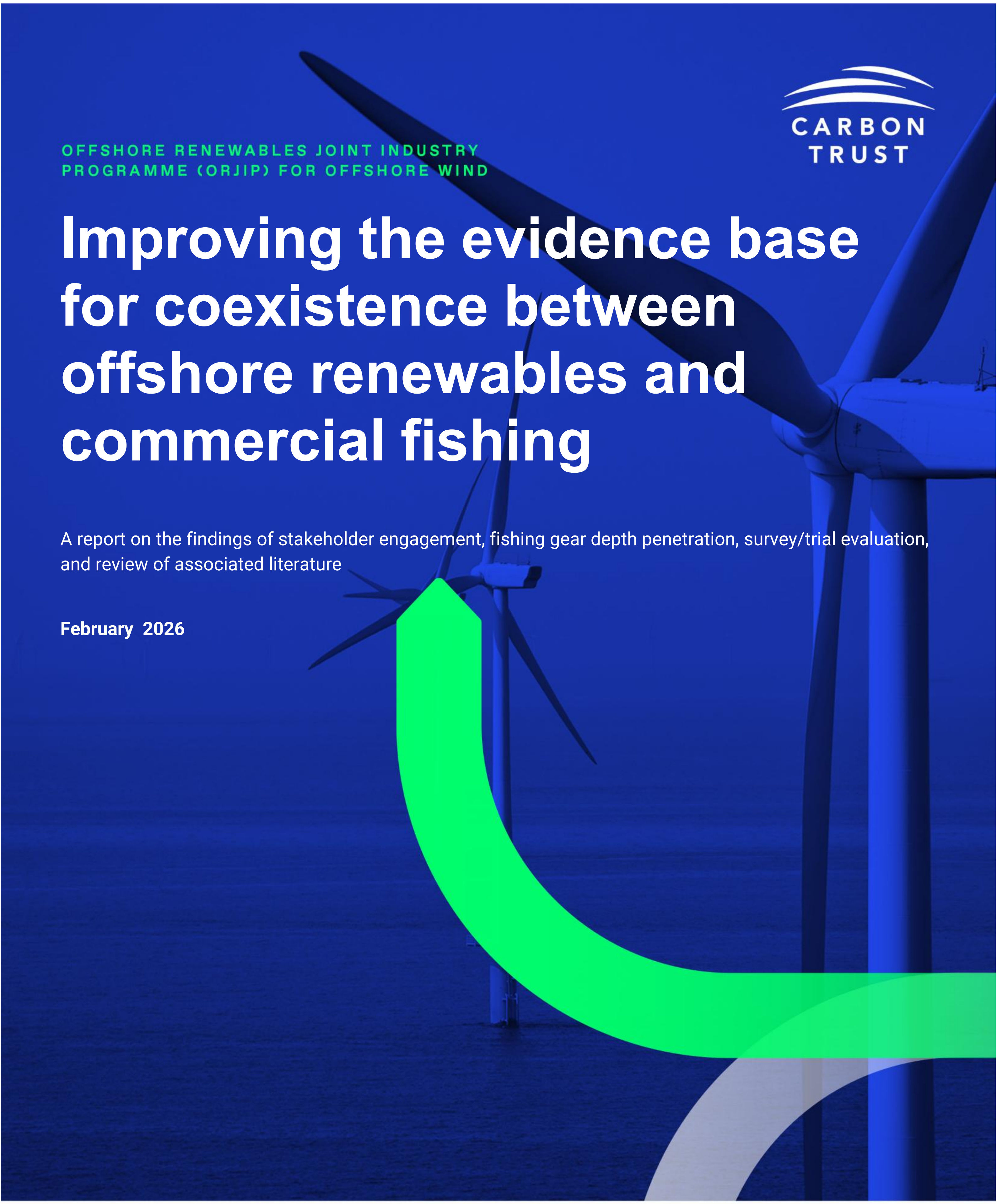

OFFSHORE RENEWABLES JOINT INDUSTRY PROGRAMME (ORJIP) FOR OFFSHORE WIND

Improving the evidence base for coexistence between offshore renewables and commercial fishing

A report on the findings of stakeholder engagement, fishing gear depth penetration, survey/trial evaluation, and review of associated literature

February 2026

orjip working to accelerate offshore consenting

ORJIP Offshore Wind

The Offshore Renewables Joint Industry Programme (ORJIP) for Offshore Wind is a collaborative initiative that aims to:

- Fund research to improve our understanding of the effects of offshore wind on the marine environment.
- Reduce the risk of not getting, or delaying consent for, offshore wind developments.
- Reduce the risk of getting consent with conditions that reduce viability of the project.

The programme pools resources from the private sector and public sector bodies to fund projects that provide empirical data to support consenting authorities in evaluating the environmental risk of offshore wind. Projects are prioritised and informed by the ORJIP Advisory Network which includes key stakeholders, including statutory nature conservation bodies, academics, non-governmental organisations and others.

The current stage is a collaboration between the Carbon Trust, EDF Energy Renewables Limited, Ocean Winds UK Limited, Equinor ASA, Ørsted Power (UK) Limited, RWE Offshore Wind GmbH, Shell Global Solutions International B.V., SSE Renewables Services (UK) Limited, TotalEnergies OneTech, Crown Estate Scotland, Scottish Government (acting through the Offshore Wind Directorate and the Marine Directorate) and The Crown Estate Commissioners.

For further information regarding the ORJIP Offshore Wind programme, please refer to the Carbon Trust website, or contact Ivan Savitsky (ivan.savitsky@carbontrust.com) and Žilvinas Valantiejus (zilvinas.valantiejus@carbontrust.com).

Delivery partners

This document was produced on behalf of ORJIP Offshore Wind by Intertek Metoc, with review undertaken by Cooper Marine Advisors. This report was authored by James Harding, Eloïse Boblin, Aodhfin Coyle, Dr Jim Andrews, Vicky Fisk, Dr Andrew Page and Bill Cooper.

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- Communities Inshore Fisheries Alliance (CIFA)
- Eastern England Fish Producers Organisation (EEFPO)
- North & East Coast, Northwest Coast and Orkney Regional Inshore Fisheries Groups (RIFGs)
- National Federation of Fishermen's Organisation (NFFO)

- Seafish
- Scottish Fishermen's Federation (SFF)
- Scottish White Fish Producers Association (SWFPA)
- Devon & Severn, Eastern, Kent & Essex and Northumberland Inshore Fisheries Conservation Authorities (IFCAs)
- ARC Marine
- AP Sensing

This project forms part of the Offshore Wind Evidence and Change programme, led by The Crown Estate in partnership with the Department for Energy Security and Net Zero and Department for Environment, Food & Rural Affairs. The Offshore Wind Evidence and Change programme is an ambitious strategic research and data-led programme. Its aim is to facilitate the sustainable and coordinated expansion of offshore wind to help meet the UK's commitments to low carbon energy transition whilst supporting clean, healthy, productive and biologically diverse seas.

Disclaimer

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It should also be noted that this report has been produced from information relating to dates and periods referred to in it. The data presented in this report are focused on North-East Europe, and more specifically concentrated on the commercial fishing methods used within the UK continental shelf. The results presented may therefore not have relevance in countries outside of the UK. Users and readers use this report on the basis that they do so at their own risk.

Who we are

Our mission is to accelerate the move to a decarbonised future. We are your expert guide to turn your climate ambition into impact.

We have been climate pioneers for more than 20 years, partnering with leading businesses, governments and financial institutions to drive positive climate action. To date, our 400 experts globally have helped set 200+ science-based targets and guided 3,000+ organisations and cities across five continents on their route to Net Zero.

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Abbreviations

AI	Artificial Intelligence
AIS	Automatic Identification System
AUV	Autonomous Underwater Vehicle
BIS	Department for Business, Innovation & Skills
BGS	British Geological Survey
BOEM	Bureau of Ocean Energy Management
CBRA	Cable Burial Risk Assessment
cm	Centimetre
COLREGs	Convention on the International Regulations for Preventing Collisions at Sea
COWRIE	Collaborative Offshore Wind Research into the Environment
CPS	Cable Protection System
CFMS	Commercial Fisheries Mitigation Strategy
CPT	Cone Penetration Tests
CTV	Crew Transfer Vessels
DESNZ	Department for Energy Security & Net Zero
DAS	Distributed Acoustic Sensing
DoC	Depth of Cover
DoL	Depth of Lowering
DTS	Distributed Temperature Sensing
EC	European Commission
EDF	Électricité de France
EIA	Environmental Impact Assessment
EEZ	Exclusion Economic Zone
EMF	Electromagnetic field
ESCA	European Subsea Cables Association
FAO	Food and Agriculture Organisation
FLCP	Fisheries Liaison and Coexistence Plan
FLO	Fisheries Liaison Officer
FLOW	Floating Offshore Wind

FLOWW	Fishing Liaison with Offshore Wind and Wet Renewables Group
FoS	Factor of Safety
FMMS	Fisheries Management and Mitigation Strategy
FPO	Fish Producers' Organisation
GIS	Geographical Information System
GW	Gigawatt
GVI	General Visual Inspection
HFIG	Holderness Fishing Industry Group
HVAC	High Voltage Alternating Current
HVDC	High Voltage Direct Current
ICEP	International Cable Protection Committee
ICES	International Council for the Exploration of the Sea
ICPC	International Cable Protection Committee
IFCA	Inshore Fisheries Conservation Authorities
INNS	Invasive Non-Native Species
INTOG	Innovation and Targeted Oil and Gas Round
iVMS	Inshore Vessel Monitoring System
JNCC	Joint Nature Conservation Committee
kg	Kilogram
KIS-ORCA	Kingfisher Information Service – Offshore Renewable & Cable Awareness
LiDAR	Light Detection and Ranging
LISIG	Low Impact Scallop Innovation Gear
m	Metres
MBES	Multibeam Echosounder
MCA	Maritime and Coastguard Agency
MFOWDG-CFWG	Moray Firth Offshore Wind Developers' Group – Commercial Fisheries Working Group
MMO	Marine Management Organisation
NFFO	National Federation
NnG	Neart na Gaoithe
OFTP	Offshore Transmission Owner

ORE	Offshore Renewable Energy
ORJIP	Offshore Renewables Joint Industry Programme
OWEKH	Offshore Wind Energy Knowledge Hub
OSPAR	Oslo and Paris Convention
OTDR	Optical Time-Domain Reflectometer
OWF	Offshore Wind Farm
PEP	Project Expert Panel
PDA	Project Development Area
RIFG	Regional Inshore Fisheries Group
ROV	Remotely Operated Vehicle
RmDoL	Recommended Minimum Depth of Lowering
SNCB	Statutory Nature Conservation Body
SAS	Synthetic Aperture Sonar
SBP	Sub-Bottom Profiler
SEP	Stakeholder Engagement Plan
SFF	Scottish Fishermen's Federation
SG	Steering Group
SSCS	Seabed Scour Control Systems
SSS	Side-scan Sonar
SUT	Society of Underwater Technology
SWFPA	Scottish Whitefish Producers Association
TDoL	Target Depth of Lowering
TTD	Target Trench Depth
UKHO	UK Hydrographic Office
USV	Uncrewed Surface Vessel
UXO	Unexploded Ordnance
VMS	Vessel Monitoring System
WROV	Work Class Remotely Operated Vehicle

Executive summary

Intertek Metoc (Intertek) was commissioned by The Carbon Trust, as part of The Carbon Trust's Offshore Renewables Joint Industry Programme (ORJIP) for offshore wind, Co-Ex (main) project, to investigate improving the evidence base for coexistence between offshore renewables and commercial fishing. The primary objective of this project was to understand opportunities to increase available evidence to support decision making around fishing activities within or near Offshore Wind Farm (OWF) developments. This report presents the results of the project, broken down into three work packages: literature review and stakeholder engagement, a review of fishing gear penetration, and a survey and trial evaluation.

The UK Government aims to nearly quadruple its 2023 offshore renewable electricity production to 50 Gigawatts (GW) by 2030. The current expansion of Offshore Renewable Energy (ORE) developments in the UK has led to an overlap in space between ORE projects and fisheries, these interactions are expected to become more frequent with ORE expansion plans. Such colocation instances can lead to increased risk to fishing gear and subsequent loss or damage to ORE infrastructure.

All information presented within this report are based on current literature, regulations, industry guidance and advice as well as stakeholder viewpoints, which are relevant at the time of publication. As the industry develops and more research is undertaken, it is expected that some assertions about information presented in this report may change over time.

Literature review and stakeholder engagement

The literature review revealed limited publications on the impacts of OWFs on commercial fishing activity, with evidence of both displacement and coexistence. Coexistence success appears to be influenced by OWF design, management, and early stakeholder engagement, but the variability in outcomes highlights the challenge of addressing fisher concerns. While some fishers cite adverse impacts, these views often lack robust evidence, presenting an opportunity for industry collaboration to improve data collection and baseline information for Environmental Impact Assessments (EIAs). Positive effects, such as artificial reef benefits from OWFs, are challenged by stakeholders, and further research is needed to fully understand their impacts on commercial fisheries.

Spatial mapping of the UK fishing fleet showed otter trawling to dominate UK fishing activities for vessels over 12 m in length, accounting for 63% of landings, focused on Scottish waters and the Central Irish Sea. Other fishing methods, such as dredging and beam trawling, are geographically concentrated in areas like the Irish Sea and Southern North Sea. Future OWF development areas in the UK are projected to overlap with fishing areas accounting for 7.3% of total UK fishery value (for vessels >12 m in length, based on averaged 2011-2020 figures), based on around 70 GW of planned Offshore Wind, while active OWFs (as identified in 2024) impacted less than 1% of fishing intensity.

Key stakeholder recommendations to enhance coexistence include inclusive OWF design, early liaison plans, and improved evidence bases for impacts like electromagnetic fields and underwater noise. Data gaps, particularly for smaller vessels, complicate assessments of fishing intensity near OWFs. Stakeholders emphasise the importance of transparent collaboration, informed decision-making, and government involvement to navigate coexistence challenges. Successful examples of coexistence included Westermost Rough OWF and the lobster fishery in this area, this success was attributed to the work of the Holderness Fishing Industry Group (HFIG). Certain turbine and array

cable layouts as well as fishing community funds highlight potential pathways, however costs associated with changes to design or siting of infrastructure can be extraordinarily high, and further constrained by other geological, environmental and engineering constraints, which can limit design flexibility and consequential project feasibility. It was also identified that spatial constraints and concerns around floating OWFs warrant attention in future planning.

Fishing gear penetration

Industry and maritime safety guidance strongly advises against any type of fishing where there is a known and charted cable, however, this is not currently written into legislation in the UK and interactions between fishing gear and subsea cables do occur.

The maximum penetration depth observed in the literature review was 35 cm for soft sediment and 29 cm for coarse sediment (Eigaard *et al*., 2016; Szostek *et al*., 2022). However, these depths are estimated and not evidenced through experimental data or field observations. Outside of the UK, in the Baltic, otter trawl penetration depths of up to 30 cm have been observed (Jones, 1992). The maximum evidenced penetration ranged between 15 and 20 cm and was observed in a study of oyster dredging in gravel (Southern Science, 1992).

This study collated measurements of fishing gear penetration across sediment types and water depths in 22 areas around the UK, focusing on offshore renewable energy (ORE) project regions. The average penetration depth ranged from 2.5 cm in gravel to 7.5 cm in sandy mud, with a maximum depth of 12.7 cm observed in sandy mud. Results largely aligned with existing literature, though the study recorded shallower penetration depths. This trend may reflect efforts by fishers to minimise seabed drag for fuel efficiency and gear preservation or could be influenced by sediment infill and natural reworking.

In terms of subsea cable burial, it is important to note that target burial is based on a case-by-case assessment. Where cable burial is not feasible, external cable protection measures are often used to protect the cable. There are a variety of cable protection measures with rock berms, concrete mattresses, fronded mats, articulated pipe/cable protection systems and rigid concrete protection, most widely used in the industry. An overview of these options highlighted that all cable protection measures have the potential to result in the snagging and subsequent damage to commercial fishing gear and/or subsea cables. When deciding on the appropriate cable protection, there are numerous factors to consider, including cost, the environment, supply, and installation feasibility, therefore fishing is one of multiple factors to consider on a site-by-site basis.

Survey and trial evaluation

Surveys are critical to offshore renewable projects, addressing risks like cable exposure and snagging hazards. Pre-installation and monitoring surveys often use technologies such as Multibeam Echosounders, Side-Scan Sonar, and Remotely Operated Vehicles. Emerging tools like uncrewed vessels promise cost-effective solutions but are still in their infancy.

Over-trawl trials are intended to determine snagging risks and potential fishing gear damage when being used over subsea cable infrastructure. A review of these trials around OWF export cables revealed methodological inconsistencies, such as varying survey designs, frequencies, and types of fishing gear tested. Key findings indicate that over-trawl trials produce localised results specific to the area used, vessel, and gear used at the time, making their outcomes limited without information of long-term risks. While over-trawl trials are intended to provide assurance to fishers to resume fishing in the over-trawled area, they are considered by some to instil a false confidence of safety, as a risk of snagging and damage still persists after an over-trawl trial.

Commissioned surveys/trials, undertaken in a controlled environment, investigating trawl gear penetration in different sediment types and over different cable protection measures on a long-term basis could improve our understanding on the impacts of fishing over installed subsea cables, helping support decision making in this sector.

Fishing gear trials looking into scallop dredges showed designs were identified which reduced damage to benthic fauna and decreased seafloor penetration. However, carbon emissions were not reduced through any noticeable lower fuel usage and some sites recorded high bycatch and debris volumes.

The Hywind floating OWF static fishing gear trial, highlighted a proof of concept with static gear successfully operated within the prescribed areas of the OWF with no safety issues, gear snagging, or gear lost. However, as these static gear trials were undertaken on mobile fishing grounds the economic viability as a replacement fishing method is not yet understood. Future studies looking into the commercial feasibility of this colocation in operational OWFs is recommended to quantify results on a larger and longer-term basis.

Cable Burial Risk Assessments (CBRAs) can be cost-efficient, site-specific, standardised methods that use reliable data to inform cable installation and burial depths, factoring in fishing risks and future threats, while adopting a cautious approach to ensure cable integrity. In some cases, modelling to support an assessment of seabed mobility, though costly and reliant on high-quality data, helps identify high-risk areas for cable exposure and supports risk assessments, monitoring strategies, and appropriate installation methods.

Technologies like Distributed Acoustic Sensing, Distributed Temperature Sensing and Optical Time-Domain Reflectometer enable real-time cable monitoring, however, can be affected by environmental and technical factors. Future improvements, such as integrating Artificial Intelligence (AI) with vessel tracking systems could enhance cable monitoring and risk management.

1. Introduction

The Offshore Renewables Joint Industry Programme (ORJIP) for Offshore Wind is a collaborative programme between The Carbon Trust and other ORJIP Offshore Wind Partners. The objective of The Carbon Trust ORJIP Offshore Wind programme is to improve the evidence base surrounding the overall impact of planned and existing offshore wind projects on the marine environment and other users of the sea, as well as consenting authorities, offshore wind farm (OWF) developers, and other relevant stakeholders. Intertek Metoc (Intertek) was commissioned by The Carbon Trust on the CoEx (Main) project to review experiences to date of coexistence and colocation between OWF developments and commercial fisheries to determine the impacts of coexistence and colocation on fishing fleets and economic value and understand examples where fishing activity has been able to continue. The project aimed to understand opportunities to increase available evidence to support decision making around fishing activities within or near offshore wind developments. The project comprised of three work packages including, literature review and stakeholder engagement, a review of fishing gear penetration as well as survey and trial evaluation.

