in EFH models is constrained by the reduced spatial coverage of suitable fish survey data that exists for these areas (MMO 2016). Further information on this topic is provided under “Evidence Gap FF.12. Inshore populations/distribution”.

Next steps in research

As described in the literature review presented above, high-resolution data on EFH is currently only available in specific areas within the UK and, in some cases, data is only available for specific species. To date, the mapping of essential habitats has been focused on fish with limited consideration of shellfish species. In addition, there is limited data currently available in relation to the distribution of fish and shellfish in inshore areas.

In order to address current evidence gaps, the development of consistent EFH mapping approaches across the UK is strongly recommended. In addition, the inclusion of shellfish species, particularly those of commercial importance (i.e scallops, *Nephrops*, crab, lobster, whelk), should be given due consideration in future mapping exercises.

The above would facilitate assessing impacts on essential habitat across different regions in a consistent manner for key fish and shellfish receptors and improve the evidence base available to inform cumulative assessments.

Next steps in research specifically focused on improving data on the distribution of fish and shellfish species in inshore waters are discussed in detail "Evidence Gap 12: Inshore populations/distribution".

Evidence Gap FF.11: Reef/fish aggregation effects

Review of current knowledge

Extensive fish monitoring survey work has been undertaken in operational wind farms in the UK, particularly in early projects developed as part of The Crown Estate's Rounds 1, 2. and 2.5. Such monitoring was generally a requirement under consent conditions and typically consisted of the undertaking of generic pre-construction and post-construction fish surveys. In some cases, species specific monitoring was also undertaken (lobster and crab surveys, shrimp surveys, elasmobranchs, etc). Monitoring surveys were generally conducted using commercial fishing vessels and gears (demersal otter trawls, beam trawls, pots, gill nets, etc).

In 2014, the MMO reviewed the results of the fish and shellfish post-construction monitoring undertaken in 17 Round 1 and 2 wind farms (MMO 2014a). The review concluded that in all cases the requirements prescribed in the licence conditions were fulfilled, however, clear conclusions could not be drawn from the results. It was considered likely that there had been no moderate or major impacts to fish populations due to impacts resulting from the sites reviewed. It was less clear, however, if there had been minor changes to the fish populations that may have gone undetected by the standard monitoring methods used due to the natural high variability in fish and shellfish populations. In the North Hoyle and Kentish Flats offshore wind farms, minor changes were detected as a result of reef effects and changes in fish communities associated with the introduction of hard substrate. However, this effect was not reported at the other sites included in the review. It was argued this this may be due to the early state of the operational phase at which monitoring was undertaken, a result of the post-construction monitoring being incomplete or due to inadequate survey design (MMO 2014a).

As described above, whilst post-construction fish and shellfish monitoring has been undertaken in numerous UK offshore wind farms, it has not been possible to draw clear conclusions on potential reef/fish aggregation effects from its findings. Extensive information on this subject is however available from studies undertaken in other countries. Some examples of these are given below:

- Lindeboom et al (2011) compiled the short-term (two year) results of monitoring carried out in the Egmond aan Zee offshore wind farm in the Netherlands, including fish monitoring. The study identified only minor effects on fish assemblages, particularly around the monopiles and suggested that some fish species, including cod, may find shelter within the wind farm.
- Stenberg et al (2011; 2015) investigated the long-term effect (seven years after construction) of the Horns Rev 1 offshore wind farm on fish abundance, spatial distribution and diversity. The studies found no evidence of negative long-term effects on key fish species or functional fish groups. Overall, fish abundance increased slightly in the area of the wind farm and species diversity was higher close to the turbines. In addition, it was found that fish associated with rocky habitats were distributed closer to the artificial reef structures introduced by the turbines than other species. The results of the study suggest that the artificial reef structures were large enough to attract fish species with a preference for hard substrate, but not large enough to have adverse negative effects on species inhabiting the original sand bottom between the turbines, including sandeels.
- Hansen et al (2012) studied the small-scale distribution of fish in the Middelgrund and Lillgrund offshore wind farms, located in Øresund Strait, between Denmark and Sweden using a stationary camera system. Fish distribution was examined at approximately 0.25 and 50 meters from the turbines. The findings of the study suggest that in areas with homogenous sandy seabed, the presence of a turbine clearly attracts fish. Whilst for

areas with more heterogenous substrate and sessile species the fish aggregation function of a turbine was not as significant.

- Reubens et al (2013a) studied the spatio-temporal distribution of cod and pouting from 2009 to 2011 in relation to three different habitats (wind farm structures, shipwrecks and sandy bottoms). The study found highest catch per unit effort values for both species around wind farm structures and indicated distinct aggregation around turbine foundations.
- Reubens et al (2013b) monitored the residency, site fidelity and habitat use of cod in relation to artificial hard substrate from a wind farm over a year and identified aggregation near the hard substrate of the turbines. In addition, a clear seasonal pattern in presence was also observed, with high number of fish present in summer and autumn and a period of low densities during the winter.
- van Hal et al (2017) studied the impact of hard substrate of the fish community in a Dutch OWF which had been operational for five years. The study suggested attraction of cod, pouting, bullrout and edible and velvet crab to the hard substrate. Flat fish and whiting appeared to be attracted to the sandy habitat within the wind farm. In addition, the results of the study suggested that offshore wind farm structures were only used temporarily for shelter or feeding.
- Krone et al (2017) compared the mobile demersal megafauna associated with common types of wind farm foundations (jacket, tripod and monopile with scour protection of natural rock) in the southern German Bight. Monopiles with scour protection were colonised with typical reef fauna and recorded an average of about 5,000 edible crabs per foundation (more than twice as much as found in foundation types without scour protection). In addition, Krone et al (2017) found strong evidence that the three foundation types functioned not only as aggregation sites, but also as nursery grounds for edible crab.
- Degraer et al (2018) provided a review of the findings of fish monitoring in two Belgian wind farms, C-Power and Belwind, 6 and 7 years after construction respectively. The study did not identify a direct wind farm reef effect on the soft-bottom epibenthos and demersal-benthopelagic fish assemblage. However, species known to be fouling on the foundations such as mussels and anthozoa sp. were found to be abundant in soft sediment samples within the wind farm and absent from soft sediment

outside the sites. It was suggested that this could indicate that the reef effect was starting to expand beyond the direct proximity of the turbines. It was noted, however, that this would need follow-up work in order to be validated.

- Methratta and Dardick (2019) undertook a meta-analysis of studies that have examined abundance of finfish inside wind farms compared to nearby reference sites and calculated the overall effect size across studies. In addition, it investigated changes in effect size for soft-bottom and complex-bottom oriented species in association with various covariates. The study included information from offshore wind farms located in the North Sea, Irish Sea, Baltic Sea and Øresund. The research found that the overall size effect was positive and significant, indicating greater abundances of fish inside wind farms. Similarly, positive and significant effect sizes were identified for various covariates for both soft-bottom and complex-bottom species.

Next steps in research

From the results of the studies carried out to date in operational wind farms, it is apparent that changes in fish assemblages and reef effects tend to be more obvious at the scale of the turbines and its surrounding area, however they are not restricted purely to the structures themselves (Degraer et al 2020). Further research is however needed to fully understand the implications of the changes in fish assemblages that have been observed to date, so that simple aggregation effects can be distinguished from potential benefits (i.e. feeding opportunities or provision of nursery or spawning habitat).

These first order effects may be considered trivial in the context of the ecosystem. However, as small-scale changes are the basis of large-scale changes, they can be used to inform impacts at regional scales. In order to assess the impact of reef and fish aggregation effects, it is therefore important to identify appropriate functional and temporal scales of ecosystems or their parts requiring investigation (Degraer et al 2020).

In order to address current knowledge gaps in respect of reef/fish aggregation effects, the following actions are recommended:

- Focusing monitoring efforts on addressing relevant questions at appropriate temporal and spatial scales, avoiding the collection of data-rich, information-poor (DRIP) data (see Wilding et al 2017).
- Consideration of the use of ecosystem-based approaches for assessment and monitoring of impacts within operational sites, allowing the integration of data and information from multiple receptors (i.e. benthos, fish, ornithology, etc).

Recommendations outlined in respect of “Evidence Gap FF.05: Strategic fisheries management” are closely related to potential reef effects and should also be considered in relation to this topic.

Evidence Gap FF.12 Inshore populations/distribution

Review of current knowledge

The lack of detailed information on the distribution of inshore fish populations has been highlighted as a key evidence gap for the development of EFH maps in inshore waters (see “Evidence Gap FF.10: Essential fish habitat”). In this context, the term “inshore”, relates to shallow coastal areas of under 20 m in depth.

Broad scale fish monitoring programmes at the regional scale, such as the International Bottom Trawl Surveys (IBTS) coordinated by ICES, allow the collection of long-term consistent standardised data on fish populations. However, the focus of these types of surveys is mainly on commercial fish stocks and they tend to cover offshore waters. The lack of a monitoring programme for inshore fish assemblages, that is coordinated and standardised at the regional scale, makes assessing and evaluating the status of inshore fish communities difficult.

In order to fill this gap, Natural England recently commissioned the University of Hull to perform a study aimed at developing a regional pilot monitoring programme for inshore fish communities in the Southwest regional sea area of England. As part of the project the following three linked reports have been published:

- Franco et al (2020a) – A review of methods for the monitoring of inshore fish biodiversity.
- Franco et al (2020b) – An assessment of the viability of fish monitoring techniques for use in a pilot approach in Southwest England; and
- Franco et al (2020c) – Regional monitoring plan for inshore fish communities in Southwest England.

It is intended that the outputs of these reports will be used to underpin a trial of inshore fish monitoring in English inshore wates, which will seek to eventually integrate inshore fish monitoring into the wider UK marine biodiversity monitoring programme.

Next steps in research

As described above, the lack of detailed information on the distribution of inshore fish populations has been identified as a key knowledge gap for the development of EFH in inshore waters.

In order to address this knowledge gap, it is recommended that an inshore fish monitoring strategy is developed for implementation across UK regions. The development and implementation of such strategy on an UK-wide basis would require a collaborative approach amongst government agencies and regions and the identification of existing monitoring work of relevance to inshore waters already being undertaken across the UK (i.e. monitoring carried out by Inshore Fisheries and Conservation Authorities (IFCAs), Regional Inshore Fisheries Groups (RIFGs) and other relevant organisations).

Evidence Gap FF.13: Cumulative pressures and impact pathways

Review of current knowledge

The assessment of cumulative effects is required through a number of legislative drivers such as EIA, Strategic Environmental Impact Assessment (SEA), Habitats Regulations Appraisal/Assessment (HRA) related regulations. However, cumulative effects are often not fully assessed due to their complexities and the lack of detailed information on proposed or existing developments and their interactions with the environment (MMO 2014b).

Frameworks to aid the assessment of cumulative effects have been developed in the UK and in other countries (e.g. MMO 2014b, Natural England 2014, Rijkswaterstaat 2019). These tend to follow the DPSIR approach which systematically identifies *drivers, pressures, state, impacts* and *responses,* and include consideration of evidence requirements in relation to activities, pressures and receptors. For example, the strategic framework for cumulative assessment developed by the MMO (2014b) includes detailed activity-pressure and pressure-receptor tables.

Despite the available guidance, assessing cumulative impacts on fish remains challenging due to the mobile nature of most species and the gaps in current knowledge on the impact of MRE developments (see Evidence Gap FF.06 to FF.12). This is of importance as understanding cumulative effects on fish species is critical to fully understand cumulative effects on other species groups (i.e. marine mammals and birds).

Modelling approaches have been used in recent years to facilitate ecosystem-based cumulative assessments (e.g. Niquil et al 2020, Nogues et al 2020, Raoux et al 2017). Existing models may be adapted to take account of different scenarios associated with the development of MRE projects, however, the improvement of knowledge gaps of the effects of MRE on fish (and shellfish) need to be progressed in parallel to maximise the utility of such models (MMO 2013b).