Each work package involved a review of literature to provide an overview of the current evidence base and highlight knowledge gaps. A series of stakeholder interviews were then undertaken to gain further understanding of each topic and identify the challenges with regard to fisheries coexistence. While stakeholder engagement provided some validation to literature sources, further evidence was obtained through data analysis, including fishing effort spatial mapping and fishing gear seabed penetration measurements. Where relevant, knowledge gaps, limitations and future considerations are summarised at the end of each section.

1.1. Background

1.1.1. Coexistence and colocation

The term coexistence is often used interchangeably with colocation, however in terms of fisheries these terms can have different meanings. A summary of definitions is provided below:

Coexistence of activities means that they can take place at either the same time and/or in the same place (or proximity close enough to affect each other), without causing significant detrimental impacts on one another.

Colocation is a subset of coexistence and refers to a planned and deliberate location of an activity, while sharing the same spatial area used by another activity, such that impacts are managed and minimised. This can relate to, for example, the placement of static gear within OWF no cable zones.

1.1.2. Offshore wind farms and transmission assets

The expansion of OWF developments in the UK has led to an overlap in space between OWF's and other users of the marine environment (Marsh *et al.,* 2022). This includes fisheries, using fishing methods such as demersal trawling and potting. The space occupied by OWF's has led to changes in fishing practices around the UK due to increased risk to fishing gear and subsequent risk of loss or damage to OWF infrastructure and cables (Gray *et al.,* 2016). Fisheries Liaison and Coexistence Plans (FLCPs) are becoming more common for site specific Offshore Renewable Energy (ORE) developments, however the future of fisheries coexistence with ORE developments is currently unclear, this is partly due to an unestablished evidence base to support informed regulatory decisions.

As of Q4 2022, the UK had 13.9 GW (gigawatts) of offshore wind fully commissioned, this was a fourfold increase from 2012 (Department for Business and Trade, 2024). The UK's ambition to achieve 50 GW of offshore wind by 2030, indicates an increased expansion of OWF developments in the next decade.

Figures obtained by the Department for Energy Security & Net Zero (DESNZ; 2023), suggest that of the 50 GW energy generation target up to 5 GW is expected to be from new offshore floating wind projects. A total of 27.3 GW of fixed turbine offshore wind energy production in the UK has had planning applications either submitted, consented, or OWFs are under construction (as of Q4, 2022). A further 41.4 GW is currently in the pre-planning application stage, of which around 45% is floating offshore wind (FLOW), with 19.3 GW attributed to FLOW in the ScotWind leasing round (Offshore Wind Scotland, 2024).

In addition to the above figures, The Innovation and Targeted Oil and Gas Round (INTOG) could add a further 5.4 GW of floating wind capacity and a further 4 GW is expected to come through the Celtic Sea floating wind leasing round.

All combined, the future UK pipeline of offshore wind will surpass the 50 GW, by an additional 40 GW, after 2030 although, the Climate Change Committee estimates up to 125 GW of offshore wind could be needed to account for future demand by 2050 (DESNZ, 2023).

Key to the transmission of offshore renewable electricity are export cables, linking the offshore generation with the onshore grid. Over short distances electricity transmission can be transferred onshore via High Voltage Alternating Current (HVAC), for projects where electricity generation is further offshore, and transmission losses are considered high, then an offshore substation is used to convert the HVAC to High Voltage Direct Current (HVDC) for transmission to onshore.

Currently in the UK, OWF developers are not permitted to own the transmission assets, therefore after installation the transmission assets are sold to an Offshore Transmission Owner (OFTO) via an Ofgem tendering round. Alternatively, transmission assets can be installed directly by an OFTO. The OFTO has responsibility of the operation, maintenance and decommissioning of the transmission assets.

Multiple export cables may be required depending on the generating capacity of an OWF. Due to separation distances required for the installation of multiple cables, they typically cover a width of several hundreds of metres, however this can vary significantly along the cable route and depend on the constraints encountered. With OWF sites such as Dogger Bank at around 130 km offshore and FLOW locations being planned in deeper water located offshore, such transmission assets can occupy a significant proportion of the space, and they can therefore be a key consideration for commercial fisheries coexistence.

1.1.3. UK commercial fisheries

As of 2022, the number of UK fishing fleet registered vessels was 5,541, which represents a 15% decrease on the preceding 12 years, correlated to a decrease of jobs in the industry. This trend is partly associated with the move to fewer but larger vessels, and the introduction of policies that limit fishing activity aimed at protecting fish and shellfish stocks as well as the marine environment. Within the European Union (EU) fishing fleets, there is also an observed decrease in the number of vessels but also a relative decrease in vessel size, attributed to improved catch efficiency of newer vessels, ensuring less days at sea and therefore reduced fuel and stores space required, compared with older vessels (European Commission, 2020).

In the UK, the fishing fleet vessel size has shown a steady decrease with 79% of the 2020 fleet represented by vessels under 10 m in length (Uberoi *et al*., 2022). However, vessels over 10 m landed 98% of total quota species from UK vessels, with smaller vessels generally targeting non-quota species. (MMO, 2023). From 2004 to 2022, fishing effort (kW days at sea) of the over 10 m fleet had decreased by around 40%. Despite this, the value of sea fish in the UK increased 13% between 2021 and 2022, driven by consumer inflation and a sharp increase in fuel costs (MMO, 2023 and Seafish, 2023).

In 2022, UK vessels landed around 640,000 tonnes of sea fish with a value of £1.04 billion, of which 38% was landed abroad (MMO, 2023). The fishing (and aquaculture) industry in Scotland contributed to just under 70% of the UK industry total (2020), with SW England occupying the second largest output (8%) followed by Northern Ireland at 5% of the UK total fishing industry (Uberoi *et al*., 2022).

Data obtained by the MMO from 2012 to 2016, showed 58% of tonnage caught in the UK EEZ was by EU member state fishing vessels of which the top five were Denmark, Netherlands, France, Iceland and Germany, accounting for 44% of the total catch value (MMO, 2020 and Uberoi *et al*., 2022). Data from 2018, analysed by Napier (2020), indicates that around 50% of demersal fleet UK EEZ landings, were by foreign fleets and nearly 80% of the pelagic landings were not from UK vessels, highlighting the presence of other nations that also fish in UK waters. Conversely, less than 15% of shellfish landings fished in UK waters were by foreign fleets (Uberoi *et al*., 2022).

2. Literature review and stakeholder engagement

2.1. Literature review

A literature review was undertaken using published journals and relevant guidance, and reference to sources such as the Offshore Wind Energy Knowledge Hub (OWEKH), the (former) Collaborative Offshore Wind Research into the Environment (COWRIE), and the United States TETHYS database hosted by the Pacific Northwest National Laboratory. The purpose of the review was to summarise published information describing positive and negative experiences of coexistence between fishing activities and OWFs.

The review focusses specifically on UK experiences of coexistence and colocation. Comparisons with other countries is difficult because some countries implement mandatory fishery closures around monopiles, turbine arrays and cables (European Commission, 2020; Bonsu *et al.*, 2024). In many countries, OWF areas are *de facto* 'No Take Zones' where fishing activities can no longer take place, however, this is not the case in the UK.

2.1.1. Why is coexistence important?

Spatial mapping undertaken in Section 2.3 indicates that many of the existing and proposed OWFs within the UK EEZ overlap with fishing grounds, which can lead to spatial squeeze. The type of fishing activity that is being conducted in these OWF areas varies from site to site, being determined by both the environmental conditions that govern the local fish and shellfish populations as well as local fishing practices. For example, the trawl fishing grounds for *Nephrops* (langoustines) in both the Moray Firth and the Forth and Tay lie largely outside the proposed OWFs in these regions; however there is significant overlap between the OWFs and areas fished by scallop dredgers (Figure 1).

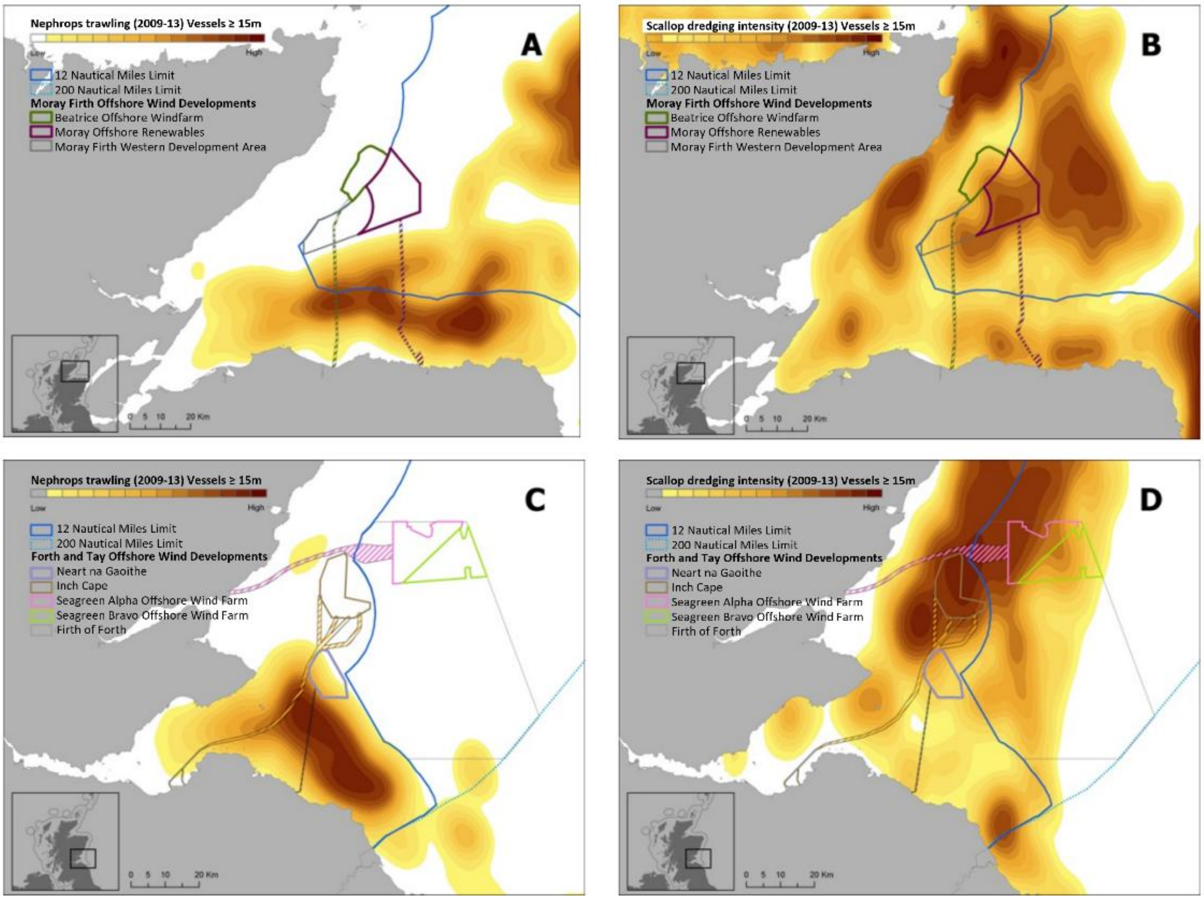


Figure 1: Maps showing distribution of fishing effort in the Moray Firth and Forth & Tay regions for fishing vessels over 15 m in length.[1]

The spatial distribution of both OWFs and fishing vessels on the east coast of Scotland, or anywhere else, are located where they are, due to several factors. Each is a response to environmental conditions: for instance, OWFs, amongst other constraints, are built in locations where there are relatively high and consistent wind speeds, in suitable water depths and where substrates ensure feasible turbine installation, as well as access to energy markets which make them economically viable. Fishing is only economically viable in areas where the abundance and accessibility of the target species is suitable. Neither activity can readily move without an adverse economic impact. If fishing in an area is to continue after an OWF is constructed, then means for coexistence becomes necessity. It should be noted that natural spatial variation in target species stocks can persist over time, which can reduce the necessity of coexistence on a temporal basis, in some cases.

2.1.2. Impacts of OWFs on fishing activity

There are currently three broad types of research into OWF impacts on commercial fishing activity, summarised below:

[1] Source: Modified from Marine Scotland (2017) Key: Fishing intensity over the period 2009-13 (prior to OWF construction). Maps A&C show distribution of effort for *Nephrops* trawlers; B&D for scallop dredgers.

- Spatial studies – using data gathered for fishery management purposes over a period of time at the fleet level, these studies examine broad-scale changes in fleet behaviour.
- Site-specific studies – using data gathered for a specific site, these studies provide a direct measure of changes in commercial fishing activity, at a local level, after an OWF has been constructed in an area.
- Effects on target species – using data gathered on the distribution and abundance of fish or shellfish within an OWF, these studies consider whether there is a beneficial or detrimental impact.

Each type of study has strengths and weaknesses. A key weakness of the spatial studies is that very limited data are available for the smaller commercial fishing vessels (<12 m length) that make up nearly 80% of the UK fishing fleet. These smaller vessels are currently not required to transmit vessel location; therefore, any significant positive or negative impact would not be detected. However, a strength of the spatial data is that it enables historical comparisons of fishing activity before and after OWF construction in an area. For the site-specific and species studies the positive or negative overall effects of an OWF on either a species or a fishing activity at one OWF may not be fully applicable to an adjacent OWF.

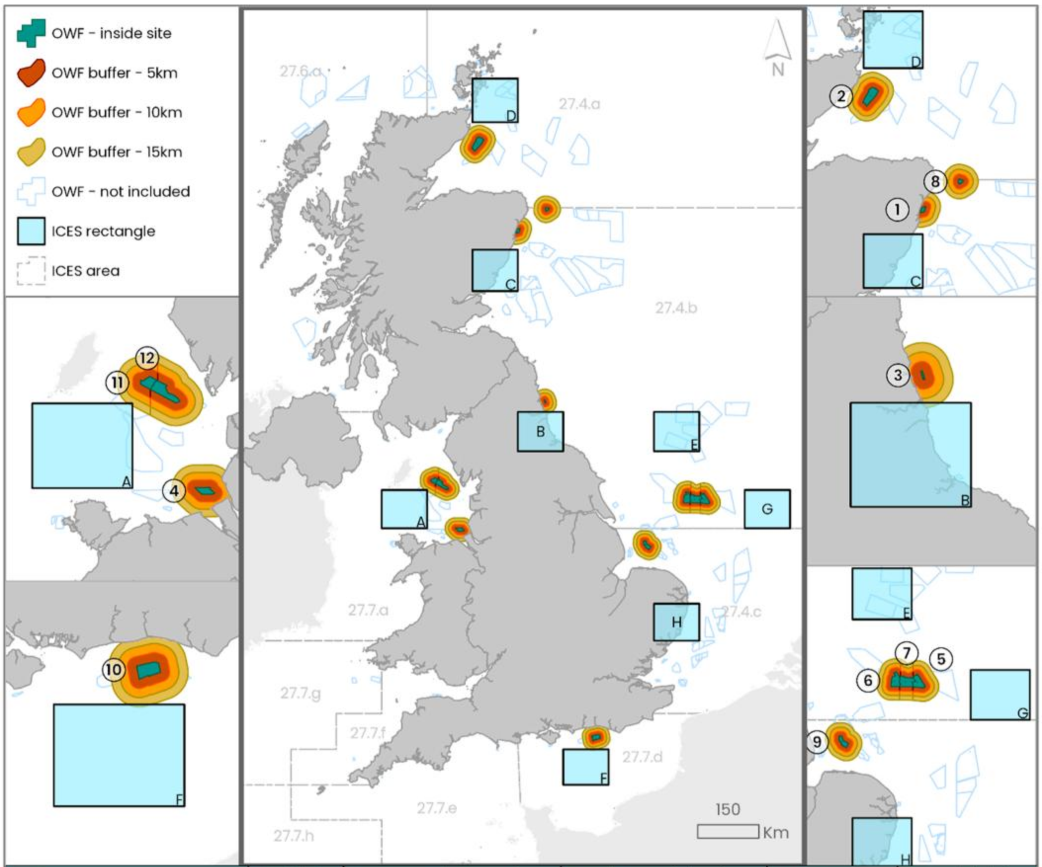
2.1.2.1. Spatial studies

In 2016, spatial data were used as part of a study to examine the impact of the six OWFs that were in operation in the Eastern Irish Sea at that time (Gray *et al*., 2016). This study noted that there had been a decline in trawling for *Nephrops* off the coast of Cumbria in NW England after the construction of the Walney 2 OWF (at that time the Walney OWF comprised of Walney 1, Walney 2 and Walney Extension).

The study concluded that some fishery coexistence did occur within the Walney 2 OWF, with a few fishers operating demersal trawl gear in cable free corridors. However, VMS data showed that overall fishing intensity had decreased post-construction within OWF boundaries. This was primarily attributed to fishers avoiding the area due to risk of fishing gear becoming entrapped by seabed infrastructure and concerns from fishers regarding vessel breakdown and possible consequential turbine collision. Interviews with fishers conducted as part of the study suggested that better knowledge of seabed hazards, the use of lower risk cable protection measures (to mobile fishing gear), monitoring of risks and cable exposure, and regular communication between fishers and OWF developers could mitigate many risks and concerns (Gray *et al*., 2016).

It is important to note, however, that the reduction in *Nephrops* trawling effort across the Walney 1/2 OWF array area that was illustrated in Gray et al. (2016) does not amount to cause and effect (i.e. this does not equate to the presence of the Walney 1/2 array area driving the change in fishing effort/distribution) at a high level of confidence. There were significant changes in the spatial distribution of VMS effort across the whole of the Irish Sea between the 2007 and 2013 datasets, and a range of factors can drive changes in fishing effort/distribution over time. Given the underlying complexities and interdependencies, establishing a causal relationship would require multi-year multivariate analysis with indication of statistical significance – which was not part of the Gray et al. (2016) study.

A more recent study of 12 OWFs around the UK was undertaken using spatial data mapping (Dunkley and Solandt, 2022). This study included sites in the Irish Sea, off the east coasts of Scotland and England, and also in the English Channel (Figure 2). It looked at the amount of fishing activity conducted by vessels towing fishing gear across the seabed (such as trawls, beam trawls and dredges). The study looked at changes in activity within the OWF array, in 'buffer' areas around the array and in a 'control' area outside the OWF.



OWF	OWF label	Year construction started	Year site commissioned	ICES rectangle	Rectangle label
Aberdeen Offshore W/F	1	2016	2018	42E7	C
Beatrice Offshore Wind Farm	2	2017	2019	46E7	D
Blyth Demo Phase 1	3	2017	2018	41E7	B
Burbo Bank Extension	4	2016	2016	36E7	A
Hornsea 1 (East)	5	2018	2020	36F3	G
Hornsea 1 (West)	6	2018	2020	38F1	E
Hornsea 1 (Njord)	7	2018	2019	38F1	E
Hywind Scotland Pilot Park	8	2017	2017	42E7	C
Race Bank	9	2016	2018	33F1	H
Rampion	10	2016	2018	29E9	F
Walney Extension 3	11	2017	2018	36E5	A
Walney Extension 4	12	2017	2018	36E5	A

Figure 2: OWF impacts on fishing activity with associated ICES statistical rectangles (Dunkley and Solandt, 2022).

This study found that nine of the 12 sites had a decrease in bottom towed fishing gear after OWF construction, when compared to adjacent areas and to a 'control' site.

Of the three OWFs that didn't show this declining trend, there was no discernible use of towed gear in two of the sites either before, during or after construction. However, for one site (Walney Extension 4, in the Irish Sea) there was an increase in fishing rate after construction (Figure 3). This change was evident for the one fishing method occurring within the site (beam trawling). Otter trawling and dredging showed a decline in the control area during and after construction.

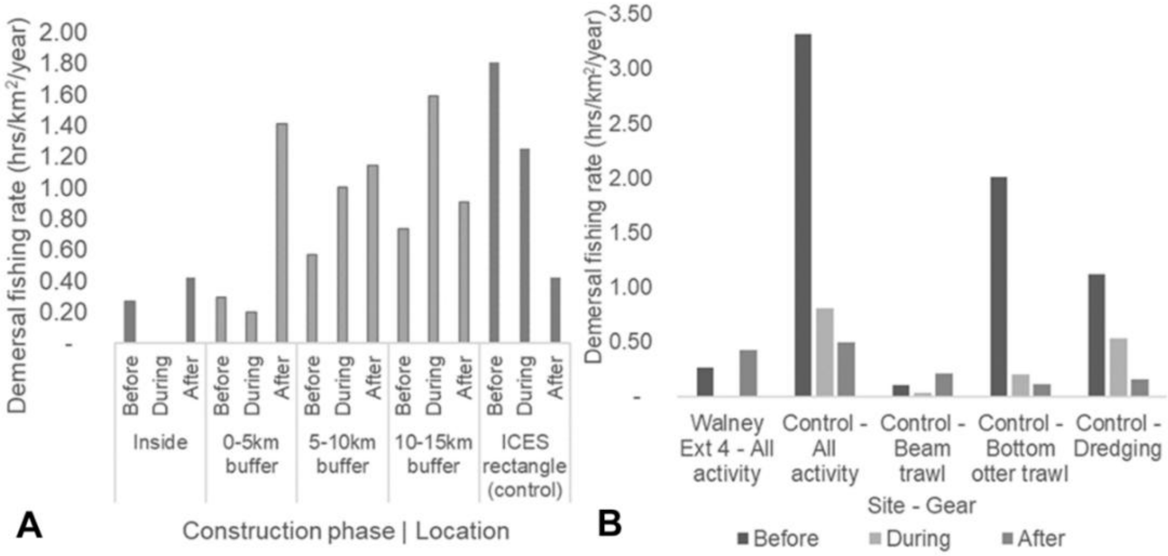


Figure 3: Change in fishing rate by gear type inside Walney extension 4 OWF, 0–5 km, 5–10 km and 10–15 km buffer cones and control area (Dunkley and Solandt, 2022).

The increase in beam trawling activity after construction of Walney Extension 4 was not attributed to the OWF but was credited to a tenfold increase in the Total Allowable Catch for sole (*Solea solea*) in the Irish Sea in 2019. This species is targeted by visiting Belgian beam trawlers in the Eastern Irish Sea in the springtime. Most of their increased activity was observed outside the OWF and to the south of the array area, although the layout of the turbines, in three distinct 'patches', provides a turbine- and cable-free avenue enabling some trawling activity.

2.1.2.2. Site specific studies

The spatial study of Irish Sea OWFs (Gray *et al*., 2016) included an attempt to examine fish landings from published data before and after OWF construction. Data presented in this study showed a that the majority of fish landings from International Council for the Exploration of the Sea (ICES) rectangles that OWFs were located in, declined by more than the corresponding fall in Irish Sea Total Allowable Catches (TACs) that have occurred since OWF construction (noting the overall conclusion of the report that there is no evidence that the large TAC reductions in the Irish Sea since 2000 are due to OWF construction). The study also shows that landings of skates and rays, which are not subject to TAC constraints, fell by 92% in the vicinity of Burbo Bank and 80% in the vicinity of the Ormonde and Walney 1&2 OWFs after their construction. However, the data used were not at a site-specific scale and can therefore not be considered conclusive. There are some site-specific studies in the UK that provide evidence of differing levels of coexistence.

On the north-east coast of England, the Westermost Rough and Humber Gateway OWFs illustrate different experiences of OWF interactions with fisheries. These two OWFs are 15 km apart and both straddle the 6 nautical mile fishery limit. Prior to their construction, local fishing vessels would fish in both areas: Westermost Rough for lobsters and the Humber Gateway area for crabs.

The lobster fishery in and around the Westermost Rough OWF has been carefully studied before, during and after construction. The lobster stock within the OWF looked to have benefitted from the closure of the OWF array area during construction. When fishing resumed after the construction of the OWF, lobsters were more numerous and larger within the OWF than in adjacent areas (Roach *et al*., 2018). Once fishing resumed, the lobster population in this site quickly became similar to the adjacent areas, but the OWF still supported a prospering lobster fishery that was similar to the pre-construction fishery (Roach *et al*., 2022)

Humber Gateway OWF and the crab fishery in this area experienced notable changes following construction. ABPmer (2022) references anecdotal reports of reduced fishing in the area, attributing this to the turbine layout restricting gear deployment under prevailing tidal conditions; however, pre- and post-construction monitoring surveys at Humber Gateway (Institute of Estuarine and Coastal Studies, 2017) found that the catch per unit effort (CPUE) for crab was higher within the wind farm area compared to outside during operation, while lobster numbers decreased inside the array but remained stable or increased at the order limits – likely due to ecological interactions, such as competition with crab. These findings suggest that that Humber Gateway OWF has not negatively impacted crab populations and continues to provide viable opportunities for fishing within the site; furthermore, dense fishing activity has since been reported in the wind farm area throughout peak fishing season.

2.1.2.3. Effects on target species

The 'reef effect' of OWFs is a potential benefit for commercially valuable species of fish and shellfish. The hard substrata of wind turbine foundations, and associated scour protection around their bases, increases the structural heterogeneity of seabed habitats in areas that are often sandy or muddy. These hard substrata can act like an artificial reef that can promote marine growth and give shelter and food to fish and shellfish species, as well as acting as an effective nursery ground (Degraer *et al*., 2020).

Studies in the Netherlands and Belgium have shown that fish and shellfish can aggregate within and around wind turbine arrays (Reubens *et al*., 2013 and Van Hal *et al*., 2017).

A pioneering study at the Gwynt y Môr OWF off the North Wales coast has recently showed in detail how commercially important lobsters use the scour protection around the base of some foundations as a habitat (Thatcher *et al*., 2023). This was the first ever study of lobster habitat use and movements within an OWF. It was made possible by close cooperation between the scientists, local fishermen, and the OWF developer (RWE Renewables), facilitated by the Fishery Liaison Officer for the project. The fishermen provided advice on which foundations were known to host lobsters (not all of them did) and assisted with the deployment and maintenance of the experiment. In this study, a total of 33 lobsters were caught from the base of three turbine foundations within the OWF array, and each had a small acoustic transmitter glued to their carapace. When they were released back into the sea, the movement of each lobster was recorded by an array of acoustic receivers, enabling their movement relative to the scour protection extending a maximum of 25 m around the base of each turbine foundation to be monitored.

The results of this study showed that most of the tagged lobsters remained very close to the edge of the scour protection for the entire period of the survey. Around 55% of all lobster location points, were observed within 35 m of the edge of the scour protection, and 68% observed within the scour protection. This research concluded very positively, noting that there is clear evidence here of a positive effect that could be of benefit to local fishing communities using static fishing gear (lobster pots).

While Thatcher *et al*. (2023) indicates the use of scour protection as a European lobster habitat, it does not discuss the potential of stock 'spill over' whereby the lobster population is enhanced outside of this region, in turn improving the fishery. The results indicate that a colocation of lobster fishing activity (static gear) very close to scour protection measures will provide most frequent interactions with target species. The key challenges facing this positive approach are identified as the willingness of OWF developers to provide access to fishing vessels so close to infrastructure while ensuring the fishing does not pose a risk to OWF assets. It should be noted that in the UK the majority of OWF do not have statutory safety zones permanently in place around the monopiles, once constructed.

In the industry there have been suggestions that leaving Nature Inclusive Designed scour protection *in situ*, post decommissioning, may be of benefit to the environment, with a potential spill over into commercial fisheries. However, this has the potential to reduce the areas which can be fished after decommissioning, as the scour protection measures can present a snagging risk. Further, there have been some concerns raised in the industry regarding marine structures acting as stepping stones for the introduction and spread of Invasive Non-Native Species (INNS), which can negatively impact native species and habitats (Degraer *et al*., 2020). At the pre-construction phase, commitments to decommissioning by OWF developers cannot be guaranteed and are liable to change because they are made while the project is still being developed; furthermore, they are subject to evolving technology, policy and legislation. Evidence looking into nature inclusive scour protection over the lifetime of the project and the benefits and disadvantages of different decommissioning approaches should help to better inform the decommissioning phase, from a commercial fisheries perspective.

2.1.2.4. Summary of published studies

There were several key conclusions to be drawn from the literature. These can be summarised as:

- Spatial studies around the UK show that some mobile fishing methods have been displaced from OWF areas(Dunkley and Solandt, 2022). There do not appear to be any studies that show a positive effect at this scale.
- Site-specific studies show a more complex pattern. At Westermost Rough, post-construction lobster fishing activity was observed to be similar to pre-construction levels (Roach *et al*., 2022). At Humber Gateway, ABPmer (2022) referenced anecdotal reports of reduced fishing activity in the area, however, post construction monitoring found higher CPUE for crab within the wind farm and a decline in lobster numbers inside the array, while populations at the order limits remained stable or increased (Institute of Estuarine and Coastal Studies, 2017); RWE have since reported dense fishing activity in the wind farm area throughout peak fishing season. These outcomes highlight that coexistence is possible but highly site-specific, influenced by fishery type and OWF design.
- Studies of fish and shellfish show that OWFs can be beneficial. Several studies which show genuine positive impacts for individual species of fish and shellfish within OWF areas (Reubens *et al*., 2013; Van Hal *et al*., 2017; Degraer *et al*., 2020; Thatcher *et al*., 2023). These studies highlight opportunities to enhance the positive benefits of OWF at the species level, which has future potential to translate into positive outcomes for fish and shellfish stocks and commercial fishing. Although, it should be noted that lab-based observations have indicated potential disruptions in behaviour patterns of crustaceans, which could limit net benefits and catchability of such species (Seafish, 2020).

The reason why there is a gap in our knowledge over 20 years after the first commercial OWF came into operation may be because there is no overall strategy for the consistent monitoring of impacts and compiling of evidence across the UK's OWF portfolio. The need for a cohesive and strategic approach to post-consent monitoring of OWF impacts on fisheries was identified over 10 years ago (MMO, 2014). The recommendations of that review appear to remain valid today.

2.1.3. Impacts of fishing activity on OWFs

There are two ways that commercial fishing operations could impact the operation of OWFs:

- Physical damage to OWF infrastructure – fishing vessels and the gear that they deploy have the potential to cause damage to the infrastructure of an OWF. Foundations, cables, and offshore substations are potentially vulnerable to physical damage.
- Interference with operations – in OWF areas where fishing is taking place there is a risk that fishing vessels and fishing gear could interfere with OWF operations, particularly regarding pre-construction surveys and access to assets for maintenance operations.

There does not appear to be any publicly available data which summarises the frequency of incidents of physical damage to OWF infrastructure or the frequency of interference with OWF operations. In general, OSW developers are not formally required to record events whereby fishing gear interferes with OWF infrastructure or activities, and there is no dedicated public repository for this type of data; however, logging such incidents could provide valuable information. As part of this study, OWF developers were asked to provide examples of such interactions with only one example supplied of static fishing gear entangled on an OWF jacket foundation.

One OWF Fishery Liaison Officer reported that interactions between OWF operations and fishing gear typically occurred two to three times per year in one site where lobster fishing takes place. The most frequent issue encountered was fishing gear not being moved during stormy weather so that it became entangled around foundations, impeding safe access by Crew Transfer Vessels (CTVs). Very occasionally a CTV itself became entangled with fishing gear, and on at least one occasion a CTV impeller has been damaged. In all instances where fishing gear was entangled around foundations, its owner had retrieved the gear. In instances where the owner could not be identified, local fishers have assisted with its removal.

Data on subsea power cable faults is relatively scarce, however there are data available on telecommunications cable faults. While some comparisons can be drawn, it should be noted that differences in installation parameters and cable protection differences between the two industries vary and therefore comparisons should be treated with some caution.

The International Cable Protection Committee (ICPC) has published information about the incidence of submarine telecommunication cable damage in UK waters between 2006-2008, and the causes (ICPC, 2009). The report found that 48% of damage was caused by anchors, 33% by fishing gear. A total of 21 faults were reported, and hence fishing gear caused around seven of the faults in submarine telecommunication cables per year. In comparison, more recent and global trends in telecommunications cable faults found that there are predicted to be over 200 cable faults per year, between 2016-2018, 35%-52% of the faults were attributed to fishing activity and around 32-45% of faults attributed to anchors. 75% of faults were recorded in water depths <100m and these statistics varied year on year (Kordahi *et al*., 2019).

A recent study of large cruise vessels anchored off the Dorset coast found that ‘scars’ on the seabed resulting from one-tonne anchors could be up to 60 cm deep and extend as furrows for over 100 m along the seabed (Tinsley, 2021). These penetration depths are significantly greater than those identified for fishing gear in Section 3 of this project, and therefore can be considered a greater threat to buried cables in certain areas, such as nearby to large ship anchorages which are often present near to large ports around the UK.

Results of stakeholder engagement with OWF developers undertaken as part of this study are presented in Section 2.4.

2.1.4. Mitigation systems

Industry advice and safety guidance from the Maritime and Coastguard Agency (MCA), UK Hydrographic Office (UKHO) and European Subsea Cables Association (ESCA) states that fishing where there are charted subsea cables should be avoided (MCA 2021, UKHO 2023 and ESCA, 2022). This is taken into consideration by many fishers whose interest is to protect their fishing gear (Gray *et al*., 2016 & stakeholder engagement responses), however this guidance is not currently written into legislation in the UK and interactions between fishing gear and subsea cables do occur. Several monitoring systems have and are being developed to raise awareness of subsea infrastructure and to monitor fishing activities around them.

Recently, a system has been developed with AI to monitor undersea cables from fishing threats. National Grid developed the system called ‘OceanBrain’ which uses data sources (including cable location, burial depth and seabed type) with fishing vessel AIS data to automatically quantify the risk of potential damage (National Grid Partners, 2024), (discussed further in Section 4.6.3). While this real-time risk assessment currently provides useful information for asset protection it doesn’t currently notify fishers of the potential risk automatically. Systems such as ‘Asset Monitor’ provide similar warnings which can be interpreted by an experienced Fisheries Liaison Officer, and the vessels contacted to be made aware of potential risks (discussed further in Section 4.6.3). While effective, the vessel is not contacted in real-time and so this may not prevent asset or fishing gear damage on initial interaction.

KIS-ORCA (Kingfisher Information Service – Offshore Renewable & Cable Awareness) provides fishing plotter files and kingfisher charts of subsea cables and renewable energy structures, aimed at ensuring that locations of subsea infrastructure are known, potentially preventing snagging incidents. This service also provides news and bulletins aimed at informing fishers and promoting safety (KIS-ORCA 2024).

FishSAFE was designed for the Oil and Gas industry, and provides fishing plotter files which use Kingfisher charts with oil and gas infrastructure shapefiles. Uniquely, the FishSAFE unit operates an alarm system which notifies fishers when they are approaching subsea oil and gas infrastructure. It also has a ‘Companion App’, aimed as a knowledge share between the oil and gas industry and the fishing industry, providing detailed information on infrastructure (FishSAFE, 2024).

These systems are aimed to raise awareness and to help fishers and other sea users understand the scale and potential risk associated with the infrastructure present. With increasing expansion in OWF developments, overlap between fishing grounds and infrastructure will become more frequent. Risks associated with fishing around infrastructure particularly affects mobile fishing gears which are more prone to snagging on infrastructure. Therefore, such awareness systems are likely to become increasingly important in ensuring the safety of sea users given the planned increase in offshore developments

2.1.5. Consultation responses summary

Fisheries consultation responses to OWF developments were obtained by reviewing documents held by the Planning Inspectorate and the Scottish Government's Marine Directorate. Consultation responses from eight OWF developers were gathered from different regions around the UK to provide a regional variety of stakeholders and fishing methods.

The consultation responses conclude that appropriate turbine spacing, and fisheries inclusive design or layout, can facilitate coexistence of mobile fishing gears, however the safety risks of this approach need to be thoroughly assessed. Some fishers prefer smaller spacing between turbines so that a OWF occupies less seabed and some prefer wider spacing so trawling/dredging between turbine rows can be undertaken. Additionally, it was noted that any cumulative assessments should consider existing displacements to fishing fleets in the area, as well as any planned or existing infrastructure. The early development of a coexistence and fisheries liaison plan is recommended as this should provide fishers with more confidence that the maximum design scenario (worst case displacement of fishing activities around OWFs and export cable corridors) will not be used to limit coexistence opportunities. The evidence base for Electromagnetic Fields (EMF) impacts was also highlighted as limited, and future concerns remain regarding floating OWFs restricting areas for fishing activities.

2.2. Fishing intensity spatial mapping

Previous studies undertaken on the impact of OWFs on the commercial fishing industry show that the two industries can sometimes compete for space (Scottish Government, 2022). To quantify the observed economic impact of OWF developments on commercial fisheries, fishing effort was mapped using vessel monitoring systems (VMS) data, against existing and proposed OWF development boundaries. Fishing effort (i.e. catch weight, value and fishing hours) was estimated using the VMS and logbook data from International Council for the Exploration of the Sea (ICES) and the Marine Management Organisation (MMO).

A VMS and Inshore Vessel Monitoring System (iVMS) is a form of satellite tracking using transmitters on board fishing vessels. The use of VMS has been a UK and European requirement for all fishing vessels over 12 m in length since 2009, under EU and retained EU legislation (European Commission, 2009). Since 2005, all EU fishing vessels larger than 15 m in length have been required to transmit a VMS signal every 2 hours which details the vessel ID, speed, heading and location. Since 2012, this requirement has also applied to all EU and UK fishing vessels larger than 12 m. Vessels larger than 15 m length are also required to transmit an Automatic Identification System (AIS) signal. Approved iVMS's will be mandatory for English waters from the 12th May 2025, however they became a requirement in Wales in February 2022. Approved iVMS's are expected to be mandatory in Scotland and Northern Ireland shortly after the England roll out. At the end of 2023, it was estimated that 80% of all English vessels <12 m in length had a iVMS system, although this is thought to be a lot less in preceding years (Fishing News, 2023).

Data commissioned by OSPAR was collected by ICES using VMS and logbook data, to show fishing intensity/pressure (ICES, 2021) and was used as part of this study. These data are grouped into 14 fishing gear types primarily focused on demersal trawling. In order to include static gear and gillnets, otherwise not included in the OSPAR/ICES dataset, fishing statistics from the Marine Management Organisation (MMO) were also presented to provide a more wholistic overview of fishing intensity within the UK EEZ. The MMO data does not include foreign fishing fleets operating within the UK, which accounts for a significant portion of the fishing activity within the UK. Consequently, this data has not been used to represent the demersal trawling fishing types, instead the OSPAR/ICES dataset has been used which does include most foreign fleets fishing in UK waters (Section 2.2.1 lists excluded fleets). The use of OSPAR/ICES data ensures a wider overview of fishing intensity mapping for the subject.

The data recorded fishing intensity from a total of 17 fishing gear types, 15 of the OSPAR/ICES fishing groups were later aggregated into four categories to provide meaningful illustrations of fishing intensity. These groups also represent the fishing methods discussed in Section 3, which were categorised using Seafish (2022) groupings and are presented in Table 1.