Next steps in research

Taking account of the findings of the literature review presented above in respect of "Evidence Gap FF.13: Cumulative impact assessments and impact pathways", the following next steps in research have been identified to address current knowledge gaps:

- Update and standardise current knowledge on cumulative pressures and impact pathways for key fish and shellfish receptors (and other inter-related receptors-benthic communities, marine mammals and birds) to allow the undertaking of consistent assessments across different projects and sectors on an UK-wide basis;

- Recommendations proposed for all other evidence gaps addressed in this report of relevance to fish and shellfish species, particularly evidence gaps FF.06 to FF.12, would also help improve the evidence base to inform cumulative assessments.

Evidence Gap FF.14: Co-existence with commercial fisheries

Review of current knowledge

The increased demand for sea space associated with the development of MRE projects has direct implications for commercial fishing. As such, it is important to understand the ways in which fisheries and MRE projects interact and identify suitable approaches to facilitate co-existence (de Groot 2014). In this context, co-existence refers to where multiple developments, activities or uses exist alongside or close to each other in the same area and/or at the same time (Defra 2019).

Various studies have been undertaken in recent years looking into key factors of relevance to promoting co-existence between MRE projects and fishing both in the UK and abroad:

- De Groot (2014) investigated the challenges for co-existence between MRE projects and fishing and explored a mitigation agenda for fishing effort displacement in the UK. The research identified three key priority areas for the mitigation agenda: developing efficient and cost- effective mechanisms for overcoming data issues for assessment of fishing effort displacement, the development of appropriate methods of assessment, and the development of an acceptable consultation protocol between MRE and fishing sectors agreed on by all stakeholders.
- Moura et al (2015) provided a compilation of best practices for addressing interactions and supporting successful cooperation between commercial fishing and offshore wind. This included consideration of aspects such as business improvements, communication, compensatory mitigation, facilities design, construction and operations, fisheries management, fisheries resource enhancement and ocean planning.

- Kafas (2017) studied the multi-use of sea space between offshore wind farms projects and commercial fishing in the East Coast of Scotland and identified key measures and actors that can contribute to the enhancement of co-existence. Key recommendations identified in the study relate to aspects such as:
    - Funding: Innovation funding for multi-use applications through lobbying and demonstration of their benefits, favourable scoring as part of bidding application subsidy rounds for proposals that maximise the sea use potential and multi-uses, greater consideration and prioritisation of local fishing vessels to encourage multi-use with affected stakeholders and implementation of technical innovation funding such as fishing community funds;
    - Marine planning: consideration of multi-use opportunity mapping by marine planning authorities instead of the current sector planning, establishment of stronger co-existence policies in marine plans with explicit reference to multi-use and development of guidance for the design of fishing friendly offshore wind farms;
    - Marine licensing: improvement in EIA methodologies to account for indirect effects such as fishing displacement, licensing authorities to request co-existence plans prior to the submission of a licence application, earlier agreement on mitigation strategies to aid with stakeholder power imbalances (i.e. development of a Statement of Common Ground (SoCG)) and allowing for innovation advancement in multiuse by exempting small-scale pilot projects from full-scale assessments; and
    - Technological innovation: need of empirical studies exploring the compatibility between offshore wind farms; fishing and innovation studies on moorings, cable installation methods, fishing-friendly cable protection measures and gear modifications; good practice guidance for the integration and interpretation of fisheries distribution data layers to improve EIAs and to demonstrate the links between multi-use and Corporate Social Responsibility; improve mapping of navigational hazards, particularly dropped objects during construction and establishment of a standardised and agreed system for monitoring of cables; and the use of over-trawlability surveys to aid the issue of clear seabed certificates.

- Primo Marine (2019) investigated key requirements and potential implications of allowing demersal fisheries in future offshore wind farms in the Netherlands. The study concluded that demersal fisheries in operational wind farms in the Netherlands would increase the cost of energy produced by the affected wind farm and recommended that the cost (impacts) are assessed against the benefits to the fishery. Aspects considered in the study include reference to potential liabilities in the event of an incident, design implications and costs associated with cable repairs and insurance claims;
- Stelzenüller et al (2020) provided an overview of general impacts of the development of offshore wind farm and other marine renewables on the European fishing sector. The review highlights pathways for possible co-existence solutions, provides best practice examples and outlines lessons learnt. The study identified a sharp increase of spatial conflict potential in the North Sea, Baltic Sea and Mediterranean over the next five years and noted that future cumulative impacts will mostly affect trawling fleets targeting mixed demersal species and crustaceans. The study suggests that economic impact assessments on fisheries need to address the direct and indirect costs of lost fishing opportunities and highlights that European-wide standarised monitoring programme would provide currently unavailable ecological and socio-economic data needed to assess cumulative impacts. From a review of various case studies Stelzenüller et al (2020) identify that early stakeholder consultation, the involvement of independent third parties, the creation of guidelines and compensation payments could alleviate the conflict potential between fisheries and MRE projects. In addition, the study proposed the use of an integrative framework to clarify and mitigate the effects of MRE project on fisheries and facilitate best practice guidance for marine spatial planning and co-operation amongst marine users.
- Dupont et al (2020) identified key conflicts between offshore wind and fisheries and described how these have been addressed in EU Members states. In addition, it highlighted best practice and potential synergies that could be developed to mitigate conflicts and improve coexistence. The study is focused on North Sea countries (Belgium, Denmark, Germany, the Netherlands and the UK) where most offshore wind farms are currently found. The key conclusions of the study are summarised below:

  - Development of offshore wind farms generates constraints on maritime activities in relation to safety and insurance aspects and these constraints vary depending on the development phase under consideration (construction vs. operation);
  - Whilst national approaches and restrictions may differ, offshore wind farms have been developed without major conflicts with other sea users in the North Sea, the most sailed and busy European sea basin;
  - Interactions with fishing have been limited where development areas supported low fishing activity;
  - Increased development of offshore wind farms may result in increased conflicts. Conflicts may be reduced with the undertaking of global socio-economic assessments under the umbrella of Marine Spatial Planning (MSP) taking a cumulative approach and then considering the particularities of each project (location, fishing methods used, target species); and
  - Early dialogue between stakeholders including all fisheries stakeholders and developers is key to prevent conflicts.
- Schupp et al (2021) reviewed stakeholders‘ perspectives from Scotland and Germany in relation to fishing within wind farms. The study identified that in both countries the offshore wind industry has demonstrated a low interest in multi-use, unless clear added value could be demonstrated, and no risks for the respective business were involved, whilst the fishing industry is more proactive towards multi-use projects. The study also highlighted that a clear commitment from policy makers is required if multi-use is to become a potential solution for reducing conflict in MSP and that this would require a regulatory framework to guide the process of assessing multi-use options by considering both environmental and socio-economic impacts.

As described under “Evidence Gap FF.03: Fisheries stakeholders integration and participation process”, and in line with the findings of the literature review in relation to co-existence presented above, the implementation of timely and effective communication between the MRE industry and fisheries stakeholders and the use of MSP processes to facilitate early integration of fisheries considerations into marine planning are both factors of key importance in promoting co-existence.

In addition, the development of effective co-existence approaches between the MRE and the fishing industry requires significant gathering and communicating of data about the compatibility the two sectors (Schupp et al 2019). Whilst significant research on the aspects of relevance to co-existence has been undertaken in recent years (see summary above) comprehensive guidance with regard to fishing specific requirements and MRE project design compatibility is currently lacking.

At a basic level, fishery operations differ by fixed or mobile gear, vessel class and other key factors. Different fishing methods interact with the water column and substrate differently, and by extension, also interact differently with the various aspects of wind farm construction and operation (Dupont et al 2020).

Co-existence strategies should therefore be designed having in mind the technical requirements of the various fishing methods as well as the particularities and needs of the MRE industry.

To date, evidence on the compatibility and viability of fishing within operational wind farms is scarce and there is yet not conclusive evidence of significant levels of towed gear fishing activity taking place in operational wind farms (Dupont et al 2020).

In this context it is important to note that in many countries where offshore wind farm projects are operational, fishing within wind farms is either not permitted or highly restricted at present (i.e. only the use of static gear is allowed) (Dupont et al 2020). In the specific case of the UK, whilst fishing by all methods is currently permitted within wind farms, many of the projects operational to date are located relatively close to shore (i.e. Round 1, Round 2 and Round 2.5) where fishing activity tends to be primarily by small local vessels operating static gears. In addition, whilst fishing is permitted, fishermen may voluntarily avoid fishing in operational projects due to concerns over safety and snagging risks (Gray et al 2016; de Groot 2014).

There are some successful examples of crab and lobster pot fisheries co-existing within offshore wind farms. Westermost Rough Offshore Wind Farm, off the Holderness coast in the East of England, provides a good example of effective co-existence and co-operation between developers and static gear fishermen (see Roach et al 2018 and Roach 2020). In addition, various studies are currently under development to assess the viability of other fishing methods in operational sites. For example, longlining trials are planned to be undertaken in the East Anglia One offshore wind farm and the viability of fishing using fish traps is currently under investigation in the Hywind floating offshore wind farm project.

Anecdotal evidence of the viability of fishing using towed gears in UK wind farms is available from the survey work that has been undertaken to date in operational sites. As described under “Evidence Gap FF.11: Reef/fish aggregation effects”, numerous surveys have been undertaken in UK wind farms using commercial fishing vessels and gears. However, these surveys were focused on monitoring fish and shellfish populations at discrete locations and therefore their scope in demonstrating the compatibility of normal fishing operations within wind farms is limited.

As noted under “Evidence Gap FF.02: Accurate and validated methods to predict fisheries displacement levels and locations”, aspects such as the width of corridor available for fishing between turbines and aspects relating to potential interactions between fishing and cables are key to facilitating co-existence.

Technological developments, particularly the current trend towards larger turbine generating capacities, are anticipated to result in increased minimum spacings in upcoming projects compared to those currently operational. This may improve the prospect for co-existence with fishing, particularly for towed gears as they are more spatially constrained. Compatibility issues may therefore be increasingly focused on potential interactions between fishing and cables, rather than layout and spacing considerations.

Effective monitoring of cable burial along with appropriate liaison and information sharing, will be critical to minimise potential interactions between fishing and cables. In addition, due consideration should be given to modelling tools or other suitable approaches which may facilitate the early identification of potential cable exposures and inform burial risk assessments (see Carbon Trust 2015 and Tertente et al 2017). In addition, research on the seabed penetration depths of the various fishing gears used across the UK in different types of seabed substrate is required to facilitate the undertaking of burial risk assessments. The use of cable protection methods which are compatible with fishing, where possible (i.e. over-trawlable), is also an aspect of importance in respect of facilitating co-existence. Similarly, the undertaking of suitable studies post-construction to assess the status of the seabed provides increased confidence to fishermen and reassurance prior to fishing within operational wind farms resuming. In this context, the implementation of effective data sharing procedures is of key importance.

The use of pro-active approaches to facilitate fishing within wind farms, such as the upgrading of navigation systems of the fishing vessels or the provision of training to skippers and crews in advance of fishing within operational wind farms, may also play an important role in facilitating co-existence (Primo Marine 2019).

Similarly, the establishment of a clear legal basis for fishing near or over cables or the establishment of arrangements for the appropriate management of liabilities is also of importance to facilitate co-existence. This is an aspect of significant concern for fisheries stakeholders.

It should be noted that in the case of floating offshore wind farm projects, in addition to the aspects mentioned above, the ability of fishing to resume in operational sites, both for towed fishing gears and static gears, would be dependent on the cabling system used. The installation of dynamic cables in floating projects would likely significantly hinder the prospect of fishing within operational sites. A better understanding of the potential interactions of floating technologies and existing fishing methods will be required to facilitate the development of appropriate co-existence strategies.