Table 1: Fishing intensity data categorisation.

Data source	Gear code	Description	Mapping group category
OSPAR	OT_CRU	Otter trawl for *Nephrops* or shrimp	Otter trawl
OSPAR	OT_DMF	Otter trawl for cod or plaice	
OSPAR	OT_MIX	Otter trawl for other species	
OSPAR	OT_MIX_CRU	Otter trawl for mixture of species with focus on shrimp	
OSPAR	OT_MIX_DMF_BEN	Otter trawl for mixed benthic species	
OSPAR	OT_MIX_DMF_PEL	Otter trawl for bentho-pelagic fish	
OSPAR	OT_MIX_CRU_DMF	Otter trawl for *Nephrops* and mixed fish	
OSPAR	OT_SPF	Otter trawl for spat or sandeel	
OSPAR	TBB_CRU	Bottom trawl for *Crangon*	Beam trawl
OSPAR	TBB_DMF	Bottom trawl for sole an plaice	
OSPAR	TBB_MOL	Bottom trawl for molluscs	
OSPAR	DRB_MOL	Dredge for scallops and mussels	Dredges
OSPAR	SDN_DMF	Danish seine for plaice and cod	Seine nets
OSPAR	SSC_DMF	Scottish seine for cod, haddock and other flatfish	
MMO	N/A	Trap	Traps and pots

MMO	N/A	Encircling Gillnet	Gillnets
MMO	N/A	Set gillnets	

For each of the fishing type category, three plots were produced to illustrating Fishing Effort (kilowatt hours), Fishing Value (Great British Pounds) and Landings (Tonnes).

To show how fishing effort is spatially located in and within the vicinity of OWFs, the location of offshore renewable energy developments from The Crown Estate were plotted (data accessed March 2024), using the following development categories (valid at the time of publication).

- Active/In-Operation;
- In Construction;
- Consented;
- In Planning;
- Pre-Planning; and
- Project Development Areas (PDA)

The Crown Estate shapefile data covers OWF site and cable agreements, as well as preferred projects from the Offshore Wind Leasing Round 4, giving a combined capacity of up to 35.5 GW. Celtic Sea Project Development Areas were also included giving a further estimated 4.5 GW capacity.

In Scotland, OWF projects including the ScotWind Leasing Round with up to 32 GW capacity, were accounted for as well as Innovation category sites from the Innovation and Targeted Oil and Gas (INTOG) Leasing Round, estimated at around 450 MW. If all projects were consented this would give up to 72.5 GW capacity of UK offshore wind.

Official statistics on the economic output of the fishing industry in the UK have been described as 'volatile' from year to year (Uberoi *et al*., 2022), therefore a 10-year average of data was used to help remove fluctuations. These averages ranged from years 2011 to 2020 for the OSPAR/ICES dataset and four years (2017 to 2020) for the MMO data set for traps and pots and gillnets. As the data for some years was not available for the whole data period, the mean average of data was used to provide comparable results for an annual basis.

Fishing intensity data within each OWF development footprint, as defined by Crown Estate shapefiles, were extracted to quantify fishing activity by category. Where fishing intensity grid cells only partially overlapped with the boundaries of OWF development categories, the entire value of the grid cell was included in the analysis.

OSPAR/ICES data were presented in Euro, therefore an average exchange rate over the 10-year period was applied to convert values into Great British Pounds.

2.2.1. Data caveats

While the OSPAR/ICES data provides a comprehensive dataset of fishing intensity, there are some caveats that come with using the data. These are summarised below:

- The data values of OSPAR/ICES were required to be anonymised, therefore this process provided data as lower and upper values for each field, of which may underrepresent or overrepresent the actual value. For this study the upper values (worst case scenario) were observed to be significantly higher than published statistics and lower values (best case scenario) significantly lower, these data were therefore considered unrealistic to the UKCS (United Kingdom Continental Shelf) fishing intensity. Therefore, data were presented as an average of these upper and lower values to provide a more likely representative dataset. While these values may not be completely representative of the actual value, the relative proportions (percentages) of fishing effort displaced by OWFs calculated, provides a more accurate representation.
- Vessels less than 12 m in length were not included in ICES/OSPAR data, nor those <15 m in length for the MMO data, the future inclusion of Inshore Vessel Monitoring Systems (iVMS) data will increase the confidence of assessments in inshore waters, where smaller vessels typically operate.
- OSPAR/ICES data on value and weight is not quality-checked in full, this can therefore be inconsistent and/or not meet the quality standards. ICES is considering ways to resolve this for future data submissions.
- Data from Portugal, Norway and Iceland was not included in the dataset.
- Data from MMO excludes foreign fleets.
- Data resolution is refined to 0.05° latitude x 0.05° longitude grid cells (~15 km^2 for the southern extent of the UK and ~30 km^2 for northern extent of the UK), although this is considered a good overall resolution, it doesn't provide a highly detailed representation of fishing activity at a local level.
- The dataset is not inclusive of all fishing types, and some fleets (e.g. pelagic fisheries) are not well represented by the dataset, therefore the values presented in Table 2 are not representative of the whole UK fishing activity and should not be interpreted that way.
- The reliability of the data outputs for each OWF development category, is inherently limited by the accuracy of the Crown Estate shapefiles used. Therefore, where development areas and export cable corridors remain undefined, the data are provisional and subject to future revision.
- Despite the relatively precise values calculated, limitations in the underlying data sources mean the results should be interpreted as indicative. They are intended to highlight general trends and interactions between different fishing activities and OWF development categories.

2.3. Results

Fishing intensity for different gear types within the UKCS is presented in Figure 4 to Figure 9[2]. A table quantifying the fishing intensity in terms of effort and value, by gear type in the UKCS, is presented in Table 2. Fishing intensity for different OWF development phases is presented in Table 3.

Table 2: Average annual fishing intensity in the UKCS by gear type.

Gear type	Landings (Tonnes)	Fishery value (£)	Fishing ffort (kWh)
Beam trawls	135,371	£377,906,631	450,501,260
Dredge	761,782	£1,141,178,381	144,341,533
Gillnets*	3,450	£7,011,127	5,575,933
Otter trawl	1,712,506	£2,701,779,357	1,610,993,775
Seine	71,049	£130,160,212	151,383,054
Pots and traps*	15,848	£32,427,259	17,968,337
Total	2,700,006	£4,390,462,968	2,380,763,893

Source data: OSPAR/ICES 2021, data includes UK and foreign fleet vessels fishing in EEZ and landing in UK and overseas ports.
Key: * These data are from the MMO years 2017 to 2020 (4 years) and are of the UK fleet only.

Table 3: Average annual fishing intensity at OWF locations by development phase.

OWF phase	UKCS landings (Tonnes)	Proportion of landings (%)	UKCS fishery value (£)	Proportion of fishery value (%)	UKCS fishing effort (kWh)	Proportion of fishing effort (%)
Active/in operation	15,636	0.58%	£24,422,184	0.56%	18,897,840	0.79%
Under construction	45,720	1.69%	£47,183,028	1.07%	25,327,834	1.06%
Consented	45,625	1.69%	£110,463,633	2.52%	161,681,625	6.79%
In planning	8,678	0.32%	£16,381,182	0.37%	15,749,897	0.66%
Pre-planning application	128,712	4.77%	£144,637,719	3.29%	38,132,657	1.60%
Project Development Area (PDA)	665	0.02%	£2,514,145	0.06%	6,977,325	0.29%

[2] Please note that as of December 2025, some of the OWF site boundaries in Figures 6-11 are out of date, e.g. the spatial extent of the Hornsea 4 array area has been reduced from 846 km^2 down to 468 km^2.

OWF phase	UKCS landings (Tonnes)	Proportion of landings (%)	UKCS fishery value (£)	Proportion of fishery value (%)	UKCS fishing effort (kWh)	Proportion of fishing effort (%)
Total	245,037	9.08%	£345,601,890	7.87%	266,767,178	11.21%

Source data: OSPAR/ICES 2021, data includes UK and foreign fleet vessels fishing in EEZ and landing in UK and overseas ports.

As previously noted, interpretations should consider that the data presented does not include iVMS data for vessel <12 m in length which was not a mandatory requirement for all countries of the UK and EU for the analysed period. The totals and proportions represent data from both ICES/OSPAR (includes foreign fleets and vessels >12 m length), and for gillnets and pots and traps, MMO data (UK vessels only >15 m length).

The spatial representation of the UK fishing fleet shows the otter trawling methods to be the most common fishing type for vessels over 12 m length, accounting for 63% of the landings within the data analysed. This was particularly prevalent around Scotland and the Central Irish Sea. Dredging had the second highest landings and value; however, this activity was ranked 4th by fishing effort partly due to this being a relatively high value fishery targeting species such as scallops. This activity was generally concentrated in the Irish Sea (North of Wales) and towards the centre of the channel. Beam trawling accounted for 19% of the total UKCS fishing effort, and only 8.6% of the fishery value. This apparent discrepancy is discussed below. Beam trawling efforts were focused around the Southern North Sea and SW England. Seine netting was generally focused within the channel and east of the UK and was seen to be of general low value with <3% of total value and landings yet 6% of fishing effort. Gill netting and static fishing (pots and traps) are expected to be underrepresented due to the data not recording vessels <15 m in length, typically used for these fishing gears. These gears accounted for a combined <1% of the total of all fields. Static gear was generally focused in inshore areas around the UK with gill netting more widely distributed.

The results show that 9.1% of landings (7.9% of fishery value and 11.2% of fishing effort) could be affected by current and future offshore renewable developments in the UKCS. This equates to an average of £346 million per annum, based on an average total UKCS fishery value of £4.39 billion per annum, calculated from the data used. Therefore, OWF developments have the potential to affect a significant proportion of the fishing fleets that fish in the UK EEZ, highlighting the importance of good marine spatial planning and coexistence between commercial fisheries and OWFs. The data presented does not represent a displacement of fishing activity due to existing coexistence activities, however they highlight the proportion of the commercial fishing industry which may be affected or is affected by OWFs, indicating the forecast scale for fisheries coexistence in the UK.

Where Active/In Operation OWFs are located, they presently account for around 0.8% of fishing effort and around 0.6% of UKCS total landings / fishery value (around £24.5 million).

The largest expected effect is from OWFs which are in the Pre-Planning application phase (3.3% by value), followed by those which have been granted consent (2.5% by value). Proposed Project Development Areas located off the North coast of Cornwall are expected to cover around 0.06% of the UK fishery value, while those distributed around the UK, and presently in the 'In Planning' stage, accounted for 0.37% of the UKCS fishery value. OWF's 'Under Construction' are expected to occupy space which account for around 1% of the fishery value.

Interestingly, the highest proportion of fishing effort was observed in areas where OWF are 'Consented' which accounted for 6.8% of the UKCS fishing effort, this was 5.2% higher than the next highest effort (Pre-Planning application). This was largely due to very high beam trawling effort in the Southern North Sea, where large OWF have been consented. While this effort is very high, the landings and value do not follow the same proportionally high value. While beam trawling is a mixed fishery which can sometimes result in low value catches, this doesn't explain why there would be a sustained fishing effort in this area when landings were low. Possible reasons for this discrepancy could be caused by a gap in obtaining logbook data in this area during the ICES compilation of data or the possible under reporting of landings. It should be noted one of the data caveats is that "value and weight is not quality-checked in full, which can therefore be inconsistent" (ICES, 2021).

The values calculated for 'Active/In Operation' OWF's do not necessarily represent coexistence as the fishing effort date range does not account for OWFs which may have become operational after the fishing effort data was recoded. These proportions and values for each OWF phase are expected to be a slight overestimate due to the data resolution, whereby the value for whole 0.05° latitude x 0.05° longitude grid cells will be used if it overlaps with an OWF or development area.

In summary, fishing activities were observed to take place at particular fishing grounds, and therefore the fishing effort does not have an even distribution around the UK. Where Active OWF's are located, they account for <1% of the >12 m length fishing intensity, with some fleets already displaced from development areas. However, future OWF development areas in the UK are projected to overlap with fishing areas accounting for 7.3% of total UK fishery value (for vessels >12 m in length, based on averaged 2011-2020 figures).

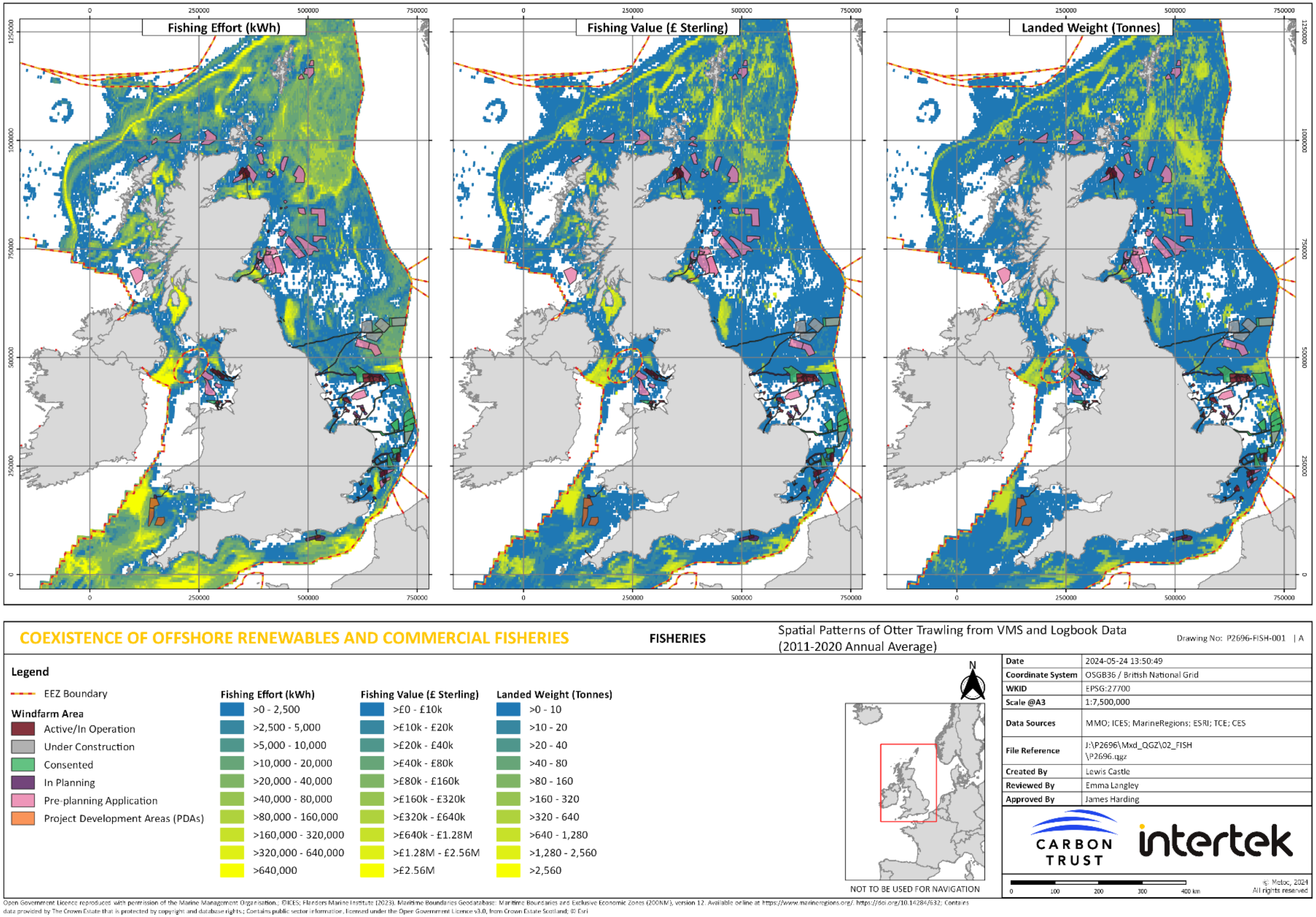


Figure 4: UK otter trawl fishing effort in and around OWFs.

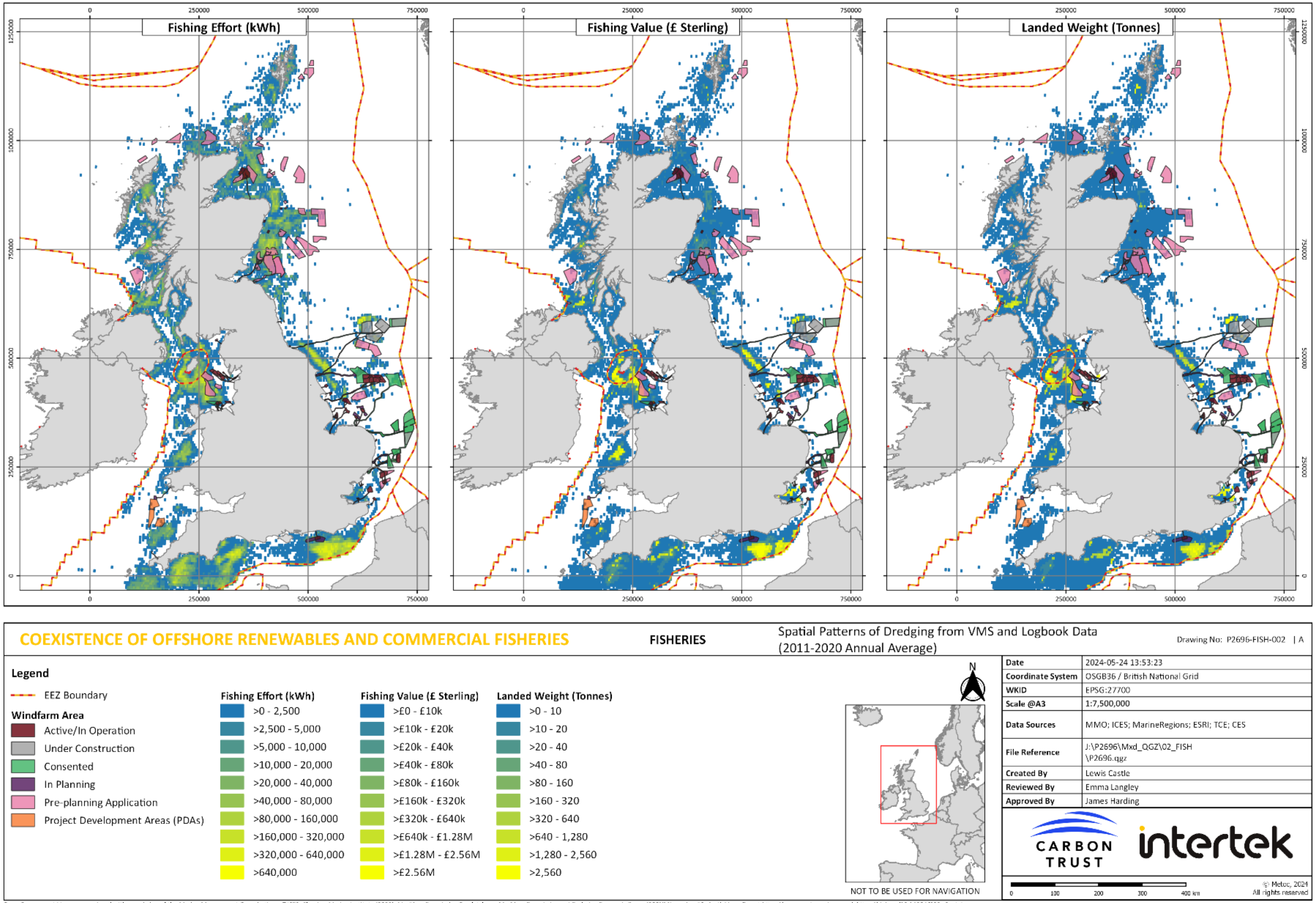


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Figure 5: UK dredge fishing effort in and around OWFs.

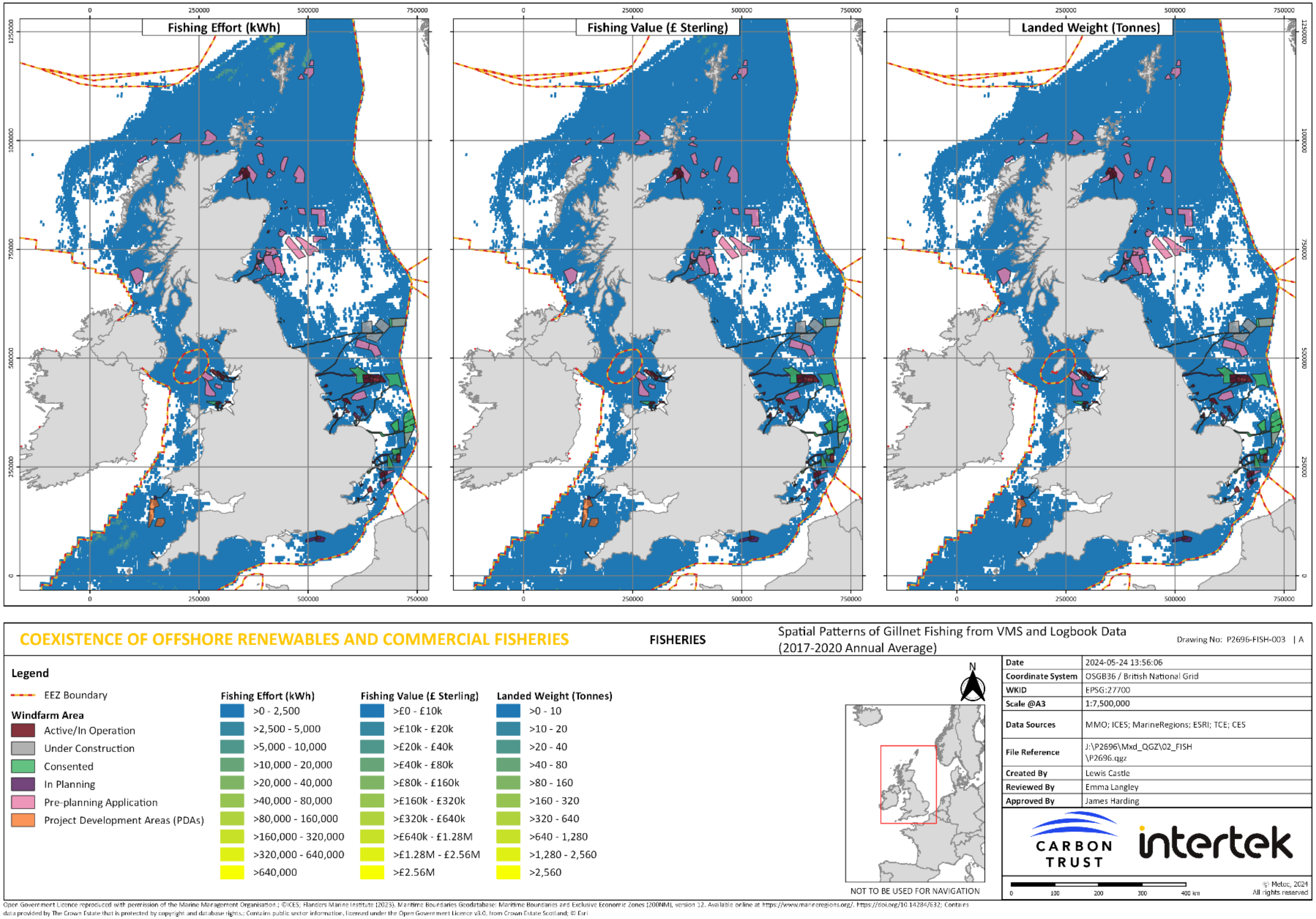

Figure 6: UK gillnet fishing effort in and around OWFs.

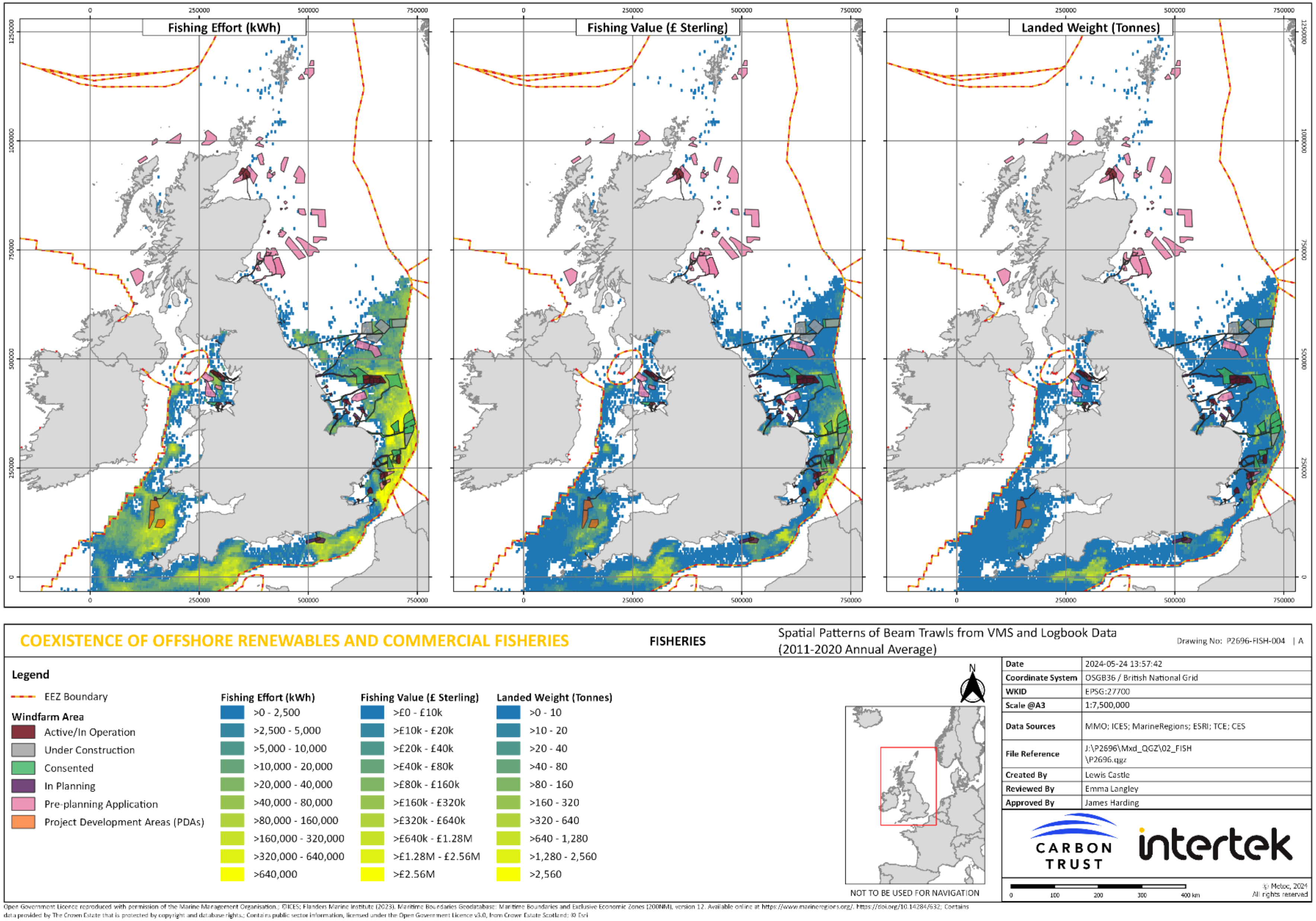

Figure 7: UK beam trawl fishing effort in and around OWFs.

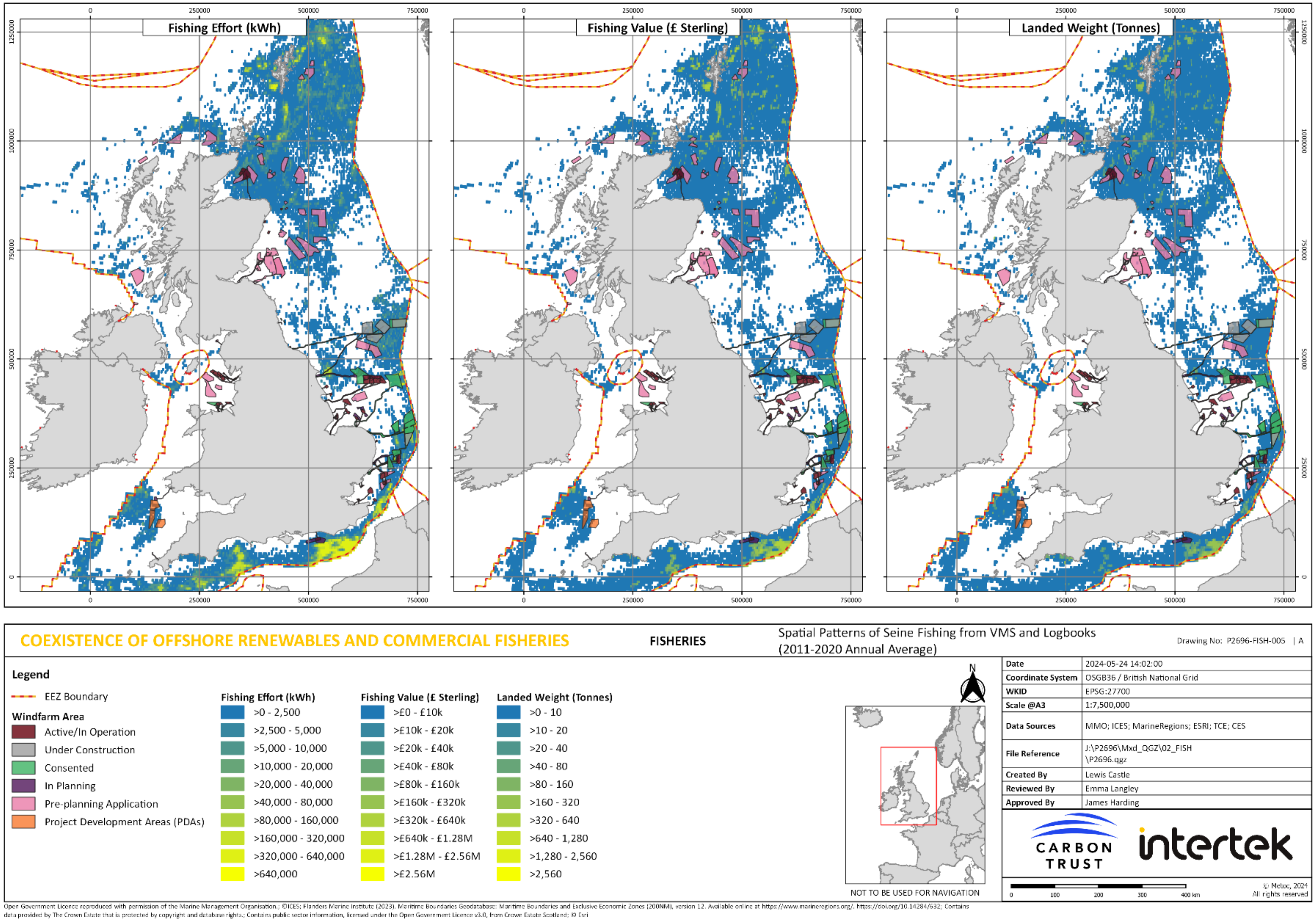

Figure 8: UK seine net fishing effort in and around OWFs.

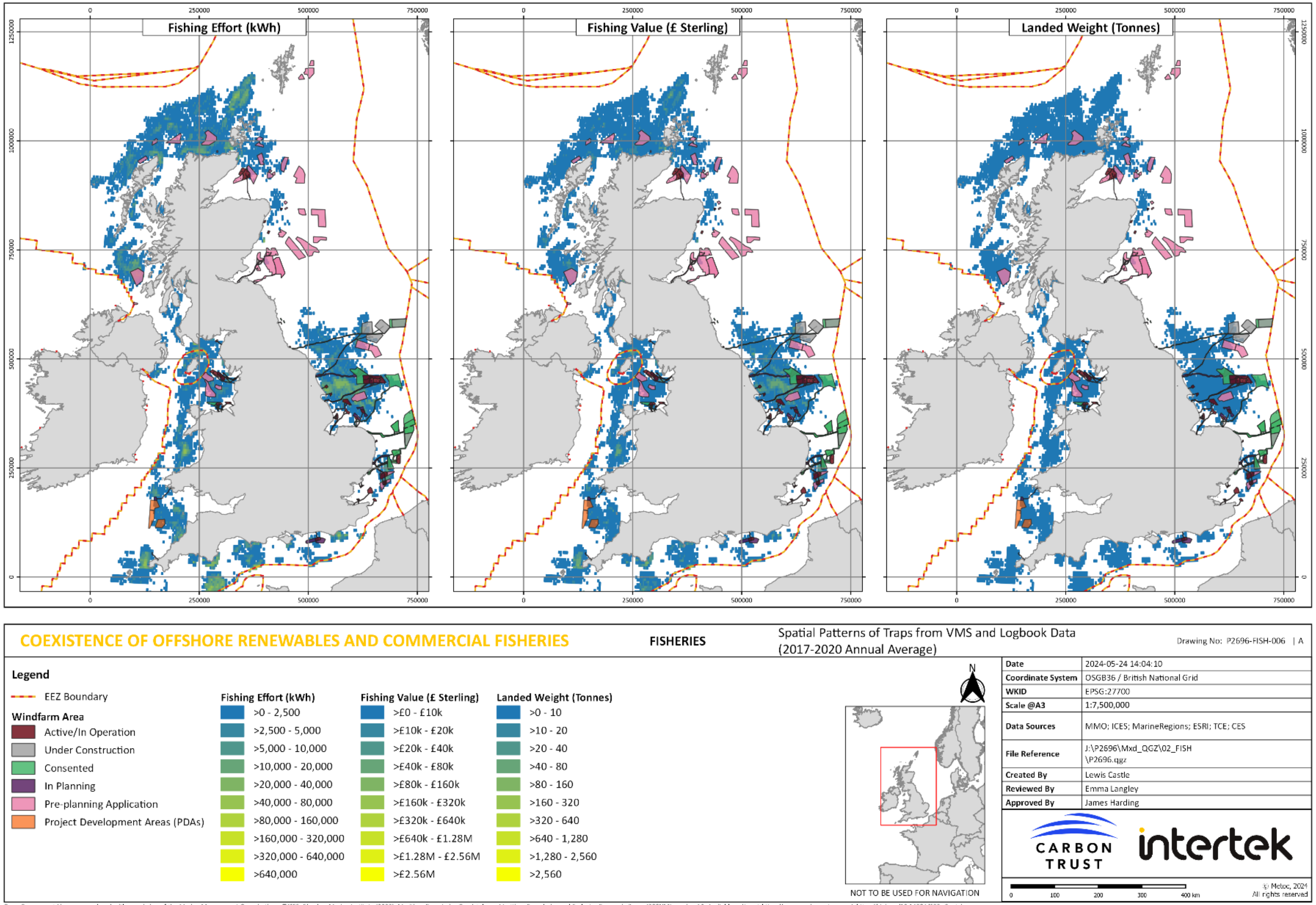

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Figure 9: UK static gear (pots and traps) fishing effort in and around OWFs.

2.4. Stakeholder engagement

The stakeholder engagement process aimed to gather insights and perspectives regarding the coexistence of offshore renewables and commercial fisheries. This section summarises the methodology, the key findings, and recommendations, derived from the stakeholder engagement interviews.

2.4.1. Methodology

2.4.1.1. Stakeholder identification

Initially, a stakeholder engagement plan (SEP) and strategy exercise was undertaken. The output of these exercises allowed for the method of interaction to stakeholders to be agreed and the identification of stakeholders who will be engaged with. This document remained 'living' throughout the project to ensure that new stakeholders were incorporated as appropriate.

Stakeholders were identified as 'individuals or organisations with a professional interest in the field of offshore renewables and commercial fisheries'. The list of stakeholders was developed on a national context around the UK. All relevant national stakeholders, individuals and/or organisations with an interest in the Project were identified using industry experience, online search engines, those already involved in the project (ORJIP project panel) and contacts gained from early engagement.

2.4.1.2. Stakeholder process

The ORJIP steering group (SG) and project expert panel (PEP) were approached through a 'Request for Data' issued by the Carbon Trust, requesting data and information relating to previous interactions or consultations responses with fisheries stakeholders and fishing trial data. Interested members of the ORJIP SG and PEP were invited to take part in stakeholder engagement interviews following engagement with the commercial fishing industry. A comprehensive questionnaire consisting of 13 topics and 25 questions was developed to gather insights and perspectives from stakeholders regarding the coexistence of these industries. OWF developers and associations were interviewed after fisheries consultations to provide targeted feedback to key points raised in the initial stakeholder process. The interview questions were focused around the scope of work and wider discussions on the topic.

Interview by virtual meeting was considered to be the most efficient method of gathering stakeholder information over a large region, these interactions have previously been successful in gathering detailed information where other methods such as sending a questionnaire and awaiting responses are only limited in effectiveness. It ensures that individuals do not need to travel and reduces potential carbon emissions associated with face-to-face interactions.

Following interviews, stakeholders were provided with a summary of their responses for review and sign-off, ensuring that their input was accurately represented in the stakeholder engagement process.

2.4.2. Results

2.4.2.1. Fisheries engagement

Overall, 53 stakeholders representing various segments of the commercial fisheries industry, each with a vested interest in the subject matter, were invited to engage in this project. Among these, 13 respondents demonstrated their commitment by accepting the invitation to partake in interviews. Despite expressed interest, several stakeholders were unable to attend scheduled interviews, while others did not respond to the interview requests. These individuals were subsequently asked to respond to the questions without interview, however, no response was received to this request. The level of participation was higher than expected, with the invite being forwarded on to key experts. These respondents, their affiliation and interview dates are summarised in Table 4.

Table 4: Fisheries stakeholder meeting details.

Organisation	Representatives position held	Date of interview	Type of stakeholder
National Federation of Fishermen Organisation (NFFO)	Chief Executive Officer	13th March 2024	Commercial Fishing Organisation
Seafish Industry Authority	Kingfisher and Geospatial Manager	15th March 2024	Commercial Fishing Organisation
Orkney Regional Inshore Fisheries Group (RIFG)	Region Chair	15th March 2024	Commercial Fishing Organisation
Scottish Fishermen's Federation	Offshore Energy Policy Manager and Industry Advisor	15th March 2024	Commercial Fishing Organisation
Eastern England Fish Producers' Organisation (FPO)	Chief Executive	19th March 2024	Commercial Fishing Organisation
Northwest Coast RIFG	Region Chair	21st March 2024	Commercial Fishing Organisation
Scottish Whitefish Producers Association (SWFPA) and North & East Coast (N & EC) RIFG	Offshore Renewable Energy Policy Officer of SWFPA and Region Chair of N & EC RIFG	25th March 2024	Commercial Fishing Organisation
Communities Inshore Fisheries Alliance	Co-ordinating Member	27th March 2024	Commercial Fishing Organisation
Inshore Fisheries Conservation Authorities (IFCA) **Association of IFCA's** **Devon and Severn IFCA**	Senior Policy Officer, Inshore Environmental Officers and Project Officer	28th March 2024	Inshore fisheries manager / regulatory body

Eastern IFCA **Kent & Essex IFCA** **Northumberland IFCA**			

2.4.2.2. OWF industry engagement

Following engagement with the commercial fishing community, the key findings were presented to the ORJIP PEP who were asked to participate in a series of interviews to provide a perspective from the OWF community.