Next steps in research

Taking account of the findings of the literature review presented above in respect of “Evidence Gap FF.14 Co-existence with commercial fisheries”, the following next steps in research have been identified to address current knowledge gaps:

- The development of detailed guidance outlining key project design and fisheries operational parameters which facilitate the viability of fishing within wind farms for different methods, including consideration of potential interactions with cables. This should be informed through consultation with relevant stakeholders and technical experts and incorporate evidence from fishing compatibility studies and/or gear trials which may be undertaken. Compatibility parameters of relevance to both fixed bottom and floating technologies should be given consideration when developing guidance.
- Strategic collaborative studies and fishing trials to investigate and demonstrate the viability of fishing in wind farms using different methods and gear configurations.
- Development of guidance/standard methodologies in respect of the monitoring of potential interactions between buried and protected cables and fishing.
- Research and guidance on existing legal frameworks with regard to fishing within wind farms and establishment of clear arrangements to facilitate the appropriate management of liabilities.
- Recommendations outlined above in respect of "Evidence Gap FF.03 Fisheries stakeholder integration and participation" would also be of relevance in respect of co-existence.

Evidence Gap FF.15: Chemical/toxicity effects

Review of current knowledge

Little attention has been given to aspects relating to the potential chemical emissions from corrosion protection systems associated with MRE offshore structures to date. As the industry expands, however, interest has grown to better understand this issue. Recent progress on this topic is summarised below:

- Preliminary studies undertaken around offshore wind farms in the Belgian part of the North Sea in which the concentration of Zn was measured, found no evidence of higher Zn levels in the wind farms than in reference areas. It was highlighted, however, that more extensive research was needed to validate the results (Degraer et al 2019).
- Recent investigations on galvanic anode materials used in corrosion protection systems (Reese et al 2020) have found that toxicologically

relevant elements such as Zn, Cd and Pb are emitted during the lifetime of galvanic anodes and that depending on chemical behaviour in the solution phase, these will be transported via the water body or associated with suspended particulate matter and subsequently deposited on the sediment in the proximity of MRE sites.

- Research focused on the study of chemical emissions from offshore wind farms and their potential impact on the environment is currently on-going as part of project funded by the German Federal Maritime Hydrographic Agency (BSH). The project is focused on the following aspects: identification of potential organic and inorganic substances emitted from corrosion protection of offshore wind farms; development of analytical methods and sampling strategies to determine emissions; and evaluation of the relevance of the identified pollutants and their influence on the local and regional environment (HZG 2021).

There is no clear evidence of negative impacts as a result of corrosion protection systems on the marine environment, however, there is a need to improve our knowledge to understand its effects. Available data is scarce and makes assessing the impact of the emissions on the marine environment difficult. In addition, whilst chemical emissions from MRE infrastructure are probably low compared to other offshore activities, they may become more important as the industry continues to grow (Kirchgeorg et al 2018).

Next steps in research

Taking account of the findings of the literature review presented above in respect of “Evidence Gap FF.13 Chemical/toxicity effects”, the following next steps in research have been identified to help address current knowledge gaps:

- Monitoring of corrosion protection systems and chemical emissions associated with operational wind farms in the UK; and
- Research on potential environmental impacts, including bioaccumulation of heavy metals within the food chain.

Recommendations

Table 5 and Table 6 outline recommendations for future research for fish and fisheries related aspects, respectively. These include information on the evidence gaps for which the proposed research is of relevance, the feasibility and challenges associated with the undertaking of the research and an indication of potential collaborators.

In addition, priority rankings of "high" "medium" and "low", have been assigned to the various research recommendations. The criteria used for assigning priority are outlined below:

- High Priority: Research is critical to reduce consenting risks and uncertainty and would facilitate the undertaking of more robust impact assessments and address key stakeholder's concerns.
- Medium Priority: Existing evidence suggests limited potential for major impacts. The research undertaken to date, however, is limited or may not fully account for the current level of proposed MRE development and/or upcoming technologies/project designs. Additional, more focused research, would increase certainty in the accuracy of assessments undertaken and reduce stakeholder's concerns.
- Low Priority: Significant concerns have not been raised to date on the particular aspect that the research may address and/or the topic is not a key consenting risk. Limited research has been undertaken on the subject to date and further investigation would improve our ability to identify potential for negative interactions with fish and fisheries receptors.

With regard to evidence gaps relating to fish receptors, key recommendations relate to improving our understanding of the impact of operational wind farms on fish and shellfish through the implementation of strategic research in operational sites. In addition, the undertaking of further research to address knowledge gaps associated with underwater noise and its effect on fish and shellfish species, as well as the development of mapping tools on essential habitat (including spawning grounds) are also considered priority aspects to reduce consenting risks and uncertainty in relation to the assessment of impacts of MRE projects (Table 5).

In the case of commercial fisheries, key recommendations relate to improving access to fisheries data and the format in which data are made available, the development of detailed assessment guidelines and the undertaking of research to allow the assessment of the displacement effects at a strategic level. In addition, the undertaking of trials to demonstrate the viability of fishing within operational sites, as well as the development of technical guidance on wind farm design and its compatibility with fishing, are considered critical to reduce consenting risks and uncertainty in relation to commercial fisheries receptors (Table 6).

As shown in Table 5 and Table 6, most of the individual research recommendations made are expected to contribute to addressing aspects which are of relevance to more than one evidence gap. It is therefore recommended that when defining future detailed research proposals to address evidence gaps, their inter-dependences are given due consideration.

Table 5 Recommendations for Future Research – Fish

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Strategic monitoring programme of fish and shellfish populations in UK offshore wind farms	FF.07 Electromagnetic Fields FF.11 Reef/fish aggregation effects	Field-based studies. 3-5 year project. Careful design required to ensure that effects from wind farms can be accurately differentiated from other factors that can affect fish and shellfish populations (i.e. reduction in fishing activity associated with construction works and operation, natural variation, etc).	Would require scoping for representative sites across regions in advance. Requires co-operation by the developer to access sites. Multiple work packages required to address different research questions: investigations in relation to reef/fish aggregation effects would require monitoring at the fish assemblage level; monitoring in relation to EMF would likely need to be focused on limited number of key selected species (which may vary on a site specific basis).	Anticipated to be driven by government and delivered with support from developers. Potential for extending this research programme to be integrated with monitoring of other receptors (benthic, ornithology, marine mammals) to provide information on potential ecosystem level effects.	High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Compilation of available data sources to aid the mapping of EFH for key species (including commercial shellfish species)	FF.09: Accurate spatial-temporal patterns of spawning activity. FF.10: Essential Fish Habitat FF.13: Cumulative pressures and impacts.	Desktop-based study with significant engagement with stakeholders and government agencies. 1 year project	Data and Information of relevance (fish surveys, stock assessments, sediment data, egg, larval and juvenile fish distribution) is spread across numerous organisations	UK regulators of marine activities, their advisors, SCBCs, IFCA, RIFGs, and research institutes.	Medium -High
Research and measurement of the particle motion component of sound	FF.06: Underwater noise and vibrations	Lab or controlled field experiments. 2 year project.	Limited experience on particle motion measurements to date. Guidance under preparation (Exeter University)	Potential for international collaborations with relevant government agencies in Europe and beyond as well as research institutions.	Medium -High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Development of updated underwater noise threshold criteria for fish, including quantitative thresholds for behavioural effects and guidance on the assessment for invertebrates	FF.06: Underwater noise and vibrations	Desktop-based. 1-3 year project.	Incorporation of particle motion component due to lack of data. Inconsistency in underwater metrics used across existing studies to date. Lack of behavioural based audiogram data.	Potential for international collaborations with relevant government agencies in Europe and beyond as well as research institutions.	Medium -High
Tracking of fish species during piling operations	FF.06 Underwater noise and vibrations	2 year project. Field based.	High cost of field work and technology required. Requires collaboration from developers for planning and access.	Research driven by government agencies with support from developers.	Medium -High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Production of updated spawning grounds maps	FF.09: Accurate spatial-temporal patterns of spawning activity by marine fish species. FF.10: Essential Fish Habitat (EFH)	Desk-top based 2-year project.	It would require coordination and input from regulators of marine activities across the UK and their advisors. Complex modelling required to predict probability of occurrence and integrate physical variables (including sediment data) in addition to survey data. The collection of additional survey data may be required.	UK regulators of marine activities, their advisors, SCBCs and research institutes.	Medium - High
Production of EFH map layers for key species (including shellfish species) at UK level	FF.10 Essential Fish Habitat	Desktop-based. 2-3 year project.	As above in respect of spawning grounds mapping.	UK regulators of marine activities, their advisors, SCBCs, IFCAs, RIFGs, and research institutes.	Medium -High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Research on noise abatement measures and their effectiveness to mitigate impacts on fish	FF.06: Underwater noise and vibrations	Desk-top study. 2 year project. Requires liaison and input from developers and technology providers.	-	Driven by government agencies with support from developers.	Medium
Development of a cable data catalogue	FF.07: Electromagnetic fields	Long-term, ongoing project. Desktop based with high engagement with developers and cable operators.	Accessibility to data from developers and cable operators. Maintenance of catalogue and ownership of the catalogue?	Offshore wind developers and sub-sea cable operators and government agencies. A coarse catalogue is currently being compiled for Defra.	Medium

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Improving our understanding of EMFs from existing cables - measurement of EMFs in the field	FF.07: Electromagnetic Effects	Field study. 2 year project.	High cost of field work and technology required. Requires collaboration from developers for planning and access.	Research could be linked to the cable data catalogue work identified above.	Medium
Development of threshold criteria in relation EMFs for fish and shellfish (including early life stages) for key sensitive groups.	FF.07: Electromagnetic Effects	Field and lab-based research. 5 year project.	Limited data available. Information exists for a handful of species. Difficult to compare evidence from different studies (different cables, voltages, burial status, etc).	UK regulators of marine activities, their advisors, SCBCs and research institutes. Significant research on EMF is being undertaken in the USA and at various English and Scottish research organisations.	Medium

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Strategic research to investigate the scale of the effect of underwater noise, EMF and collision risk on fish and invertebrates that may result in population level impact or economic impact to fisheries.	FF.06: Underwater noise and vibrations FF. 07: Electromagnetic Effects FF. 08: Collision risk	Field, lab-based research and modelling. Long term project to address the 3 components.	Multiple work packages. Use of complex models and modelling to help scale up effects.	UK regulators of marine activities, their advisors, SCBCs, fisheries stakeholders and research institutes.	Medium -High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Development of modelling tools to predict potential effects of fishing closures in wind farms to inform management decisions	FF.05: Strategic Fisheries Management FF.11: Reef/fish aggregation effects FF.14: Co-existence with commercial fisheries	Desk-top based. 2 year study.	Existing available data to feed the models may be limited. Requires high technical expertise on mathematical modelling.	Research institutions and government agencies, across UK, Europe and beyond.	Medium

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Studies on the potential for implementation of stock enhancement programmes within operational wind farms	FF.05: Strategic Fisheries Management. FF.11: Reef/fish aggregation effects FF.14: Co-existence with commercial fisheries	Long-term study. Field based.	Scoping for suitable sites would be required in advance. It would require engagement and support from both the fishing industry and developers.	Developers, industry wide-groups.	Medium