Overall, five stakeholders from the ORJIP PEP requested an interview as part of this Project. An interview with one OWF developer could not be arranged, however four stakeholders representing OWF developers, one of which also representing an industry association, were interviewed. The responses gained were broadly similar, however differences in perspectives were evident giving a relatively clear outcome to the topics discussed.

The respondents, their affiliation and interview dates are summarised in Table 5.

Table 5: OWF industry stakeholder meeting details.

Organisation	Representatives position held	Date of interview	Type of stakeholder
ESCA / EDF Renewables	ESCA Liaison officer and ESCA Fisheries Engagement Officer / EDF Renewables Fisheries Engagement Officer	24th April 2024	Subsea Cables Association and OWF Developer
SSE Renewables	Commercial Fisheries Manager	25th April 2024	OWF Developer
Ocean Winds	Fisheries Manager and Offshore Consents Manager	2nd May 2024	OWF Developer
Ørsted	Senior Lead Strategic Specialist and Commercial Fisheries Managers	3rd May 2024	OWF Developer

2.4.3. Stakeholder responses

A summary of each of the key topic areas that was discussed as part of the stakeholder meetings is provided in this section.

2.4.3.1. Current relationship

One of the main responses received from fisheries stakeholders was that current relationships between commercial fishers and offshore renewable developers regarding coexistence were 'variable' (Figure 10). Fisheries stakeholders had examples of very good relationships and very bad relationships with developers. It was felt to be vital that a strong relationship between the stakeholders and offshore wind developers was established early in each OWF project. This seemed largely to be determined by two factors, good Fisheries Liaison Officers (FLO) and early, open and honest dialogue.

A range of responses were given by OWF developers, none of which summarised their relationship as ‘poor’ or ‘very poor’. Where a ‘good’ relationship was described, this was defined as ‘cautiously positive’ and heading in the right direction. Positive relationships between national organisations such as the SFF and NFFO were described across all OWF Industry stakeholders interviewed, with negative interactions observed more exclusively with smaller forums or individual fishers, often relating to compensation agreements.

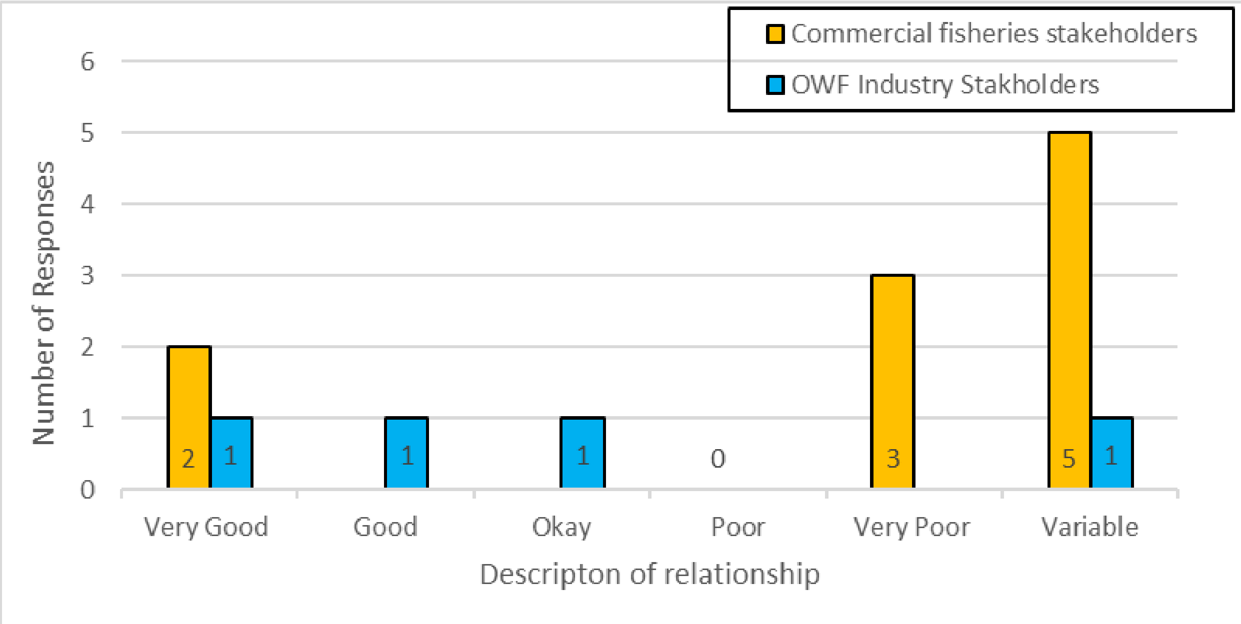


Figure 10: Relationship between offshore fishers and OWF developers.

2.4.3.2. Existing coexistence

Fisheries stakeholders reported that coexistence between OWFs and commercial fishing activity varied throughout the UK. In England, two separate examples were provided that contrasted experiences, with fishing at one OWF returning to levels the same as prior to construction whilst another OWF had permitted fishing, but this was no longer feasible due to the OWF and so levels had reduced. In Scotland, Moray Firth OWF was highlighted as a positive example of fishing returning to previously recorded levels, despite this, some areas of Moray East OWF were not considered safe to fish, discussed in Section 4.2.2. At some other OWFs, fishing levels were low due to hazardous fishing perceived due to array layout and inter-array cables and safety concerns regarding validity of fishing vessel’s insurance due to limited rescue services in emergencies.

The OWF developers recorded significant amounts of fishing activity within their OWFs, particularly with static gear, but also some mobile fishing gear (limitations on this are often due to lack of space to operate the gear for methods such as Seine netting). One developer reported that 60% to 70% of its east coast sites have static gear within the arrays and particularly along the nearshore areas of export cables. The fishing activity was observed to vary on a case-by-case basis with reports of fishers becoming more confident with fishing in OWF sites and over subsea cables, yet lower levels of coexistence observed in areas with a deeper water depth, which are generally located further offshore and fished less frequently in by the UK static gear fleet. It was mentioned by another stakeholder that fishing activity occurs within windfarms regularly & most of the time, both industries go about their business without a negative impact on the other.

2.4.3.3. Examples of coexistence

Fisheries stakeholders were asked to provide examples of fishing fleets that were either positively or negatively affected by offshore wind developers.

- No stakeholders reported a positive impact from OWFs. The best outcome observed was 'business as usual', which was reported for one OWF (Westermost Rough).
- Negative impacts were reported by all fisheries stakeholders. The main impact was spatial squeeze and the loss of some fishing grounds to the OWFs.
- It was perceived some OWFs had become a *de facto* closed area, for some fishing methods (namely mobile fishing gears).
- One example was cited as an opportunistic change in fishing methods, in response to an OWF. This was for the former Blyth OWF where some local pot (creel) fishermen had deployed *Nephrops* pots in an area previously fished mainly with trawls. This change was, however, reported to be very limited and had to be viewed in the context of the loss of access to this area by the *Nephrops* trawl fishery.

OWF industry stakeholders were not asked to comment on the effects of ORE on commercial fisheries as they do not fish these areas themselves, however the following examples of fisheries coexistence on OWFs were cited in interviews:

- Westermost Rough OWF – Static lobster fishery;
- Beatrice OWF – Squid and static gear fishing;
- Dogger bank OWF – Mobile demersal fishing;
- Greater Gabbard OWF – Static lobster fishery and Seine Netting; and
- Moray East OWF – Demersal trawling, squid, and static gear.

2.4.3.4. Concerns and challenges

All fisheries stakeholders interviewed raised similar concerns and challenges. Figure 11 below outlines the main concerns and challenges.

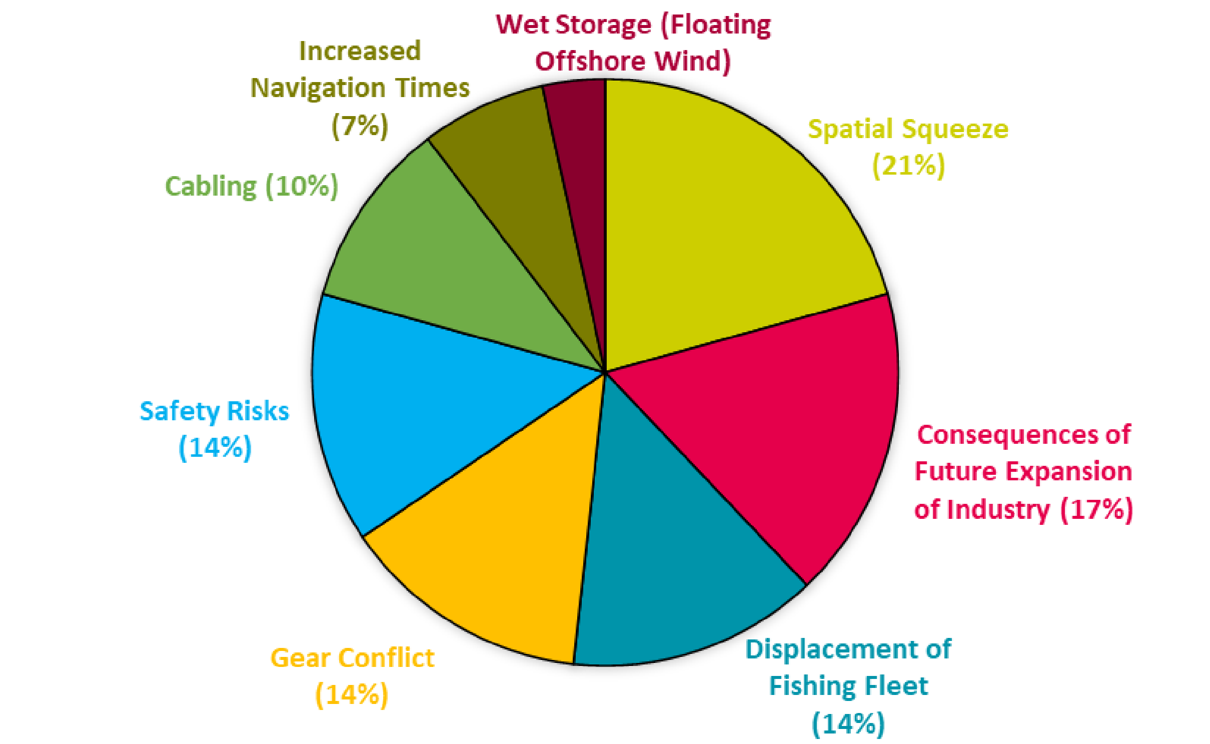


Figure 11: Primary concerns and challenges raised during fisheries stakeholder interviews.

- **Spatial squeeze** was identified as the key issue, causing displacement of fishing fleets and gear conflict between displaced fishers and those already operating outside the OWF. There was concern that this situation would only get worse as the OWF industry expands. Scottish stakeholders also mentioned competition for space between fishing fleets and OWF vessels within and around small fishing ports.
- **Safety risks** associated with operating within OWF arrays were also a prominent concern, with some fishers apparently unwilling to risk operating in areas where seabed obstructions were uncertain, and wind turbine foundations created navigation hazards. Safety concerns over the increased use of Uncrewed Survey Vessels (USVs) were also raised.
- **Cabling** and cable protection measures were mentioned as a potential safety risk, with concerns raised about the uncertain extent of inter-array cable burial in some OWFs, and also that the layout of inter-array cabling did not often allow for 'corridors' along which fishing vessels could continue to operate.
- **Increased navigation times** for fishing fleets due to the need to avoid OWF areas (during survey & construction periods) and / or to travel further to new fishing grounds post-construction was also raised as a challenge that could affect the economic viability of individual vessels and / or the entire fleet in an area.

All OWF industry stakeholders interviewed raised concerns and challenges that were largely different to those given by fisheries stakeholders. Figure 12 below outlines the main concerns and challenges raised by OWF industry stakeholders.

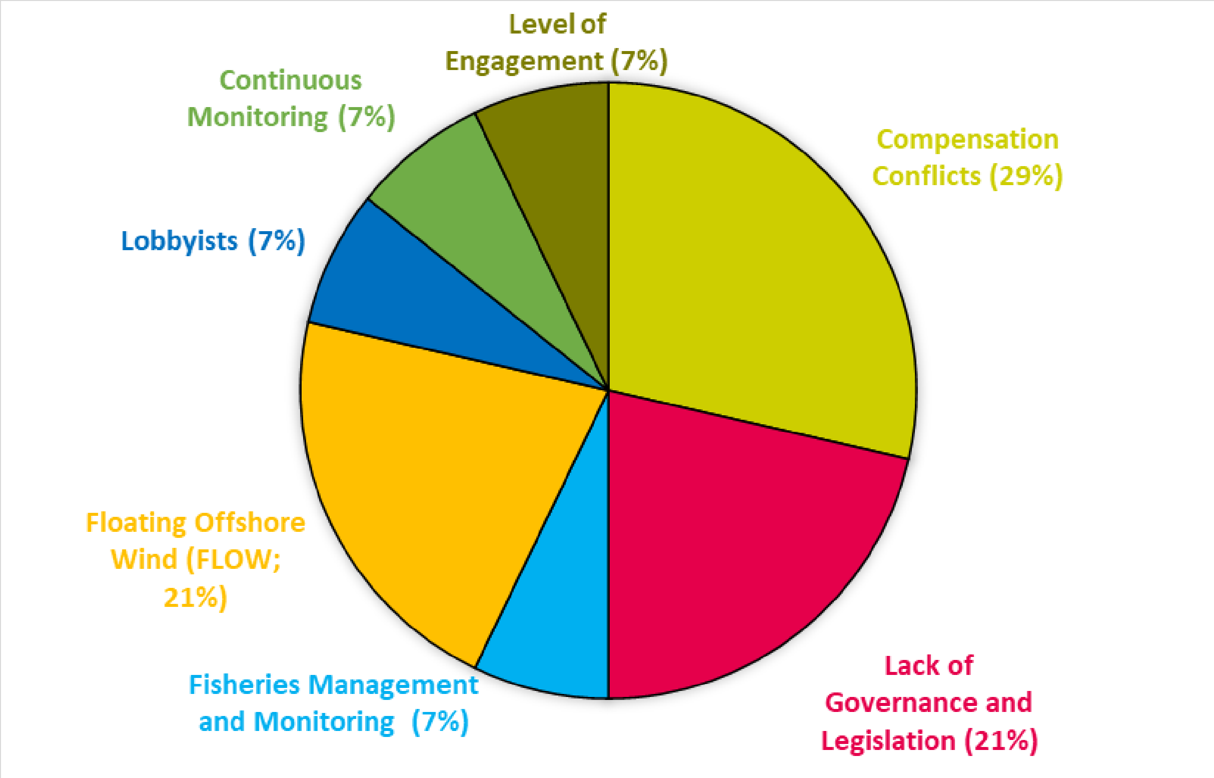


Figure 12: Primary concerns and challenges raised during OWF industry stakeholder interviews.

- **Compensation conflicts** were the most frequently mentioned concern, it was reported across the developers interviewed that a small proportion of the commercial fisheries community were chasing compensation claims. At times this has led to conflicts and unreasonable actions by some fishers causing risk to vessels and delays to activities. It was also noted that if some uncooperative fishers were to receive non evidence-based payments and financially benefit, this would not be fair to those who do cooperate and are willing to enter into an evidence-based agreement.
- **Lack of Governance and Legislation** follows on from the above point where it was highlighted that there is no legislative framework under which compensation disputes can be resolved. Consequently, developers are tasked to resolve conflicts themselves. Where fishers are remaining disruptive and unreasonable there is currently only rules such as Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREGs), which can be used in a legislative manner, where required, however breaches can be difficult to prove, and these do not cover a lot of scenarios which developers may face. It was mentioned that presently, there is insufficient legislation in place to adequately deconflict activities of some fishers and it was recommended this is put in place.
- **FLOW** was also frequently raised as an ongoing concern as there is the uncertainty in the engineering and what the engineering solutions are going to be (e.g. anchoring and mooring systems). At the present time, there are also insufficient examples of floating OWFs to draw conclusions from.

- **Lobbyists**, it was noted that politically, the fishing community have a relatively large voice which can quite easily cause delays to consenting OWFs which can cost developers considerable amounts of time and money to resolve.
- **Fisheries management** of different regions and a lack of vessel monitoring data was also raised, as OWFs occupy very large areas, fishing activity is often not observed by associated platforms, or vessels and AIS tracking of vessels can be masked (albeit controversially, without legitimate reason). Further, with privacy regulations in place removing details of vessels fitted with VMS, developers are not always aware if fishing vessels are working in close vicinity to their assets and if so what type of fishing they are doing.

Further challenges which are presently not well understood include continuous monitoring of OWFs for fisheries impacts, and if impacts are observed, how these should be dealt with. In addition, gauging the appropriate level of engagement with the fishing community was raised as being difficult to anticipate.

2.4.3.5. Knowledge and awareness

This topic was addressed to fisheries stakeholders, and engagement interviews revealed a spectrum of perspectives regarding awareness and information sources related to the impacts of offshore renewables on commercial fishing. There were three broad areas of response from stakeholders for this topic.

- Knowledge of what operations are going on or proposed for an OWF and where they are taking place.
- Knowledge of impacts of OWF on fish and fishing.
- Knowledge of the risks and regulations associated with fishing around existing OWFs.

Most of the fisheries stakeholders interviewed (70%) were involved in the planning and consultation process for the OWFs that they have an interest in. They felt well-informed about what operations are taking place within those OWFs and the associated regulations.

This topic also posed the question to stakeholders what sources of information they rely on regarding regulations governing fishing around or in areas of offshore renewables. This question received different responses from all commercial fishing stakeholders, these included:

- Members of their organisations;
- Peers within the industry;
- Universities;
- Government publications;
- KIS-ORCA / Kingfisher bulletins; and
- Notice to Mariners issued by the OWF project.

Several stakeholders praised the FishSAFE system that is used to inform fishers about the location of oil and gas infrastructure and provide real-time updated information on new restrictions and hazards. It was reported that developers, such as Equinor, have also updated this to include FLOW infrastructure. This system was seen as having a positive impact to commercial fisheries, due to its alarm feature and information provided through its mobile App. One of the FishSAFE partners was interviewed and indicated that there was potential to develop this system to include OWF infrastructure.

2.4.3.6. Data research

During the fisheries stakeholder interviews, a common theme emerged regarding the general lack of up-to-date and site-specific information concerning the impacts of offshore renewables on fish and shellfish stocks.

Stakeholders expressed frustration over the scarcity of data regarding short-term, long-term and cumulative effects on marine life. This apparent dearth of information was seen as a significant obstacle to informed decision-making and effective management of ORE projects. However, there was also recognition that fishermen possess valuable knowledge and insights that could contribute to improving the evidence base. Many fisheries stakeholders expressed a willingness and ability to provide information based on their direct experiences and observations at sea. Conversely, it was mentioned by OWF developers that there was a general reluctance by some fishing fleets to provide data on fishing activities.

Collaborative efforts to gather and analyse data from fishers could help fill critical knowledge gaps and enhance the understanding of the interactions between offshore renewable energy developments and fish/shellfish populations, ultimately supporting more sustainable and informed decision-making processes. This data should give far greater resolution and spatial coverage compared with publicly available data and independent studies.

A requirement for further information relating to the risks associated with cable protection measures was also noted. Existing information is considered outdated, because they may not accurately reflect current conditions, technologies, or understanding of potential risks. Further, information regarding how the insurance industry will respond to increased risks associated with coexistence was also mentioned.

2.4.3.7. Impact assessment

Fisheries stakeholders were asked what they perceive to be the most significant impacts of offshore renewables on commercial fishing which yielded findings largely consistent with those identified in Section 2.4.3.4 regarding concerns and challenges. However, several additional points were raised that were not previously recorded. Concerns raised included:

- Impact assessments rely on outdated and spatially irrelevant information:
    - Impact assessments are crucial in evaluating the potential effects of OWFs on the marine environment and fishing activities.
    - Assessments can rely on outdated data, e.g. EMF, which may not accurately represent the current state of the marine ecosystem.
    - Furthermore, the spatial relevance of the data used in these assessments may be limited e.g. by the spatial scale of ICES rectangles, failing to capture the specific conditions in the proposed OWF area.

The stakeholder concern in terms of placing reliance on spatially irrelevant information could lead to incomplete or inaccurate assessments of potential impacts, undermining the effectiveness of mitigation measures and decision-making processes.

- Lack of follow-up studies on impacts:
    - Despite the significance of OWFs and their potential impact on fish, shellfish, and fishers, there has been a notable absence of follow-up studies in the public domain.
    - The Holderness Fishing Industry Group (HFIG) stood out as an exception in conducting follow-up studies. This Group was established by the fishing community in Bridlington and was supported by grant funding between 2017 until it was wound up in March 2024. The FIG conducted valuable research which showed that the Westermost Rough OWF had little long-term impact on the local lobster fishing fleet.

  This lack of comprehensive follow-up studies was considered to hinder our present understanding of the long-term effects of OWFs on marine biodiversity, fisheries, and the livelihoods of fishers.

- Fishing industry's willingness to collaborate with OWFs for data collection:
    - Despite the challenges and uncertainties surrounding the impacts of OWFs on fishing activities, there was said to be a willingness among fishing industry stakeholders to collaborate with OWF developers.
    - Fishers recognize the importance of gathering information before, during, and after the construction of OWFs to better understand their effects on fish stocks, shellfish populations, and fishing grounds. Such surveys around OWFs are now considered rare, with theoretically based desktop information being used to determine such impacts.

Key themes raised in fisheries engagement included concerns that the current evidence base for underwater noise, electromagnetic fields, and sediment plume impacts on commercial fisheries was not sufficient. Such concerns were also posed to the OWF industry stakeholders interviewed.

One OWF industry stakeholder mentioned that they did not agree that there is insufficient data available on above topics, noting that although not in scientific papers, post-construction data is available on the Marine Data Exchange. However, other OWF industry stakeholders provided some agreement, mentioning that more work could be undertaken on understanding noise impacts on fish, and they appreciate the most EMF studies are lab based and not field based, which could be worthy of more research. For the topic of sediment plumes, developers mentioned that these are minimised in design and deployment of anti-scour protection, and they regard this to be less worthy of more research. It was also mentioned that future studies could be focused on understanding inshore fisheries better. These could look at impacts to fish stocks in relation OWFs as artificial reefs and nursery grounds, with potential 'spill over' effects, and how these can be compared with displacement impacts.

It was also mentioned by several stakeholders that data sharing is important between OWF developers and the fishing industry to help coexistence. It was also noted that external factors such as fish stock health, quotas and climate change are also important considerations when accounting for fluctuations observed in the commercial fishing industry.

Maximum design scenario

Developers were asked to comment on the view that Maximum Design Scenario (worst-case scenario approach) gives insufficient attention to enabling coexistence opportunities.

A varied response was provided to this, one developer agreed that this approach is often based on hypothetical scenarios and is therefore often not realistic. Another developer mentioned that they actively try to coexist with the fishing community and incorporate their opinions into design, where feasible. While other developers mentioned that it is logical to start from the maximum design for the project and then reduce the design and build in mitigation measures which minimise impacts.

It was also mentioned that there is no legislation in the UK to prevent fishing after OWF construction, in which case the Maximum Design Scenario cannot actively exclude fishers post-construction.

Spatial squeeze

The OWF industry stakeholders interviewed were generally in agreement that there is spatial squeeze to commercial fishers from OWFs. However, it was mentioned that there is currently fishing coexistence taking place at some OWFs, which helps to offset this. One developer mentioned that the fishing activity pre- and post- construction is generally the same at their sites so no spatial squeeze should be felt at those sites, or at least only temporarily during construction. Other marine spatial areas, such are MPAs, exclude fishers unlike OWFs.

One OWF industry stakeholder mentioned that the UK government is aware of increasing spatial squeeze as they have leased areas of the seabed to multiple users. They also felt there should be more appreciation from fishers that in order to meet government renewable targets, and there will need to be compromises regarding where they fish.

Initiatives such as The Crown Estate's Whole of Seabed Programme and Department for Environment, Food & Rural Affairs' (Defra) Marine Spatial Prioritisation Programme (MSPP), include coexistence workshops which look to minimise spatial squeeze, and work undertaken on the Celtic Sea FLOW site selection was considered good in accounting for fishing activities to minimise spatial squeeze. It should be noted this programme is not applicable in Scottish Waters.

Impact from commercial fishing on OWFs

The OWF industry stakeholders were asked what impacts commercial fishing may have on OWFs.

One developer mentioned that where fishers are engaged at an early stage, kept well-informed, and cables are buried, then the biggest impacts are felt in the consultation phase.

Other impacts raised included disruption payments, which can be attached to the development of an OWF. Where these are not amicably resolved, then these can become legal cases which require a lot of time and resource to settle and can affect construction programmes. Further, where fishers are not cooperative, they can disrupt operations and cause delays, which can cost developers huge sums, and in some cases where conflicts arise, situations can escalate to potential safety issues for OWF personnel on vessels contracted to developers. It should be noted that instances of non-cooperation are generally confined to a small proportion of the fishing community. However, the scale of such occurrences can be very large and have the potential to adversely affect the reputation of most fishers who do engage constructively.

A significant impact of commercial fisheries on OWFs that was raised was a mindset fear of the unknown and fear of the perception of how detrimental impacts may be on fisheries in terms of displacement, economic disadvantage, its impact on communities and supply chain. This fear can drive a strong narrative which can cause delays to the consenting process.

2.4.3.8. Cable protection measures

An in-depth discussion unfolded concerning cable protection measures during the majority of interviews with fisheries, exploring a range of options including rock berms, concrete mattresses, fronded mats, cable protection systems, and rigid concrete cable protection (discussed further in Section 3.3).

- Cable burial was identified as overwhelmingly the most favoured option, primarily due to its effectiveness in safeguarding cables while minimizing environmental and navigational impacts (such as the risk of snagging fishing gear).
- Where cable burial is not possible, no alternative measure emerged as universally preferred.
- Suitability of alternative measures depends on the specific location characteristics and fishing fleet considerations.
- Concrete mattresses were identified as an unpopular choice, despite manufacturers claiming their designs decrease risk to mobile fishing gears.
- Safety considerations on a case-by-case basis were deemed paramount in the selection and implementation of cable protection measures for offshore renewable energy projects.

OWF industry stakeholders mentioned that for locations where cables are planned to be buried, developers will aim to achieve target burial depth to provide adequate protection for cables, however, where the target burial depth cannot be achieved during installation, secondary cable protection may be required. A consensus was provided that there are numerous factors to consider for the selection of secondary cable protection measures including cost, asset integrity, environment, and risk to other vessels. Fishing is one of multiple factors to consider on a site-by-site basis.

2.4.3.9. Mitigation measures

Fisheries stakeholders widely acknowledged that the most effective mitigation strategy would involve actively avoiding fishing grounds for OWF placement whenever possible. It was noted with concern that licensing rounds and developers have overlooked this crucial aspect during the site selection process in the past. Other mitigation measures highlighted included:

- Early, open, honest & effective liaison: Many stakeholders highlighted a perceived disparity between the OWF industry and other offshore sectors, such as subsea cables and oil & gas, particularly in terms of proactive and consistent engagement with fishing communities.
- Integrating fishing considerations into project design and schedule.
- Cooperation payments – ideally evidence-based payments, direct to the impacted individuals, though there are some exceptional cases where community funding has worked well, e.g. the West of Morecambe Fisheries Fund for instance.

- Reefs / habitats creation – mixed responses, some stakeholders supported efforts, others concerned that this would aggregate fish in places where fishermen can't catch them.
- A positive example included the arrangement of inter-array cables by the East Anglia One OWF which run parallel to turbines and are arranged into a neat corridor, ensuring consideration for trawling activities. Similar designs of other projects should help facilitate coexistence for trawling activities, where feasible.

OWF industry stakeholders noted that costs associated with changes to design or siting of infrastructure can be extraordinarily high, and further constrained by other geological, environmental and engineering constraints, which can limit design flexibility and consequential project feasibility.

OWF industry stakeholders identified other mitigation measures that are used in the industry and suggestions of how these could be improved:

- Informing fisheries through Notice to Mariners, Kingfisher bulletin and KIS-ORCA. It was mentioned there are ongoing discussions on how aspects of KIS-ORCA may be improved. One developer mentioned that including the cable burial status would be a useful feature. One developer mentioned they operate a website similar to Kingfisher which identifies possible cable exposure, shallow burial and other important information.
- It was mentioned by several OWF industry stakeholders that there should be more awareness that it is particularly hazardous to fish over cables. There can be an inherent tension in providing information which supports fishing over cables, where the maritime safety advice from organisations such as UKHO and ESCA is to avoid fishing where there are known and charted cables.
- Future monitoring through telemetry such as Distributed Temperature Sensing (DTS) and Distributed Acoustic Sensing (DAS) should help to provide additional information on cable burial for example, which could be used to inform fishers of particularly high risk areas.
- Engagement and effective communication were seen as a key driver to ensuring better coexistence and helps build trust and confidence between the two industries. It is thought that if both industries share data and feedback throughout the OWF development process, this will help to resolve potential unknowns and reduce conflicts. It should be noted, however, that the level of engagement from fishers varies in different regions and a small proportion of the fishing community can cause relatively large delays and very high costs for developers.
- In Scotland, the pre-construction submission of a Fisheries Management and Mitigation Strategy (FMMS) was highlighted by OWF developers as useful in facilitating coexistence. Other communications tools such as the BarentsWatch portal – Norway was also listed as being effective.
- Fisheries community funds were highlighted as effective and able to make positive contributions to fishing communities. However, it should be noted that, if not managed correctly, then their benefits can be very limited.
- Other initiatives such as gear marker funds, the provision of free marker buoys to fishers so that they can clearly and correctly mark their gear when operating within OWF sites, and gear retrieval systems which allow fishermen to retrieve gear they have lost within OWFs, were also viewed as successful.

- Although FishSAFE was highlighted by fishers as a useful tool for the oil and gas industry, it was felt that this was difficult to achieve in OWF, which cover large areas and don't operate permanent exclusion zones.

2.4.3.10. Collaboration opportunities

During the fisheries stakeholder interviews regarding collaboration opportunities between offshore renewables and commercial fishing, participants were asked how the two industries could work together to address shared challenges.

- Many respondents expressed a lack of recognition regarding shared challenges between the sectors, but emphasised the importance of early, meaningful, and transparent engagement as the primary method of collaboration.
- Suggestions included forming working groups, engaging with communities, and establishing fisheries liaison mechanisms. However, concerns were raised about the effectiveness of existing forums and mechanisms for collaboration.
- Some respondents criticized Fisheries Liaison Guidelines, noting that they have been under revision for an extended period of 8.5+ years and lack effectiveness. Specifically, the Fishing Liaison with Offshore Wind and Wet Renewables Group (FLOWW) guidelines (The Crown Estate, 2014), while often considered good, were criticized for being overly lengthy and detailed, drifting away from the core objective of facilitating good liaison practices.
- Participants highlighted issues with excessive detail, particularly concerning compensation measures, which were deemed unhelpful and detracted from the guidelines practical utility.

Key collaboration opportunities raised by OWF industry stakeholders included:

- Updating of the FLOWW guidelines, which is currently being undertaken.
- Regional Fishing Industry Groups, such as the Holderness Fishing Industry Group, which is no longer operational, were seen as good collaborative approaches to solve shared colocation and coexistence challenges.
- Future collaborative initiatives mentioned also included looking into the use of static gear in OWFs instead of mobile fishing gear, as studies undertaken in Hywind OWF provided some positive initial results, discussed further in section 4.3.3.

It was noted by OWF industry stakeholders that an example of good cross industry collaboration includes the work undertaken for fisheries liaison guidelines as part of the marine spatial prioritisation.

2.4.3.11. Regulatory and policy perspective

Fisheries stakeholders expressed significant concerns about regulatory framework and government oversight regarding offshore renewables and commercial fishing coexistence.

- Lack of ongoing engagement can be seen as a major flaw in regulatory process, allowing developers to proceed without considering concerns of affected parties.

- Apprehension about DEFRA-led marine spatial prioritisation process, perceived to prioritise offshore renewables and marine conservation over commercial fishing.
- Stakeholders advocate for granting fisheries a more formal role in decision-making processes, suggesting regulatory changes to address concerns and issues raised.
- Stronger leadership at government level deemed necessary to facilitate coexistence, with current the consenting regime heavily reliant on developers and statutory nature conservation bodies, lacking involvement from government-led policy makers.

Similarly to the fisheries stakeholder engagement, OWF industry stakeholders expressed significant concerns about a lack of regulatory framework and government oversight regarding offshore renewables and commercial fishing coexistence. In particular:

- Regulatory systems in the UK were generally considered not fit-for-purpose, hindering the speed of consent and not offering rules to follow. Noting, licences are given to developers for space that fishers operate in, and the two industries are expected to resolve any issue that may occur without regulations.
- A key recommendation form consultation is that a coexistence legal framework is put in place and that the consenting regime under section 36 of the Electricity Act 1989 (EA 1989) is reviewed. Further, a clearer route to get the challenges heard by ministers is recommended.
- It was thought by one stakeholder that there are ways of working more efficiently with what already exists, for example improving FLOWW guidelines. However, these are guidelines and do not sit in a legal framework.

2.4.3.12. Community and socioeconomic impacts

The fisheries stakeholder interviews highlighted both socio-economic direct and indirect impacts of OWF developments on the fishing industry.

Direct impacts included the loss of income resulting from the physical footprint of OWFs and the displacement of fishing effort during both the construction and operation phases. Fishermen expressed concerns about reduced access to traditional fishing grounds and potential disruptions to their livelihoods. Additionally, the movement of vessel crews to alternative jobs was identified as a consequence of decreased fishing opportunities in areas affected by OWF development.

Indirect impacts centred around spatial squeeze and increased vessel traffic in local ports. The influx of activity associated with OWF projects could strain existing port infrastructure and create logistical challenges for fishermen, potentially affecting their operations and access to essential services.

OWF industry stakeholders noted several factors involved in supporting fishing communities and maintaining socioeconomic value of commercial fisheries impacted:

- Assessment of economic impacts are best assessed through understanding the baseline economic value of an area achieved through the sharing of data from the fishing community.
- Supporting local community initiatives, rejuvenation of local infrastructure e.g. ports and harbours can benefit fishers as well as developers. Other initiatives such as the electrification on fishing fleets could also be considered.

- Employing fishers' services and specialist consultant and/or e.g. guard vessel work can help, especially in areas where the fishing industry is more deprived.
- Lobster/bivalve seeding can be seen as beneficial on a socioeconomic scale, although evidence of benefiting stocks and fisheries is very limited.
- As agreed with fisheries stakeholders, fisheries community funds were highlighted as benefiting fishing communities. However, it should be noted that where funds are run by the community and support community initiatives, they are generally more successful than being used as compensation payments.

2.4.3.13. Future outlook

Fisheries stakeholders provided insights on emerging technologies and practices influencing coexistence between OWF's and commercial fisheries. Various concerns were given, as follows:

- Floating wind technology presents uncertainties due to the present lack of commercial-scale implementation in the UK.
- Complexity anticipated in implementing FLOW, especially in the Celtic Sea.
- Scepticism regarding the effectiveness of FOWFs with regard to fisheries coexistence, due to large mooring coverage, limiting fishing within array footprint.
- Call for more research on OWF effects on fish and shellfish stocks, including the impact of EMF.
- Fishers eager to contribute to research using tools like 'Catch Cams' to monitor marine life around OWFs.
- Concerns raised about potential spatial squeeze from proposed mitigation measures like artificial reefs, which may become 'no take zones'.

OWF industry stakeholders echoed several of the fisheries stakeholder concern - FLOW remains an uncertainty from a fisheries coexistence perspective and research on this is recommended, as well as updates to existing literature for aspects such as underwater noise impacts on fish and EMF.

More research on the potential of OWF as artificial reefs and potential 'spill over' should help to evidence concerns of OWF as 'no take zones'.

The use of cable monitoring systems such as DTS and DAS in the future should also help better inform developers regarding cable burial status, for example. However, there remains scepticism as to whether such detailed data should be made available where industry advice is not to fish near subsea cables (MCA 2021, UKHO 2023 and ESCA 2022). Further, the legal implications of using such data to inform fishers of risks are uncertain and could present challenges.

The lack of legislation is seen by some developers as a big hindrance to coexistence, by establishing legal frameworks, this is expected to help establish rules that are expected to help with challenges in existing and future OWF sites.

2.5. Limitations and knowledge gaps

2.5.1. Literature review

2.5.1.1. Limitations

- The key limitation identified by this literature review, is the relative paucity of scientific information presently available from which informed conclusions can be drawn.

2.5.1.2. Knowledge gaps

- There are gaps in knowledge identified regarding the actual impacts of OWF on fish stocks and commercial fishing activity at all levels, ranging from the reef effects of physical structures, to the post-construction impacts of individual OWFs, as well as cumulative effects of OWFs on fishing fleets at a regional seas level.
- The impacts of commercial fishing on OWFs was highlighted as poorly understood with incidents often dealt with internally with OWF developers.
- Decommissioning impacts to fisheries following a total removal or partial removal of infrastructure and potential reclaiming of fishing grounds is not yet currently well understood.

2.5.2. Consultation responses

2.5.2.1. Limitations

- The consultation responses gathered were not inclusive of all OWF developments, rather they are considered to represent a subset of OWFs providing feedback from different UK regions, covering different fishing fleets.

2.5.2.2. Knowledge gaps

- It was suggested there is presently a limited evidence base on the effects of EMF from high voltage submarine cables on fish stocks and behaviour. While EIAs often incorporate assessment on EMF impacts, which often conclude only highly localised and minor or negligible impacts on select fish and shellfish species, such conclusions are based on the current knowledge base which is primarily reliant on lab-based experiments on select fish species. EMF associated with dynamic cables in FLOW farms are a concern for some fisheries stakeholders. Further information and identification of key knowledge gaps in this subject area are detailed in OSPAR (2023) and Gill *et al*. (2023).
- The impact of FLOW on mobile fishing gear fleets is also not fully understood. With numerous FLOW pontoon and mooring designs being considered for developments, it is currently not well understood whether these will facilitate fishing coexistence, or whether these structures will be more vulnerable to fishing activities.