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Pilot studies to determine the level of recovery of habitats and species during the operational phase of offshore wind farm projects, timescales of such recovery and potential for spill over effects and associated benefits to fishermen	FF.05 Strategic Fisheries FF.11 Reef/fish aggregation effects FF.14: Co-existence with commercial fisheries	Long-term study (>5 years) to allow monitoring of changes over time. Field-based study complemented with analysis of fisheries data and information.	Scoping for suitable sites and species/fisheries would be required in advance. It would require engagement and support from both the fishing industry and developers.	This would be anticipated to be driven by Government and delivered with support from developers.	Medium
Collection of behavioural data to feed fish collision risk models	FF.08: Collision risk	1-2 years. Field based.	Limited information currently available in relation to fish behaviour	MMO, Marine Scotland, NRW, DAERA, SNCBs and research institutes	Low-Medium

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Development of standard cumulative pressures/impact pathways matrices for key fish and shellfish receptors and other inter-related receptors (i.e. benthic communities, marine mammals, birds)	FF.13: Cumulative pressures and impact pathways.	Desktop-based study with significant consultation and inputs from relevant stakeholders. 1-2 year project.	It would require coordination and agreement between all main regulators of marine activities across the UK and SNCBs.	UK regulators of marine activities, their advisors and SNCBs. May be possible to build on previous work undertaken by these organisations (e.g. MMO 2014b)	Low - Medium

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Guidance on key fish population structuring divisions required for assessment	FF.09: Accurate spatio-temporal patterns of spawning activity by marine fish species. FF.10: Essential Fish Habitat (EFH) FF.13: Cumulative pressures and impact pathways	Desk-top study. 1 year.	Requires coordination and agreement between regulators of marine activities across the UK and their advisors.	UK regulators of marine activities, their advisors, SCBCs, IFCA, RIFGs, and research institutes.	Low

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Development of an inshore fish monitoring strategy for implementation across UK regions.	FF.12 Inshore populations/distribution FF.13: Cumulative pressures and impact pathways	Desktop-based study with significant consultation and inputs from relevant stakeholders. 1 - 2 year project.	Development of such a strategy on an UK-wide basis would require a collaborative approach amongst government agencies. The strategy should allow the integration of existing monitoring programmes (such as stock assessments and localised studies on inshore fish species undertaken by IFCAs, RIFGs and other organisations), as appropriate.	UK regulators of marine activities, their advisors, SNCBs, IFCAs, RIFGs, and research institutes.	Low

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Monitoring of corrosion protection systems and associated chemical emissions from operational wind farms in the UK	FF.15: Chemical/toxicity effects	Field-based studies at selected project/s, lab-based studies or both. Direct involvement of developers required to facilitate access to sites if field-based. Strategic project at UK level. 1-2 year project.	Monitoring methodology/ experimental set up may be challenging depending on approach (i.e. particularly if samples are collected in the field around operational turbines).	Potential for collaboration with European organisations currently engaged in research on this topic (see literature review under "Evidence Gap FF15: Chemical/toxicity effects".	Low

Table 6 Recommendations for Future Research – Fisheries

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Development of UK wide fishing activity data layers by fishery (including information for both under 12 m and over 12 m vessels)	FF.01: Accurate mapping of fishing activity	2 year project. Desktop based with significant input from fisheries stakeholders required. Potential for this to be developed as an interactive fisheries sensitivity mapping tool.	Limited quantitative spatial data available for under 12 m fleets.	Driven by government agencies with support from fisheries stakeholders. Potential for integration with other related mapping exercises (i.e. fish spawning grounds and EFH).	High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Development of models to predict displacement at a strategic level (MRE development and other activities)	FF:02: Accurate and validated method to predict fisheries displacement levels and locations. FF.13: Co-existence with commercial fisheries	2 year project. Desktop based.	Expected to require complex mathematical modelling tools. Constrained by the limitations of the available fisheries data (particularly for under 12 m vessels). Requires accurate information on MRE development and other activities with potential to result in fisheries displacement.	Driven by government agencies with input from fisheries stakeholders, MRE developers and other marine industries/ activities.	High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Strategic monitoring of changes to fishing activities and displacement associated with MRE projects in the UK	FF.02: Accurate and validated method to predict fisheries displacement levels and locations. FF.13: Co-existence with commercial fisheries	2 year project. Desktop based. Significant input from developers, fisheries stakeholders and regulators required.	Constrained by the imitations of the available fisheries data.	Driven by government agencies with support from developers and the fishing industry	High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Technical guidelines on offshore wind farm project design and its compatibility with fishing	FF:02: Accurate and validated method to predict fisheries displacement levels and locations. FF.13: Co-existence with commercial fisheries.	1-2 year project. Desktop based with significant inputs from developers and fisheries stakeholders.	Dependent on effective consultation and constructive feedback from developers and fisheries stakeholders.	Driven by government agencies and/or industry wide groups, with input from developers and fisheries stakeholders.	High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Guidance on data requirements to inform commercial fisheries assessments	FF.01: Accurate mapping of fishing activity FF:02: Accurate and validated method to predict fisheries displacement levels and locations. FF.04: Improvements in Environmental Impact Assessment Methodologies	1 year project. Desktop based. with significant input from fisheries stakeholders.	-	Driven by government agencies with support from fisheries stakeholders	Medium-High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Development of a standard methodology for assessment of impacts from MRE projects on commercial fisheries.	FF.04: Improvements in Environmental Impact Assessment Methodologies	Desk-top based study. 1 -2 year project.	Data limitations due to format of available fisheries data and confidentiality issues to allow refined assessments by fleet segment. Challenging to apply standard methodologies across the under 12 and over 12 fleets.	Research driven by government agencies with input from fisheries stakeholders, developers and EIA practitioners.	Medium-High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Feasibility studies/trials of fishing within wind farms using different fishing gears and operating practices	FF:02: Accurate and validated method to predict fisheries displacement levels and locations. FF.13: Co-existence with commercial fisheries	2 year project. Field based. Input from developers and fishermen required.	May require co-operation from developers for planning and access to sites, if research is undertaken within existing projects (potential for virtual wind farms could also be explored). Scoping for suitable sites would be required in advance (different sites may suit studies for different gears).	Driven by government agencies with support from developers and fisheries stakeholders.	Medium-High

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Research and guidance on existing legal frameworks with regard to fishing within wind farms	FF.04: Improvements in Environmental Impact Assessment Methodologies FF:02: Accurate and validated method to predict fisheries displacement levels and locations. FF.13: Co-existence with commercial fisheries	1-2 year project. Desktop based. Input from developers and fishermen required.	Establishment of clear arrangements to facilitate the management of liabilities. Integration and coherence with existing legislation of fishing over cables.	Driven by government agencies with support from developers and fisheries stakeholders.	Medium

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Feasibility study on the potential for co-location of MPAs and offshore wind farms in the UK	FF:02: Accurate and validated method to predict fisheries displacement levels and locations. FF.05: Strategic Fisheries management FF.13: Co-existence with commercial fisheries	2 year project Desk-top based	-	Driven by government with support from SNBCs.	Medium

Research	Evidence Gap (s)	Feasibility	Challenges	Collaborations	Priority
Study on best approaches to facilitate integration and participation of fisheries stakeholders	FF.03: Fisheries stakeholders and participation process. FF.13: Co-existence with commercial fisheries	1 year project. Desktop based with significant input from fisheries stakeholders. Informed through workshops and questionnaires to incorporate fishermen's views.	-	FLOWW Group and/or other relevant industry wide groups.	Low-Medium

References

ABPmer. 2017. Displacement of Fishing Effort from Marine Protected Areas, ABPmer Report No. R.2790. Commissioned Report, Number 241. York. http://publications.naturalengland.org.uk/publication/5674265573064704.

Agri-Food and Bioscience Institute (FBI. 2021). Essential Fish Habitat (EFH). Available online at: https://www.afbini.gov.uk/articles/essential-fish-habitat-efh. [Accessed 03.02.2021].

Aires, C., González-Irusta, J.M., Watret, R. (2014) Updating Fisheries Sensitivity Maps in British Waters. Scottish Marine and Freshwater Science Vol 5 No 10. Edinburgh: Scottish Government, 88pp. https://data.gov.uk/dataset/d43013b9-b7c0-450f-93c9-57e1ce9b1782/updating-fisheries-sensitivity-maps-in-british-waters [Accessed 18.06.21].

Ashley, M., Mangi, S., Rodwell, L. 2014. The potential of offshore windfarms to act as marine protected areas – A systematic review of current evidence. Marine Policy, Vol 45, pp. 301-309.

Ashley, M., Austen, M., Rodwell, L., Mangi, S. 2018. Co-locating offshore wind farms and marine protected areas. In Offshore Energy and Marine Spatial Planning, pp. 246-259. London, UK: Routledge.

Bastardie, F., Nielsen, J.R., Ulrich, C., Egekvist, J and Degei, H. 2010. Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite-recorded vessel geo-location. Fisheries Research. 106: 41-53.

Bastardie, F., Nielsen, J.R., Eigaard, O.R., Fock, H.O., Jonsson, P. and Bartolino, V. 2015. Competition for marine space: modelling the Baltic Sea fisheries and effort displacement under spatial restrictions. ICES Journal of Marine Science Vol 72 No 3, pp. 824-840.

BEIS. 2019. Department for Business, Energy and Industry Strategy, Offshore wind Sector deal. https://www.gov.uk/government/publications/offshore-wind-sector-deal. [Accessed 16.06.2021]

Berry, M., Sundberg, J. and Francisco, F. 2019. Salmonid response to a vertical axis hydorkinetic turbine in a stream aquarium. Proceedings of the 13th European Wave and Tidal Energy Conference. 1-6 Sept 2019, Naples, Italy. https://tethys.pnnl.gov/sites/default/files/publications/Berry-et-al-2019-EWTEC.pdf

Bevelhimer, M. Shcerelis, C., Colby, J. and Adonizio, M.A. 2017. Responses by Fish Passing Near and operating tidal turbine in the East River, New York. Transactions of the American Fisheries Society. Vol 146 No. 5, pp 1028 -1042.

BOEM. 2020. Guidelines for Providing Information on Fisheries Social and Economic Conditions for Renewable Energy Development on the Atlantic Outer Continental Shelf Pursuant to 30 CFR Part 585. United States Department of Interior. Bureau of Ocean Energy Management. Office of Renewable Energy Programs. May 27, 2020. https://www.boem.gov/sites/default/files/documents/about-boem/Social%20%26amp%3B%20Econ%20Fishing%20Guidelines.pdf

Boyle, G., New, P., 2018. ORJIP Impacts from Piling on Fish at Offshore Wind Sites: Collating Population Information, Gap Analysis and Appraisal of Mitigation Options. Final report –June 2018. The Carbon Trust. United Kingdom. 247 pp. https://prod-drupal-files.storage.googleapis.com/documents/resource/public/ORJIP%20Piling%20Study%20Final%20Report%20Aug%202018%20%28PDF%29.pdf

Breen, P., Vanstaen, K. and Clark, R.W.E. 2015. Mapping inshore fishing activities using aerial, land and vessel-based sighting information. ICES Journal of Marine Science, Vol. 72 No.2, pp 467-479.

BSI. 2015. Environmental impact assessment for offshore renewable energy projects - Guide. PD 6900:2015. http://shop.bsigroup.com/upload/271276/PD%206900.pdf

Buxton, C.D., Hartmann, K., Kearney, R. and Gardner, C. 2014. When is spillover from marine reserves likely to benefit fisheries? Plos ONE Vol 9 No 9: e107032.

Cappell, R., Huntington, T., Nimmo, F., and MacNab, S. 2018. UK scallop fishery: current trends, future management options and recommendations. Report produced by Poseidon Aquatic Resource Management Ltd. https://www.nwwac.org/_fileupload/Papers%20and%20Presentations/2019/Madrid_2019/1417%20Poseidon%20UK%20Scallop%20final%20report%2011_10_18.pdf

Carbon Trust 2015. Cable Burial Risk Assessment (CBRA) Methodology. Guidance for the Preparation of Cable Burial Depth of Lowering Specifications. CTC 835 February 2015. https://prod-drupal-files.storage.googleapis.com/documents/resource/public/owa-ct-appplication-guide-for-cbra-feb-04-1.pdf

Cefas and MCEU. 2004. Guidance Note for Environmental Impact Assessment in Respect of FEPA and CPA Requirements. http://www.cefas.co.uk/publications/files/windfarm-guidance.pdf

Chollett I., Box S.J. and Mumby, P.J. 2016. Quantifying the squeezing or stretching of fisheries as they adapt to displacement by marine reserves. Conservation Biology 30: 166–175.

Christie, N., Smyth, K., Barnes, R. and Elliott, M. 2014. Co-location of activities and designations: A means of solving or creating problems in marine spatial planning? Marine Policy, 43, 254-263.

Copping, A.E., Hemery, L.G., Overhus, D.M., Garavelli, L., Freeman, M.C., Whiting, J.M., Gorton, A.M., Farr, H.K., Rose, D.J. and Tugade, L.G. 2020. Potential Environmental Effects of Marine Renewable Energy Development - The State of Science. Journal of Marine Science and Engineering. 8, 879.

Coull, K.A., Johnstone, R., and S.I. Rogers. 1998. Fisheries Sensitivity Maps in British Waters. Published and distributed by UKOOA Ltd. https://www.cefas.co.uk/media/o0fgfobd/sensi_maps.pdf

Cresci, A., Allan, B.J.M., SHerma, S.D., Skiftesvik, A.B and Browman, H.I. 2020. Orientation behaviour and swimming speed of Atlantic herring larvae (Clupea harengus) in site and in laboratory exposures to rotated artificial magnetic fields. Journal of Experimental Marine Biology and Ecology. 526, 151358.

Cresci, A., Paris, C.B., Foretich, M.A., Durif, C.M.F., Shema, S., O'Brien, C.J. E, Vikebø, F.B., Skiftesvik, A.B and Browman, H.I. 2019. Atlantic haddock (*Melanogrammus aeglefinus*) larvae have a magnetic compass that guides their orientation. iScience. 19, 27, 1173-1178.

CSA Ocean Sciences Inc. and Exponent. 2019. Evaluation of Potential EMF Effects on Fish Species of Commercial or Recreational Fishing Importance in Southern New England. U.S. Dept. of the Interior, Bureau of Ocean Energy Management, Headquarters, Sterling, VA. OCS Study BOEM 2019-049. 59 pp. https://espis.boem.gov/final%20reports/BOEM_2019-049.pdf

DAERA. 2018. Draft Marine Plan for Northern Ireland. Public Consultation. April 2018. http://www.daera-ni.gov.uk/sites/default/files/consultations/daera/Marine%20Plan%20for%20NI%20final%2016%2004%2018.PDF

DECC. 2016. UK Offshore Energy Strategic Environmental Assessment.OESEA3 Environmental Report. Future Leasing/Licensing for Offshore Renewable Energy, Offshore Oil & Gas, Hydrocarbon Gas and Carbon Dioxide Storage and Associated Infrastructure. March 2016. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/504827/OESEA3_Environmental_Report_Final.pdf

Defra. 2019. Department for Environment, Food and Rural Affairs, Marine Management Organisation. South West Marine Plan Iteration 3 Engagement. https://consult.defra.gov.uk/mmo/sw-mp-iteration-3-online-engagement/user_uploads/sw-co-1_clean.pdf

Degraer, S., R. Brabant, B. Rumes, and L. Vigin, eds. 2018. Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Assessing and Managing Effect Spheres of Influence. Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, Brussels, 136 pp. https://tethys.pnnl.gov/sites/default/files/publications/Degraer-et-al-2018_0.pdf

Degraer, S., Brabant, R., Rumes, B. & Vigin, L. (eds). 2019. Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Marking a Decade of Monitoring, Research and Innovation. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, 134 p. https://tethys.pnnl.gov/sites/default/files/publications/Degraer-2019-Offshore-Wind-Impacts.pdf.

Degraer, S., D.A. Carey, J.W.P. Coolen, Z.L. Hutchison, F. Kerckhof, B. Rumes, and J. Vanaverbeke. 2020. Offshore wind farm artificial reefs affect ecosystem structure and functioning: A synthesis. Oceanography, Vol 33 No 4, pp. 48–57.

Dinmore, T., Duplisea, D., Rackham, B., Maxwell, D. and Jennings S. 2003. Impact of a large-scale area closure on patterns of fishing disturbance and the consequences for benthic communities. ICES Journal of Marine Science. Vol 60, pp 371–380.

de Groot, J., Campbell, M., Ashley, M. and Rodwell, L. 2014. Investigating the Co-Existence of Fisheries and Offshore Renewable Energy in the UK: Identification of a Mitigation Agenda for Fishing Effort Displacement. Ocean & Coastal Management, Volume102(A), pp. 7-18.

Dupont, C., Herpers, F., and Le Visage, C. 2020. Recommendations for Positive Interactions Between Offshore Wind Farms and Fisheries: Short Background Study, Luxembourg: Publications Office of the European Union. https://www.msp-platform.eu/sites/default/files/recommendations_for_positive_interactions_between_offshore_wind_farms_and_fisheries.pdf.pdf.

Edmonds, N., Firmin, C., Goldsmith, D., Faulkner, R. and Wood, T. 2016. A review of crustacean sensitivity to high amplitude underwater noise: Data needs for effective risk assessment in relation to UK commercial species. Marine Pollution Bulletin, 108(1-2), pp. 5-11.

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. Sci. Ser. Tech. Rep., Cefas Lowestoft, Vol 14, 56p.

Enever, R., Lewin, S., Reese, A. and Hooper, T. 2017. Mapping fishing effort: Combining fishermen's knowledge with satellite monitoring data in English waters. Fisheries Research. Vol 189, pp. 67-76.

Faulkner, R.C., Farcas, A., and Merchant, N.D. (2018) Guiding principle for assessing the impact of underwater noise. Journal of Applied Ecology. Vol 55, pp. 2531 – 2536.

FLOWW 2014. FLOWW Best Practice Guidance for Offshore Renewables Developments: Recommendations for Fisheries Liaison (January 2014). https://www.thecrownestate.co.uk/media/1775/ei-km-in-pc-fishing-012014-floww-best-practice-guidance-for-offshore-renewables-developments-recommendations-for-fisheries-liaison.pdf

FLOWW.2015. FLOWW Best Practice Guidance for Offshore Renewables Developments: Recommendations for Fisheries Disruption Settlements and Community Funds (August 2015). https://www.thecrownestate.co.uk/media/1776/floww-best-practice-guidance-disruption-settlements-and-community-funds.pdf

Formicki, K., Korzelecka-Orkisz, A., and Tański, A. 2019. Magnetoreception in fish. Journal of Fish Biology, Vol 95 No 1, pp. 73-91.

Franco, A., Nunn, A., Smyth, K., Hänfling, B. and Mazik, K. 2020a. A review of methods for the monitoring of inshore fish biodiversity. http://publications.naturalengland.org.uk/publication/4755646568464384

Franco, A., Barnard, S. and Smyth, K. 2020b. An assessment of the viability of fish monitoring techniques for use in a pilot approach in SW England. http://publications.naturalengland.org.uk/publication/6508611700523008.

Franco, A., Hänfling, B., Young, M. and Elliott, M. 2020c. Regional monitoring plan for inshore fish communities in the Southwest of England. http://publications.naturalengland.org.uk/publication/5448945545510912.

Fraser, S., Nikora, V., Williamson, B. and Scott, B. 2017. Automatic Active Acoustic Target Detection in Turbulent Aquatic Environments. Limnology and Oceanography Methods, Vol 15 No 2, pp. 184-199.

Fraser, S., Williamson, B.J., Nikore, V., and Scott, B.E. 2018. Fish distribution in a tidal channel indicate the behavioural impact of a marine renewable energy installation. Energy Reports. Vol 4, pp. 65-69.

Gerritsen, H. and Lordan, C. 2011. Integration of vessel monitoring systems (VMS) data with daily catch data from logbooks to explore distribution of catch and effort at high resolution. ICES Journal of Marine Science, Vol 68 No 1, pp. 245 -252.

Gill, A., Gloyne-Philips, I., Neal, K., Kimber, J. 2005. COWRIE 1.5 The Potential Effects of Electromagnetic Fields Generated by Sub-Sea Power Cables Associated with Offshore Wind Farm Developments on Electrically and Magnetically Sensitive Marine Organisms - A Review (Report No. COWRIE-EM FIELD 2-06-2004). Report by Centre for Marine and Coastal Studies Ltd (CMACS). Report for Collaborative Offshore Wind Research into the Environment (COWRIE). https://tethys.pnnl.gov/sites/default/files/publications/The_Potential_Effects_of_Electromagnetic_Fields_Generated_by_Sub_Sea_Power_Cables.pdf

Gill, A.B., Huang, Y., Gloyne-Philips, I., Metcalfe, J., Quayle, V., Spencer, J. and 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). https://tethys.pnnl.gov/sites/default/files/publications/Sensitive_Fish_Response_to_EM_Emissions_from_Offshore_Renewable.pdf

Girardin, R., Vermard, Y., Thébaud, O., Tidd, A. and Marchal, P. (2015). Predicting fisher response to competition for space and resources in a mixed demersal fishery. Ocean and Coastal Management, Vol106, pp. 124–135.

González-Irusta, J.M. and Wright, P.J. 2015. Spawning grounds of Atlantic cod (Gadus morhua) in the North Sea. ICES Journal of Marine Science. Vol 73 No 2, pp. 304-315.

González-Irusta, J.M. and Wright, P.J. 2017. Spawning grounds of whiting (Merlangius merlangus). Fisheries Research. Vol 195, pp. 141-151.

González-Irusta, J.M. and Wright, P.J. 2016. Spawning grounds of haddock (Melanogrammus aeglefinus) in the North Sea and West of Scotland. Fisheries Research. Vol. 183, pp. 180-191.

Goñi, R., Badalamenti, F. and Tupper, M. 2011. Fisheries - Effects of marine protected areas on local fisheries: Evidence from empirical studies. In - Marine Protected Areas: effects, networks and monitoring - a multidisciplinary approach. Publisher: Cambridge University Press, Cambridge, UK. Editors: J. Claudet.

Gray, M., Stromberg, P.L and Rodmell, D. 2016. Changes to fishing practices around the UK as a result of the development of offshore windfarms - Phase 1 (Revised). The Crown Estate, 121 pp. https://www.thecrownestate.co.uk/media/2600/final-published-ow-fishing-revised-aug-2016-clean.pdf

Greenstreet, S. P. R., Fraser, H. M., and Piet, G. J. 2009. Using MPAs to address regional-scale ecological objectives in the North Sea: modelling the effects of fishing effort displacement. – ICES Journal of Marine Science, Vol 66, pp. 90–100.

Haggett, C., ten Brink, T., Russell, A., Roach, M., Firestone, J., Dalton, T., McCay, D. 2020. Offshore Wind Projects and Fisheries: Conflict and Engagement in the United Kingdom and the United States. Oceanography, Vol. 33 No 4, pp. 38-47.

Hagos. K.W. 2007. Impact of Offshore Wind Energy on Marine Fisheries in Rhode Island. University of Rhode Island Coastal Institute IGERT Project. White Paper in Integrated Coastal Science. EVS 614-Spring 2007. RI Department of Environmental Management, Division of Fish and Wildlife. Marine Fisheries Section.

Halouani, G., Villanueva, C-M., Raoux, A., Dauvin, J., Lasram, F., Foucher, E., Loc'h, F., Safi, G., Araignous, E., Robin, J. and Niquil, N. 2020. A spatial food web model to investigate potential spillover effects of a fishery closure in an offshore wind farm. Journal of Marine Systems. Vol 212: 103434.

Hammar L, Andersson S, Eggertsen L, Haglund J, Gullström M, et al. 2013. Hydrokinetic Turbine Effects on Fish Swimming Behaviour. PLoS ONE 8 (12): e84141.

Hansen, K., Stenberg, C. and Møller, P. 2012. Small Scale Distribution of Fish in Offshore Wind Farms, paper presented at International Council for the Exploration of the Sea, Bergen, Norway. https://www.ices.dk/sites/pub/CM%20Doccuments/CM-2012/O/O1112.pdf

Hawkins, A.D., Johnson, C. and Popper. A.N. 2020. How to set sound exposure criteria for fishes. The Journal for Acoustical Society of America. Vol 147, p. 1762.

Hawkins, A.D., Pembroke, A.E. and Popper, A.N. 2015 Information gaps in understanding the effects of noise on fishes and invertebrates. Reviews in Fish Biology and Fisheries. Vol 25, pp. 39–64.

Hawkins, A.D and Popper, A.N. 2018. Effects of man-made sound on fishes. In: Slabbekoorn H, Dooling RJ, Popper AN, Fay RR (eds) Effects of anthropogenic noise on animals. Springer, New York, pp. 145–177.

Hawkins, A.D and Popper A.N. 2017. A sound approach to assessing the impact of underwater noise on marine fishes and invertebrates. ICES Journal of Marine Science. Vol 74 No 3, pp. 635-651.

Hooper, T., Ashley, M.C. and Auster, M.C.V. 2015. Perceptions of fishers and developers on the co-location of offshore wind farms and decapod fisheries in the UK. Marine Policy, Vol 61, pp. 16-22.

Hutchison, Z. L., Sigray, P., He, H., Gill, A. B., King, J. and Gibson. C. 2018. Electromagnetic Field (EMF) Impacts on Elasmobranch (shark, rays, and skates) and American Lobster Movement and Migration from Direct Current Cables. Sterling (VA): U.S. Department of the Interior, Bureau of Ocean Energy Management. OCS Study BOEM 2018-003. https://tethys.pnnl.gov/sites/default/files/publications/Hutchison2018.pdf

Hutchison, Z.L., Gill, A. B., Sigray, **P**, He, H. and King, J.W. 2020a. Anthropogenic electromagnetic fields (EMF) influence the behaviour of bottom-dwelling marine species. Scientific Reports, Vol 10 No 1: 4219.

Hutchison, Z.L., D.H. Secor, and A.B. Gill. 2020b. The interaction between resource species and electromagnetic fields associated with electricity production by offshore wind farms. Oceanography. Vol 33 No 4, pp. 96–107.

Hutchison, I., Tait, C., Sheehy, J. and Morgan, P. 2020c. Review of underwater video data collected around operating tidal stream turbines (Report No. 1225). Report by Scottish Natural Heritage. Report for Scottish Natural Heritage. https://www.nature.scot/research-report-1225-review-underwater-video-data-collected-around-operating-tidal-stream-turbines.

Hynes, S., Gerritsen, H., Breen, B. and Johnson, M. 2016. Discrete choice modelling of fisheries with nuanced spatial information. Marine Policy 72, pp. 156-165.

HZG.2021. OffChEm Project 2017 -2021. Chemical Emissions from offshore wind farm - Potential impacts on the marine environment and their evaluation. https://www.hzg.de/institutes_platforms/coastal_research/biogeochemistry_in_coastal_seas/marine_bioanalytical_chemistry/projects/OffChEm/index.php.en#tab-1. [Accessed 06.02.2021].

ICES. 2019. ICES Technical Guidelines. Spatial distribution of fishing effort and physical disturbance of benthic habitats by mobile bottom trawl fishing gear using VMS.https://www.ices.dk/sites/pub/Publication%20Reports/Guidelines%20and%20Policies/16.03.03.03_Guidelines_Vessel_Monitoring_Systems_Data.pdf

Jones, I.T., Stanley, J.A. and Mooney, T.A. 2020.Impulsive pile driving noise elicits alarm responses in squid (Doryteuthis pealeii). Marine Pollution Bulletin 150:110792.

Judd, A. 2012. Guidelines for Data Acquisition to Support Marine Environmental Assessments of Offshore Renewable Energy Projects. Report by Centre for Environment Fisheries and Aquaculture Science (CEFAS). https://tethys.pnnl.gov/sites/default/files/publications/CEFAS_2012_Eenvironmental_Assessment_Guidance.pdf

Krone, R., Dederer, G., Kanstinger, P., Krämer, P. and Schneider, C. 2017. Mobile demersal megafauna at common offshore wind turbine foundations in the German Bight (North Sea) two years after deployment– Increased production rate of Cancer pagurus. Marine Environmental Research Vol 123, pp.53–61.

Kafas, A., Jones, G., Watret, R., Davies, I. and Scott, B. 2013. 2009 - 2013 amalgamated VMS intensity layers, GIS Data. Marine Scotland, Scottish Government. https://marinedata.scotland.gov.uk/dataset/2009-2013-amalgamated-vms-intensity-layers

Kafas, A., McLay, A., Chimienti, M., Gubbins, M. 2014a. ScotMap Inshore Fisheries Mapping in Scotland: Recording Fishermen's use of the Sea. Scottish Marine and Freshwater Science Volume 5 Number 17. Edinburgh: Scottish Government, 32p. Available at: https://marinedata.scotland.gov.uk/dataset/scotmap-inshore-fisheries-mapping-scotland-recording-fishermen%E2%80%99s-use-sea

Kafas, A., Davies, I., McLay, A., Gubbins, M. and Scott, B. 2014b. New Perspectives on Fisheries: Combining the Distribution of Inshore and Offshore Commercial Fisheries in Scotland [Presentation]. Presented at Environmental Impact of Marine Renewables 2014, Stornoway, Scotland, UK. https://tethys.pnnl.gov/sites/default/files/publications/EIMR-2014-Abstract-Kafas.pdf.

Kafas, A. 2017. MUSES [Multi-Use in European Seas] Project Case Study 1A: Offshore Wind and Commercial Fisheries in the East Coast of Scotland. MUSES Deliverable: D.3.3, 38 pp. https://muses-project.com/wp-content/uploads/sites/70/2018/02/ANNEX-1-CASE-STUDY-1A.pdf.

Kirchgeorg, T., Weinberg, I., Hörnig, M., Baier, R., Schmid, M.J. and Brockmeyer, B. 2018. Emissions from corrosion protection systems of offshore wind farms: Evaluation of the potential impact on the marine environment. Marine Pollution Bulletin Vol136, pp 257-268.

Kunc, H.P., McLaughlin, K.E., Schmidt, R. 2016. Aquatic noise pollution: implications for individuals, populations, and ecosystems. Proc B 283:20160839.

Lee, J., South, A. B., and Jennings, S. 2010. Developing reliable, repeatable, and accessible methods to provide high-resolution estimates of fishing-effort distributions from vessel monitoring system (VMS) data. ICES Journal of Marine Science, Vol 67, pp. 1260–1271.

Latto, P. L., Reach, I.S., Alexander, D., Armstrong, S., Backstrom, J., Beagley, E., Murphy K., Piper, R. and Seiderer, L.J. 2013. Screening spatial interactions between marine aggregate application areas and sandeel habitat. A Method Statement produced for BMAPA.

Lindeboom, H., Kouwenhoven, H., Bergman, M., Bouma, S., Brasseur, S., Daan, R., Fijn, R., de Haan, D., Dirksen, S., van Hal, R., Lambers, R., ter Hofstede, R., Krijgsveld, K., Leopold, M., Scheidat, M. 2011. Short-Term Ecological Effects of an Offshore Wind Farm in the Dutch Coastal Zone: A Compilation. Environmental Research Letters, Vol 6 No 3, 035101.

Love, M., Nishimoto, M., Clark, S., Bull, A. 2016. Renewable Energy in situ Power Cable Observation (Report No. BOEM 2016-008). Report by University of California Santa Barbara. Report for Bureau of Ocean Energy Management (BOEM). https://www.boem.gov/sites/default/files/environmental-stewardship/Environmental-Studies/Pacific-Region/Studies/BOEM-2016-008.pdf

Love, M., Nishimoto, M., Clark, S., McCrea, M. and Bull, A. 2017. Assessing potential impacts of energized submarine power cables on crab harvests. Continental Shelf Research, 151, 23-29.

Mackinson, S., Curtis, H., Brown, R., McTaggart, K., Taylor, N., Neville, S. and Rogers, S. 2006. A report on the perceptions of the fishing industry into the potential socioeconomic impacts of offshore wind energy developments on their work patterns and income. Sci. Ser. Tech Rep., Cefas Lowestoft, 133: 99pp. https://www.cefas.co.uk/publications/techrep/tech133.pdf.

MASTS. 2021. Scottish Inshore Fisheries Integrated Data System (SIFIDS) Project. Available online at: https://www.masts.ac.uk/research/emff-sifids-project/. [Accessed 24.2.2021].

MASTS. 2020. MASTS Coastal Forum Small Grant. Report for CSG6 - Effects of electromagnetic fields from renewable energy subsea power cables on post disturbance recovery of coastal invertebrates. https://www.masts.ac.uk/media/37051/csg6_report_emf_ericachapman.pdf.

Matzner, S., Trostle, C., Staines, G., Hull, R., Avila, A., Harker-Klimes, G. 2017. Triton: Igiugig Fish Video Analysis (Report No. PNNL-26576). Report by Pacific Northwest National Laboratory (PNNL). Report for US Department of Energy (DOE). https://tethys.pnnl.gov/sites/default/files/publications/Triton-Igiugig-Report.pdf.

Merchant, N.D. and Robinson, S.P. 2020. Abatement of underwater noise pollution from pile-driving and explosions in UK waters. Report of the UKAN workshop held on Tuesday 12 November 2019 at The Royal Society, London. 31pp. https://acoustics.ac.uk/wp-content/uploads/2020/02/Merchant_Robinson_2020_Noise-_Abatement_Workshop_20200206_vFINAL.pdf

Methratta, E. and Dardick, W. 2019. Meta-Analysis of Finfish Abundance at Offshore Wind Farms. Reviews in Fisheries Science & Aquaculture, Vol 27 No 2, pp. 242-260.

MMO. 2013a. Spatial models of Essential Fish Habitat (South Coast Inshore and Offshore Marine Plan Areas). A report produced for the Marine Management Organisation by the Institute of Estuarine and Coastal Studies, 73pp. MMO Project No: 1044. ISBN: 978-1-909452-21-3.

MMO.2013b. Evaluation of the current state of knowledge on potential cumulative effects from offshore wind farms (OWF) to inform marine planning and marine licensing. A report produced for the Marine Management Organisation, pp 71. MMO Project No: 1009.

MMO. 2014a. Review of post-consent offshore wind farm monitoring data associated with licence conditions of offshore wind farms. A report produced for the Marine Management Organisation, pp 194. MMO Project No: 1031. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/317787/1031.pdf.

MMO. 2014b. A Strategic Framework for Scoping Cumulative Effects. A report produced for the Marine Management Organisation, pp 224. MMO Project No: 1055.https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/389876/MMO1055_Report_Final.pdf.

MMO. 2014c. East Inshore and East Offshore Marine Plans. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/312496/east-plan.pdf.

MMO 2016. Follow on to the Development of Spatial Models of Essential Fish Habitat for the South Inshore and Offshore Marine Plan Areas. A report produced for the Marine Management Organisation, pp 142. MMO Project No: 1096. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/505809/MMO1096-Essential_fish_habitat_follow_on_Report.pdf.

MMO. 2021. Evidence Projects Register. Available online at: https://www.gov.uk/government/publications/evidence-and-the-marine-management-organisation-mmo/evidence-projects-register.[Accessed 05.02.2021].

Moura, S., Lipsky, A. and Morse, M. 2015. Options for Cooperation between Commercial Fishing and Offshore Wind Energy Industries. A review of Relevant Tools and Best Practices. SeaPlan. November 2015.

Mueller-Blenkle, C., McGregor, P.K., Gill, A.B., Andersson, M.H., Metcalfe, J., Bendall, V., Sigray, P., Wood, D.T. and Thomsen, F. (2010) Effects of Pile-driving Noise on the Behaviour of Marine Fish. COWRIE Ref: Fish 06-08, Technical

Report 31st March 2010. https://dspace.lib.cranfield.ac.uk/bitstream/handle/1826/8235/Effects_of_Pile-driving_Noise-2010-2.pdf?sequence=1&isAllowed=y.

National Archives, 2022. Open Government Licence, https://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/ [Accessed: 31.03.2023]
Natural England. 2014. Development of a generic framework for informing Cumulative Impact Assessments (CIA) related to Marine Protected Areas through evaluation of best practice. http://publications.naturalengland.org.uk/publication/6341085840277504.

Nedelec, S., Campbell, J., Radford, A., Simpson, S. and Merchant, N. 2016. Particle motion: the missing link in underwater acoustic ecology. Methods in Ecology and Evolution, Vol 7 No 7, pp. 836-842.

Newton, K. C., Gill, A. B., and Kajiura, S. M. 2019. Electroreception in marine fishes: chondrichthyans. Journal of Fish Biology, Vol 95 No 1, pp. 135-154.

Niquil N. et al. 2020. Toward an Ecosystem Approach of Marine Renewable Energy: The Case of the Offshore Wind Farm of Courseulles-sur-Mer in the Bay of Seine. In: Nguyen K., Guillou S., Gourbesville P., Thiébot J. (eds) Estuaries and Coastal Zones in Times of Global Change. Springer Water. Springer, Singapore.

Nogues, Q., Raoux, A., Araignous, E., Chaalali, A., Hattab, T., Leroy, B., Lasram, F.B.R, David, V., Le Loc'h, F., Dauvin, J., Niquil, N. 2020. Cumulative effects of marine renewable energy and climate change on ecosystem properties: Sensitivity of ecological network analysis. Ecological Indicators. 121. 107128.

Normandeau, Exponent, Tricas, T. and Gill, A. 2011. Effects of EMFs from Undersea Power Cables on Elasmobranchs and Other Marine Species. OCS Study BOEMRE 2011-09, U.S. Department of the Interior, Bureau of Ocean Energy Management, Regulation, and Enforcement, Pacific OCS Region, Camarillo, California. https://tethys.pnnl.gov/publications/effects-emfs-undersea-power-cables-elasmobranchs-other-marine-species

Pol, M. and Ford, K. 2020. Offshore Wind Energy and the Fishing Industry in the Northeastern USA - In Modern Fisheries Engineering: Realizing a Healthy and Sustainable Marine Ecosystem, Ed. 1st (pp. 115-125). London, UK: CRC Press.

Popper, A.N., Hawkins, A.D., Fay, R.R., Mann, D.A., Bartol, S., Carlson, T.J., Coombs, S., Ellison, W.T., Gentry, R.L., Halvorsen, M.B., Løkkeborg, S., Rogers, P.H., Southall, B.L., Zeddies, D.G. and Tavolga, W.N. 2014. Sound Exposure Guidelines for Fishes and Sea Turtles: A Technical Report prepared by ANSI-Accredited Standards Committee S3/SC1 and registered with ANSI.

Popper, A. and Hawkins, A. 2019. An overview of fish bioacoustics and the impacts of anthropogenic sounds on fishes. Journal of Fish Biology, Vol 94 No 5, pp. 692–713.

Primo Marine (2019) Consequences of possible sea-bed fishery in future offshore wind farms. Report to Rijksdienst voor Onderemend Nederlands. https://offshorewind.rvo.nl/file/download/55040156.

Radford., A.N, Kerridge., E, Simpson., S.D. 2014. Acoustic communication in a noisy world: can fish compete with anthropogenic noise? Behavioural Ecology, Vol 25, pp.1022–1030.

Raoux, A., Tecchio, S. Pezy, J., Lassalle, G., Degraer, S., Wilhelmsson, D., Cachera, M., Ernande, B., Guen, C., Haraldsson, M., Grangeré, K., Le Loc'h, F., Dauvin, J., Niquil, N. 2017. Benthic and Fish Aggregation Inside an Offshore Wind Farm: Which Effects on the Trophic Web Functioning?. Ecological Indicators, 72, pp. 33-46.

Reach, I.S., Latto P., Alexander, D., Armstrong, S., Backstrom, J., Beagley, E., Murphy, K., Piper, R., and Seiderer, L.J. 2013. Screening spatial interactions between marine aggregate application areas and Atlantic herring potential spawning areas. A Method Statement produced for BMAPA.

Reese, A., Voigt. N., Zimmermann. T., Irrgeher, J., Profock, D. 2020. Characterization of alloying components in galvanic anodes as potential environmental tracers for heavy metal emissions from offshore wind structures. Chemosphere. 257.

Reilly, K., O'Hagan, A.M. and Dalton, G.J. 2015. Attitudes and perceptions of fishermen on the island of Ireland towards the development of marine renewable energy projects. Marine Policy. 58. 88-97.

Reubens, J., Braeckman, U., Vanaverbeke, J., van Colen, C., Degraer, S., Vincx, M. 2013a. Aggregation at Windmill Artificial Reefs: CPUE of Atlantic Cod (Gadus morhua) and Pouting (Trisopterus luscus) at Different Habitats in the Belgian Part of the North Sea. Fisheries Research, Vol 139, pp. 28-34.

Reubens, J., Pasotti, F., Degraer, S. and Vincx, M. 2013b. Residency, Site Fidelity and Habitat Use of Atlantic Cod (Gadus morhua) at an Offshore Wind Farm Using Acoustic Telemetry. Marine Environmental Research, Vol 90, pp. 128-135.

Rijkswaterstaat. 2019. Framework for Assessing Ecological and Cumulative Effects 3.0 for the roll-out of offshore wind energy 2030. Sub-report. Methods. https://www.noordzeeloket.nl/en/functions-and-use/offshore-wind-energy/ecology/accumulation-ecological-effects/framework-assessing-ecological-cumulative-effects/. [Accessed 16.06.2021]

Rijnsdorp, A. D., Piet, G. J., Poos, J. J. 2001. Effort allocation of the Dutch beam trawl fleet in response to a temporarily closed area in the North Sea, 2001. ICES CM 2001/N: 01.
https://www.ices.dk/sites/pub/CM%20Doccuments/2001/N/N0101.pdf

Roach, M., Cohen, M., Forster, R., Revill, A. S., and Johnson, M. 2018. The effects of temporary exclusion of activity due to wind farm construction on a lobster (Homarus gammarus) fishery suggests a potential management approach. ICES J. Mar. Sci. 75,1416-1426.

Roach (2020) Westermost Rough Offshore Wind Farm Shellfish Survey 2017. https://www.researchgate.net/publication/344025609_Westermost_Rough_Offshore_Wind_Farm_Shellfish_Survey_2017.

Robertson, M., Locke, S., Uttley, M., Helmer, L and Kean-Hammerson, J. 2021. Exploring the role of offshore wind in restoring priority marine habitats. Case

Study: Opportunities for native oyster (Ostrea edulis) restoration at the Gunfleet Sands Offshore Wind Farm. Blue Marine Foundation. Blue Marine Foundation. January 2021. https://www.bluemarinefoundation.com/wp-content/uploads/2021/01/BLUE-wind-farm-feasibility-study-report-FINAL.pdf. [Accessed: 14.06.2021].

Rodwell, L.D., de Groot., J., Ashley, M. Campbell, M. and Linley, A. 2013. Fisheries and Marine Renewable Energy Interactions - Assessment Mitigation. A summary report on an expert workshop for the Marine Renewable Energy Knowledge Exchange Programme (MREKEP). Centre for Marine and Coastal Policy Research, Plymouth University, UK. https://nerc.ukri.org/innovation/activities/energy/offshore/fisheries-report/.

Russi, D., Pantzar, M., Kettunen, M., Gitti, G., Mutafoglu, K., Kotulak, M, and ten Brink, P. 2016. Socio- Economic Benefits of EU Marine Protected Areas. Report prepared by the Institute for European Environmental Policy (IEEP) for DG Environment. https://oppla.eu/sites/default/files/uploads/socio-economic-benefits-eu-mpas.pdf.

Seafish. 2019. Future of Our Inshore Fisheries – Conference Report. https://www.seafish.org/document?id=0de29d54-39e2-4764-b5b4-b12b426f7743.

Schupp, M.F., Kafas, A., Buck, B.H., Krause, G., Onyango, V, Stelzenmuller, V, Davies, I and Scott, B.E. 2021. Fishing within offshore wind farms in the North Sea; Stakeholder perspectives for multi-use from Scotland and Germany. Journal of Environmental Management. Vol 279: 111762.

Schupp, M., Bocci, M., Depellegrin, D., Kafas, A., Kyriazi, Z., Lukic, I., Schultz-Zehden, A., Krause, G., Onyango, V., Buck, B. 2019. Toward a Common Understanding of Ocean Multi-Use. Frontiers in Marine Science, Vol 6, p. 165.

Scott, K., Harsanyi, P., Easton, B.A.A., Piper, A.J.R., Rochas, C.M.V. and Lyndon, A.R. 2021. Exposure to Electromagnetic Fields (EMF) from submarine power cables can trigger strength-dependent behavioural and physiological responses in edible crab, Cancer pagurus (L.). Journal of Marine Science and Engineering. Volume 9, p. 776.

Scott, K., Harsanyi, P. and Lyndon. A.R. 2018. Understanding the effects of electromagnetic field emissions from Marine Renewable Energy Devices (MREDs) on the commercially important edible crab, Cancer pagurus (L.). Marine Pollution Bulletin. Vol 131(PtA), pp. 580-588.

Slijkerman, D. and Tamis, J. 2015. Fisheries Displacement effects related to closed areas: a literature review of relevant aspects. (Report/ IMARES; No C170/15). IMARES. https://edepot.wur.nl/366172.

Scottish Natural Heritage (SNH). 2016. Assessing collision risk between underwater turbines and marine wildlife. SNH guidance note. https://www.nature.scot/assessing-collision-risk-between-underwater-turbines-and-marine-wildlife.

Solan, M., Hauton, C., Godbold, J.A., Wood, C.L., Leighton, T.G. and White, P. 2016. Anthropogenic sources of underwater sound can modify how sediment-dwelling invertebrates mediate ecosystem properties. Scientific Reports, Vol 6, 20540.

Sparling, C.E., Seitz, A.C., Masden E., and Smith, K. 2020. Collision Risk for Animals around Turbines. In A.E. Copping and L.G. Hemery (Eds.), OES-Environmental 2020 State of the Science Report: Environmental Effects of Marine Renewable Energy Development Around the World. Report for Ocean Energy Systems (OES). (pp. 28-65). https://tethys.pnnl.gov/sites/default/files/publications/OES-Environmental-2020-State-of-the-Science-Ch-3_final_hr.pdf

Spiga., I, Cheesman., S, Hawkins., A, Perez-Dominguez., R, Roberts., L, Hughes., D, Elliott., M, Nedwell. J and Bentley. M 2012. Understanding the Scale and Impacts of Anthropogenic Noise upon Fish and Invertebrates in the Marine Environment. SoundWaves Consortium Technical Review (ME5205). https://research.ncl.ac.uk/soundwaves/links/pubblications/REVIEW%20new.pdf

Stelzenmüller, V., Gimpel, A., Letschert, J., Kraan, C. and Döring, R. 2020. Impact of the use of offshore wind and other marine renewables on European fisheries. Report by Thunen Institute. Report for European Parliament. https://www.europarl.europa.eu/RegData/etudes/STUD/2020/652212/IPOL_STU(2020)652212_EN.pdf

Stenberg, C., van Deurs, M., Støttrup, J., Mosegaard, H., Grome, T., Dinesen, G., Christensen, A., Jensen, H., Kaspersen, M., Berg, C., Leonhard, S., Skov, H., Pedersen, J., Hvidt, C., Klaustrup, M. 2011. Effect of the Horns Rev 1 Offshore Wind Farm on Fish Communities: Follow-up Seven Years after Construction (Report No. 246-2011). Report by DTU Aqua (National Institute of Aquatic Resources). Report for Danish Energy Agency. https://backend.orbit.dtu.dk/ws/portalfiles/portal/7615058/246_2011_effect_of_the_horns_rev_1_offshore_wind_farm_on_fish_communities.pdf

Stenberg, C., Støttrup, J., van Duers, M., Berg, C., Dinesen, G., Mosegaard, H., Grome, T., Leonhard, S. 2015. Long-Term Effects of an Offshore Wind Farm in the North Sea on Fish Communities. Marine Ecology Progress Series, 528, 257-265.

Taormina, B., Bald, J., Want, A., Thouzeau, G., Lejart, M., Desroy, N., and Carlier, A. 2018. A review of potential impacts of submarine power cables on the marine environment: Knowledge gaps, recommendations and future directions. Renewable and Sustainable Energy Reviews, Vol 96, pp. 380-391.

Taormina, B., Di Poi, C., Agnalt, A.-L., Carlier, A., Desroy, N., Escobar-Lux, R. H., D'eu, J.-F., Freytet, F., and Durif, C. M. F. 2020. Impact of magnetic fields generated by AC/ DC submarine power cables on the behavior of juvenile European lobster (Homarus gammarus). Aquatic Toxicology, Vol 220, 105401.
ten Brink, T.S. and Dalton, T. 2018. Perceptions of Commercial and Recreational Fishers on the Potential Ecological Impacts of the Block Island Wind Farm (US). Frontiers in Marine Science. Vol 5, No 439.

Tertente, V. Secomendi, M. Owne, M. J. 2017. Application of the Bathymetric Position Index Method (BPI) for the purpose of defining reference seabed level for cable burial. https://www.researchgate.net/publication/318672698_Application_of_the_Bathymetric_Position_Index_Method_BPI_for_the_purpose_of_defining_a_reference_seabed_level_for_cable_burial

The Scottish Government. 2015. Scotland's National Marine Plan. A Single Framework for Managing our Seas https://www.gov.scot/publications/scotlands-national-marine-plan/ [Accessed: 15.06.2021].

The Scottish Government. 2019a. Future of Fisheries Management in Scotland: National Discussion Paper. https://www.gov.scot/publications/national-discussion-paper-future-fisheries-management-scotland/pages/7/. [Accessed: 02.06.2021]

The Scottish Government. 2019b. Monitoring Socio-economic Impacts of Marine Protected Areas: 2019 Report. https://www.gov.scot/publications/scottish-marine-protected-areas-socioeconomic-monitoring/. [Accessed: 02.06.2021]

The Scottish Government. 2020a. Sectoral Marine Plan for Offshore Wind Energy. October 2020. https://www.gov.scot/publications/sectoral-marine-plan-offshore-wind-energy/. [Accessed: 02.06.2021]

The Scottish Government. 2020b. Scotland's Fisheries Management Strategy 2020 - 2030. Published by the Scottish Government, December 2020. https://www.gov.scot/publications/scotlands-future-fisheries-management-strategy-2020-2030/. [Accessed: 02.06.2021]

The Scottish Government, 2022. Marine Energy Research https://www.gov.scot/policies/marine-renewable-energy/science-and-research/. [Accessed: 02.06.2021]

Tidau, S. and Briffa, M. 2016. Review on behavioural impacts of aquatic noise on crustaceans. Proc. Mtgs. Acoust. 27(1): 010028.

Tidd, A.N., Hutton, T., Kell, L.T. and Blanchard, J.L. 2012. Dynamic prediction of effort reallocation in mixed fisheries. Fisheries Research 125: 243–253.

UK MPS. 2011. UK Marine Policy Statement. HM Government Northern Ireland Executive, Scottish Government and Welsh Assembly Government. March 2011. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69322/pb3654-marine-policy-statement-110316.pdf.

van Hal, R. Griffioen, A.B., van Keeken O.A. 2017. Changes in fish communities on a small spatial scale, an effect of increased habitat complexity by an offshore wind farm. Mar. Environ. Res. Vol 126, pp. 26–36.

Vandendriessche, S., J. Derweduwen, and K. Hostens. 2015. Equivocal effects of offshore wind farms in Belgium on soft substrate epibenthos and fish assemblages. Hydrobiologia, Vol 756, pp. 19–35.

Vanstaen, K. and Breen, P. 2014. MB0117: Understanding the distribution and trends in inshore fishing activities and the link to coastal communities. Cefas contract report C5401. http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=1&ProjectID=18126 [Accessed 16.06.2021].

Vaughan, D. 2017. Fishing effort displacement and the consequences of implementing Marine Protected Area management - An English perspective. Marine Policy, Vol 84, pp. 228-234.

Verfuss, U.K., Sinclair, R.R. & Sparling, C.E. 2019. A review of noise abatement systems for offshore wind farm construction noise, and the potential for their application in Scottish waters. Scottish Natural Heritage Research Report No. 1070. https://www.nature.scot/naturescot-research-report-1070-review-noise-abatement-systems-offshore-wind-farm-construction-noise

Viehman, H.A. and Zydlewski, G.B. 2015. Fish Interactions with Commercial - Scale Tidal Energy Device in the Natural Environment. Estuaries and Coasts, Vol 38, pp. 241-252.

Viehman, H., Hasselman, D., Boucher, T., Douglas, J., Bennett, L. 2020. Integrating Hydroacoustic Approaches to Predict Fish Interactions with In-stream Tidal Turbines. Report by Echoview Software.

Welsh Government. 2019. Welsh National Marine Plan. 2019. https://gov.wales/sites/default/files/publications/2019-11/welsh-national-marine-plan-document_0.pdf

Weilgart. 2018. The Impact of Ocean Noise Pollution on Fish and Invertebrates. Lindy Weilgart, PHD. Oceancare & Dalhousie University. May 2018. https://www.oceancare.org/wp-content/uploads/2017/10/OceanNoise_FishInvertebrates_May2018.pdf

Wilding, T., A.B. Gill, A. Boon, E. Sheehan, J.-C. Dauvin, J.-P. Pezy, F.X. O'Beirn, U. Janas, L. Rostin, and I. De Mesel. 2017. Turning off the DRIP ('Data-rich, information-poor')—rationalising monitoring with a focus on marine renewable energy developments and the benthos. Renewable and Sustainable Energy Reviews, Vol 74, pp. 848–859.

Williams, R., Wright. A.J., Ashe, E. et al. 2015. Impacts of anthropogenic noise on marine life: publication patterns, new discoveries, and future directions in research and management. Ocean Coastal Management, Vol 115, pp.17–24.

Whitton, T.A, Jackson, S.E., Hiddick, J.G., Scoulding, B., Bowers, D., Powell, B, Jackson, T.D., Gimenez, L. and Davies, A.G. 2020. Vertical migrations of fish schools determine overlap with a mobile tidal stream marine renewable energy device. Journal of Applied Ecology. Vol 57 No 4, pp. 725-741.

Appendix 1 – Consultation Questionnaires

Consultee Details	
Name	
Position	
Organisation	
Country	
E-mail	
Questions	

Q.1) Is your organisation currently undertaking research or has recently completed research of relevance to the knowledge gaps identified as part of ScotMER's Fish and Fisheries Evidence Map? Yes/No If Yes, please fill in the table below noting the specific knowledge gap(s) of relevance to the research carried out by your organisation. If No, please continue to <u>Question 3</u> below		
ID	ScotMER's Knowledge Gap	Research by your organisation (Y/N)
FF.01	Accurate mapping of fishing effort and catches in space and time	
FF.02	Accurate and validated method to predict fisheries displacement levels and locations (associated with the introduction of Marine Renewable Projects)	
FF.03	Fisheries stakeholder integration and participation process	
FF.04	Improvement in Environmental assessment methodologies (Environmental Impact Assessments, Cumulative Impact Assessment, etc)	
FF.04 a)	Coexistence and compatibility between commercial fisheries and offshore renewables	
FF.05	Strategic Fisheries Management – Marine Renewable development areas and their potential to play a role as fisheries management areas and integrated approach to fisheries management and marine planning	
FF.06	Underwater Noise and Vibration – Impacts on fish and shellfish	

FF.07	Electromagnetic Fields (EMFs) – Impacts on fish and shellfish	
FF.08	Collision risk (tidal turbines) – especially large fish of conservation concern	
FF.09	Accurate spatio-temporal patterns of spawning activity by marine fish species.	
FF.10	Essential fish habitat – especially fish spawning and nursery grounds (sensitivity maps)	
FF.11	Reef/fish aggregation effects	
FF.12	Inshore fish and shellfish populations/distribution	
FF.13	Cumulative pressure & impact pathways on individual species level	

Q2) If your organisation is involved /has recently been involved in research of relevance to the knowledge gaps identified in ScotMER's Fish and Fisheries Evidence Map, please fill in the sections below with details of the research undertaken.

Please complete the information below for each research project.
Delete/add additional projects to the list below as appropriate

PROJECT 1

- Link to ScotMER evidence gap no.:
- Project Name:
- Overall Aim:
- Status/Year(s) research was carried out:
- Species relevant to research:
- Region relevant to research e.g. Scotland/UK/EU/US etc.:
- Type of development relevant to research (e.g. offshore wind, floating wind, tidal, wave):

- Summary of Results (if available):
- Provide links to relevant project papers/ reports/project information:
- Where specific data has been collected as part of the project, specify the format of the data/information (i.e. word document, GIS outputs, spreadsheet, etc):
- Where relevant, please specify the location and availability of data collected as part of the research (dataset, data holder, publicly available, available for research purposes, confidential):
- Contact details of key research author(s) for further correspondence, if required:

<u>PROJECT 2</u>

- Link to ScotMER evidence gap no.:
- Project Name:
- Overall Aim:
- Status/Year(s) research was carried out:
- Species relevant to research:
- Region relevant to research e.g. Scotland/UK/EU/US etc.:
- Type of development relevant to research (e.g. offshore wind, floating wind, tidal, wave):
- Summary of Results (if available):
- Provide links to relevant project papers/ reports/project information:

• Where specific data has been collected as part of the project, specify the format of the data/information (i.e. word document, GIS outputs, spreadsheet, etc): • Where relevant, please specify the location and availability of data collected as part of the research (dataset, data holder, publicly available, available for research purposes, confidential): • Contact details of key research author(s) for further correspondence, if required:
Q3) Are you aware of research being undertaken/recently completed by other organisation(s) of relevance to the evidence gaps identified by ScotMER's Fish and Fisheries Evidence Map? If Yes, please provide details below
Q4) Do you consider that the results of research already undertaken (either by your organisation or other parties) sufficiently address any of the evidence gaps currently identified in ScotMER's Fish and Fisheries Evidence Map? On that basis, should any of the evidence gaps be removed from future versions of the Evidence Map? Please provide details below, including reference to relevant evidence gaps and the rationale as to why you feel the research undertaken addresses them

Q5) Do you consider that there are additional evidence gaps to those currently identified in ScotMER's Fish and Fisheries Evidence Map that should be explored? Please provide details below, including rationale as to why you feel they should be considered
Q6) Please add any additional information that you feel may be of relevance to inform this consultation

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