2.5.3. VMS spatial mapping

2.5.3.1. Limitations and knowledge gaps

- Inshore fishing vessels <12 m vessel length (<15 m for MMO data) were not represented in the datasets.
- It is possible that the introduction of Inshore Vessel Monitoring Systems (iVMS) for smaller (< 12 m length) vessels will increase the confidence of assessments in inshore waters, where smaller vessels operate. This system is still being implemented so it would not provide historic data. During stakeholder discussions the IFCAs indicated that the release of this information for such analyses would require consent from individual fishing operators and that this could not be guaranteed.
- The data values of OSPAR/ICES were required to be anonymised, this process used an algorithm which transforms data. While ICES undertook rigorous quality control of the dataset some areas may be misrepresented.
- OSPAR/ICES data on value and weight is not quality-checked in full by the expert groups, this can therefore be inconsistent and/or not meet the quality standards. ICES is considering ways to resolve this for future data submissions.
- Data from countries including Portugal, Norway and Iceland were not included in the OSPAR/ICES dataset and data from MMO excludes all foreign fleets (UK only). A fully inclusive data set of vessels fishing in the UKCS will provide more accurate statistics.
- Data resolution is refined to 0.05° latitude x 0.05° longitude grid cells. Although this is considered a good resolution, it doesn't provide a highly detailed representation of all fishing activity at a local level.

2.5.4. Stakeholder engagement

2.5.4.1. Limitations

- The key issue with stakeholder engagement for a project of this nature is that interviews can only be conducted with those stakeholders who volunteered to be interviewed. Many stakeholders were invited to participate that either declined to participate or failed to respond. However, the range of experience of those interviewed was considered very broad, and they collectively represent the majority of the UK fishing fleet and OWF developers, so this limitation is not likely to significantly skew the responses.
- Although virtual meetings via Microsoft Teams, and providing a list of questions to participants beforehand, can be an efficient method of stakeholder engagement, it comes with a degree of limitations (technical issues, difficulty building rapport, the risk of distractions and the 'digital divide'). Aside from some minor connection issues, these limitations were not felt to be an issue and in particular the stakeholder lead interviewer (Fisheries Liaison Officer) had an existing working relationship with many of the stakeholders, enabling a ready exchange of views during the process.

- The key limitation of the stakeholder engagement process is getting a balanced dataset from both the fisheries and OWF industries, therefore stakeholder engagement with OWF developers and relevant organisations was undertaken following engagement with the fishing community.
- A lower number of OWF developers / associations were interviewed compared with fisheries organisations. These participation levels were reflected by the smaller number of developers in the UK which operate at a national level (with multiple projects) compared with fisheries associations who operate at both a national and regional level. The relative consistency in the answers gathered indicated that a representative cross-section of stakeholders was interviewed for the project.

2.5.4.2. Knowledge gaps

Throughout the stakeholder engagement process, various data gaps were identified which the commercial fishing industry would like to see addressed in the future. These include:

- Lack of Up-to-Date Information: It was believed by some that there is a general lack of up-to-date and site-specific information concerning the impacts of OWF on fish and shellfish stocks. An improved understanding on the relative risks posed by key areas of concern; sediment plumes, EMF and underwater noise on fisheries, should help address this in the future.
- Limited Understanding of Interaction Effects: There is a lack of comprehensive understanding of the interactions between OWF developments and marine ecosystems, particularly in terms of short-term, long-term, and cumulative effects on marine life. As well as only a very limited understanding of OWF as artificial reefs and nursery grounds and subsequent 'spill over' effects on surrounding fisheries.
- Data on Cable Protection Measures: Further information is requested regarding the risks associated with cable protection measures, with existing information considered inadequate.
- Insurance Industry Response: There is a need for information on how the insurance industry will respond to increased risks associated with the coexistence of OWF and commercial fisheries.
- Fishing Industry's Knowledge and Awareness: While representative organisations and federations involved in the process demonstrate a high level of engagement and knowledge, there is often a disconnect with individual fishermen who often express feeling uninformed or poorly informed about the implications of OWFs on their livelihoods.
- There is a lack of information on the frequency of incidents of physical damage to OWF infrastructure or the frequency of interference with OWF operations. It is therefore recommended that OWF Developers formally record fishing gear interactions that impact OWF activities.
- Post-Construction Fishing Feasibility: Verification of cable burial for post-construction fishing feasibility is requested, to ensure the sustainability of fishing activities around OWFs. As built designs of an OWF can vary significantly to a Maximum Design Scenario. A post-consent follow-up to ensure final designs consider coexistence should provide more confidence in the

consenting process from fisheries stakeholders. Follow-Up Studies will help to evidence this. Some fisheries stakeholders support the use of over-trawl trials, under controlled conditions, after OWF construction.

- Community and Socioeconomic Impacts: Further data is required to better assess the direct and indirect socioeconomic impacts of offshore renewables on the fishing industry, at a local level, including loss of income, reduced access to fishing grounds, and increased vessel traffic in local ports.
- Data Sharing: inshore fishing data is rarely freely exchanged by the fishing community yet can prove of great value to OWF developers in determining coexistence opportunities and economic impacts. Also data from OWF developers such as exact positions of cable protection measures may benefit fishers. A forum for data sharing this and similar information could be valuable.
- Spatial Relevance of Impact Assessments: Some stakeholders thought that impact assessments often rely on outdated data, and the spatial relevance of the data used may be limited, failing to capture the specific conditions in proposed OWF areas. Data sharing could help address this.
- Spatial Squeeze: while some studies show there is evidence of fishing intensity displacement at some OWFs, some developers state that the pre and post construction fishing intensity is similar. A better understanding of this displacement and the consequential competition for space between fishers will help highlight the key regions or fishing fleets most affected.
- A Lack of UK Government Input and Legislative Framework: There is a key 'gap' between sectors and the establishment of rules and regulations, which should remain a key area of improvement within the UK.

3. Fishing gear penetration depth review

3.1. Literature review

3.1.1. Methodology

A literature review on seabed depth penetration of different fishing gears was undertaken using published journals and relevant guidance. Classifications and groupings of fishing gear types was undertaken using The Food and Agriculture Organisation's (FAO) classification and illustrated definition of fishing gear (He *et al*., 2021) and Seafish's Basic Fishing Methods (Seafish, 2022). The main fishing gear types that are used commercially in the UK were identified and only fishing gears that were evidenced to interact with the seabed were reviewed. The majority of literature reviewed is from the UK, with some from other European countries. These have been highlighted in the data. Sources included published literature, journals, books and websites. A total of 74 literature sources were reviewed. A summary of this review and its findings is provided between Sections 3.1.4 and 3.1.9, with a summary of fishing gear penetration depths provided in Appendix 1.

3.1.2. Industry guidance

It should be noted that while this review discusses fishing gear penetration, with association to commercial fishing coexistence, industry guidance strongly advises against any type of fishing, where there is a known and charted cable. The Marine and Coastguard Agency (MCA) guidance on Navigation – safe and responsible anchoring and fishing practices (MGN 661) states that "it is an offence in United Kingdom and international legislation to damage a cable either wilfully or through culpable negligence. So, damages to a cable or pipeline may result in legal action" (MCA, 2021). The marine environment can be dynamic which can lead to cable exposure or shallower cable burial, particularly in areas that are frequently fished, therefore there will always remain a risk where fishing practices are undertaken in the vicinity of subsea cables.

It is important to note that guidance that advises against fishing where there is a charted subsea cable is not currently written into legislation in the UK, and interactions between fishing gear and subsea cables do occur.

3.1.3. Cable burial guidance

The main guidance documents used for Cable Burial Risk Assessments that account for fishing gear penetration is provided by The Carbon Trust (2015), DNV GL (2016), Department for Business, Innovation & Skills (BIS 2008) and Bureau of Ocean Energy Management (BOEM, 2011). In countries such as Germany, a minimum Depth of Lowering of 20 cm is used as a baseline for risk assessment. Guidance for the UK indicates cable burial depth should be determined using a risk-based approach (DNV GL, 2016).

Guidance regarding cable burial risk and the preparation of cable burial Depth of Lowering has been produced (Carbon Trust, 2015), discussed further in Section 4.4.

The penetration of fishing gear into the seabed has been studied. Linnane *et al.* (2000) states that fishing gear penetration is limited to a maximum of 30 cm in soft sediment, noting this value has been adopted in the Carbon Trust CBRA guidance. The assumption of up to 30 cm seabed penetration of fishing gear is often used as a proxy for impact assessment and design considerations. In the UK cable burial risk assessments, a 100% depth contingency (factor of safety) is often added to the assumed 30 cm seabed penetration, with a recommendation of 60 cm minimum Depth of Lowering. Further guidance from BIS published in 2008, recommended cable burial depths of up to 60 cm accounting for hydraulic dredges in soft sediments. Furthermore, guidance from BOEM (2011), predominantly used in the United States of America, suggests generic expected values for fishing gear penetration of <40 cm in fine sands and firm clay to >85 cm in very soft clay, with a minimum cable burial of 100 cm recommended, subject to examination of the site-specific details.

Literature used to support present UK guidance, such as Linnane *et al.* (2000), has been used to understand fishing gear penetration depths (Carbon Trust, 2015). With an increased demand for offshore renewable energy, a recent up-to-date review of such literature has been undertaken to further understand the potential impacts of commercial fisheries coexistence. Furthermore, fishing gear use and techniques may have also changed since Linnane *et al.* (2000) was published. Greater penetration is avoided by fishers, where possible, in order to reduce wear on gear, reduce drag and reduce fuel usage. A more recent and comprehensive review of fishing gear penetration by gear type and sediment is therefore merited to provide more accurate and relevant information.

3.1.4. Fishing gear types

There are a variety of fishing gears used to catch commercially valuable fish and shellfish in the UK that can interact with OWF's and associated cables. A review of demersal fishing in the greater North Sea found that beam trawling made up 50% of total effort in 2018 (ICES, 2022). This was followed by otter trawling and other gears targeting demersal fishes. Beam and otter trawling targeting crustaceans was also common. Other frequently used fishing gears include seine nets, gill nets, static gears and dredges (ICES, 2022; EMODnet, 2024). A summary, adapted from information in Eigaard *et al.* (2016), He *et al.* (2021), Seafish (2022) and Seafish (2024), of fishing gears used in the UK to capture commercial fish and shellfish is provided below in Table 6. This table focuses on commercial fishing gears that interact with, and have the potential to penetrate, the seabed and includes the most impactful demersal gears.

Table 6: Commercial fishing gears used in the UK that interact with the seabed.

Gear category	Description
Seine nets	Seine nets are cone-shaped nets used to encircle and herd fish using seine ropes. This gear is often used from a vessel and includes Scottish seines and Danish (anchored) seines. This gear traditionally targets clean, sandy and muddy seabed types, however recent improvements and mechanisation have led to a shift into deeper water and to different target species. This transition includes use of heavier fishing gear and translates to an increased penetration depth in soft sediments, not yet defined in literature. This maximum penetration depth, however, is expected to remain significantly lower than other demersal trawls. Such changes have ensured seine net fishing in harder and more rocky ground, which was previously only targeted by demersal trawlers. Seine nets are mostly used in the north of Scotland and England. Danish seine netting generally covers a one spot of seabed encircling an area typically <2 km^2 of seabed, whereas pair seine netting can be towed for several

	hours, forming linear tracks covering distances from <1 km up to ~20 km.
Trawls	Bottom trawling gears consisting of heavy-duty ropes, chains and weights. Trawls can be used in pairs or used as part of multi-rig trawling. Beam trawling uses a rigid beam to maintain the opening of the net mouth, whilst otter trawls make use of doors to spread the nets. Beam trawling is popular with Belgian and Dutch fishing fleets and is used throughout the UK, with high intensities towards the south of England. Pulse trawling is also occasionally used in the UK, mainly by Dutch vessels (Ford *et al*., 2019). Otter trawling is widely used throughout the UK (EMODnet, 2024), and trawl scars are usually clearly defined as a widespread track with furrows either side, which can be up to 40 km in length.
Dredges	Dredging is often used for collecting scallops as well as mussels and oysters and can be towed or mechanized / hydraulic. Dredging can be nomadic in the UK and is subject to strict legislation. Mechanized dredges are not widely used in the UK. Tow distances are typically around 10km or less, but can be longer.
Gillnets	Gillnets consist of walls of netting used to catch fish by gilling or entrapping them in pockets. There are a wide variety of gillnet styles, including anchored net such as trammel nets. Gillnets are often used in the southwest of England. These are static and typically up to 200m long in the UK.
Traps and pots	Pots and traps are used throughout the UK and mainly target crabs, lobsters, crayfish, *Nephrops* and cuttlefish. This gear has at least one tapered entrance, making it easy for biota to enter but difficult to exit. Pots and traps can be shot individually or, more commonly, attached using string and laid on the seabed.

3.1.5. Factors impacting fishing gears penetration

The fishing gears discussed above operate in similar areas to both fixed (typically in depths less than 60 m) and floating (typically in depths greater than 50 m) offshore windfarm (OWF) developments (Noonan, 2021), with similar water depths, sediment types and proximity to the coast (Gray *et al.,* 2016). OWF developments require large surface areas to accommodate power generation activities, leading to an increase in pressures placed on commercial fisheries. Many European OWF installations are currently situated in the North Sea, which is also intensely commercially fished (ICES, 2022; Bonsu *et al*., 2024). The likelihood of cable and fishing gear damage is often dependent on the penetration of fishing gears into the seabed. Fishing gears vary in size, weight, rigging, target species, target substrate and towing speed, all of which can lead to varying penetration depths *in situ* (Eigaard *et al*., 2016). Passive fishing gear, such as pots and traps, differ in nature to towed gear. Passive gear often uses anchors and weights to fix the gear to the seabed while mobile gear is dragged across the seafloor, penetrating the substrate (Drew & Larsen, 1994; Polet *et al.,* 2010 & Depestele, 2010).

The depth of penetration of commercial fishing gears is dependent on factors including sediment type (Eigaard *et al.,* 2016). Generally, penetration is deeper in finer and softer sediments (Grieve *et al* 2014; Eigaard *et al.,* 2016). This has been observed in demersal gears, with deeper penetration in muddy sediments (Gubbay & Knapman, 1999; Bergman & Santbrink, 2000; Ivanović *et al.,* 2011). For example, Ivanović *et al.* (2011) found that the penetration of a trawl roller clump as 10 to 15 cm in muddy sand and 4 to 5 cm in clean sand. It should be noted that no literature in this review made mention of any veneer or vertical variation in sediment type and so it has been assumed that sediment veneers were not present and only the sediment described in each source was investigated.

Another factor that can impact fishing gear penetration is the frequency of fishing. Repeated fishing over the same area can potentially lead to cumulative deeper penetration. Fishing events can also lead to changes in benthic habitats and communities and repeated fishing may lead to more pronounced impacts and long-term changes (DeAlteris *et al*., 1999; Grabowski *et al*., 2014). Sediment recovery times from fishing activity can vary significantly, subject to local hydrodynamic conditions and deposition rates. Studies have shown that recovery can take several days in sandy coastal areas (Depestele *et al*., 2016), to several years in deeper soft sediments (Palanques *et al*., 2001; Gilkinson *et al*., 2015). Damage to sensitive benthic features may take over a decade to recover or remain permanent (Szostek *et al*., 2015 & Foden *et al*., 2010).

To fully understand the interaction between UK commercial fishing gear and OWF's, potential penetration depths of commercial fishing gear has been investigated with focus on gear type and sediment type. A summary table of penetration depths based on fishing gear and sediment type, along with sources and notes is provided in Appendix 1.

3.1.6. Seine nets

Seine nets are cone-shaped nets that can encircle and herd fish using seine ropes (He *et al.*, 2021). There are several types of seine nets including beach seines and seines used from a vessel including Danish (anchored) and Scottish seines (Seafish, 2022). Danish seines are set out from an anchor point using ropes and as the ropes are winched in from a vessel, the area between them diminishes and the seine gradually closes. Scottish seining is often considered as a hybrid between anchored seining and demersal otter trawling. As the vessel moves forward the seine ropes are winched. As beach seines do not interact with the offshore seabed environments, no review of data and literature for this seine type has been undertaken.

3.1.6.1. Boat seines

Boat seine gear penetration

There is no documented scientific literature regarding the penetration depth of boat seines, however it is assumed that Danish seines are less penetrative than other demersal gears such as bottom trawling due to the lighter weight of the ground gear and lack of trawl doors (Eigaard *et al*., 2016). As Scottish seining is considered a hybrid between demersal otter trawling and anchored seining, it is likely that the penetration depth is closer to that of otter trawling (Grieve *et al.,* 2014). In general, the benthic disturbance and impact of demersal seines is likely to be minor compared to other demersal fishing gear (Valdermarsen & Suuronen, 2003). Although no data has been published to confirm these assumptions, several studies have estimated the penetration depth using industry interviews and available literature. For example, Grieve *et al.* (2014) estimated an overall average of the entire seine gear of 0.11 cm. As these are estimates, the figures should not be heavily relied upon.

Boat seine component penetration

When in use, seine hauls can impact the seabed in two ways; from the seine ground gear and the seine rope. The largest impact from boat seines (Danish and Scottish seines) is from the seine ropes, as the seine ground gear only covers a small proportion of the total area fished (Eigaard *et al.,* 2016). Eigaard *et al.* (2016) estimated that seine ropes have a maximum surface penetration of 2 cm. The penetration depths of other component types have also been estimated by Grieve *et al.* (2014), reporting a penetration depth of 1.8 cm for the ground gear and 0.1 cm for the sweep.

3.1.7. Trawls

Trawls consist of a cone-shaped body of netting that is towed across the seabed or in the midwater (He *et al.*, 2021). As midwater trawls do not interact with the seafloor, they have not been considered in this literature review. Bottom trawling gears often consist of heavy-duty ropes, chains, discs, bobbins and / or weights that ensure that seabed contact is maintained during fishing while minimizing the risk of damage to the net. Otter boards (trawl doors), often used in single boat bottom trawls, can be used to keep the net in contact with the seabed. The horizontal opening of the net mouth can be maintained in several ways including the use of a rigid beam (beam trawls), otter boards (otter trawl) or two vessels towing the net, known as a pair trawl (He *et al.*, 2021). Otter trawls and beam trawls have similar penetration depths and are classed as two of the four most penetrative demersal gears (Eigaard *et al*. 2016). Factors such as towing speed, size, weight, sediment, environment and rigging can impact penetration depths. For example, the use of a roller clump can lead to penetration depths of 10 to 15 cm in muddy sand substrates, of which is reduced to 4 to 5 cm in rippled clean sand (Ivanovic´ *et al*., 2011). Tickler chains, used to cause fish to swim off the seabed and into the path of the net, and rock-hoppers may lead to the turning and displacement of large pebbles and boulders in areas with mixed sediments (Cruetzberg *et al*., 1987; Eigaard *et al*., 2016). In general, demersal trawls are thought to penetrate 5 to 30 cm of the substrate under usual fishing conditions, and potentially deeper in unusual conditions (Drew & Larsen 1994). The penetration depth of commercial fishery trawling used in the UK is discussed below, with reference to literature that discusses gear components as well as a description of overall gear penetration depth.

3.1.7.1. Beam trawls

Beam trawls differ to other demersal trawling due to use of a rigid beam across the net mouth (He *et al*., 2021). The main physical disruption of the seabed is through contact of the gear components with sediment, however beam trawl penetration does not increase considerably with size of gear (Depestele *et al*., 2016). Numerical modelling of the mechanical interaction between beam trawls and the seabed indicates that the seabed bathymetry changes between approximately 1 and 2 cm and that it is further increased by higher trawling frequencies (Depestele *et al*., 2016). These indications are, however, estimates based on modelling and not observed penetration depths, so should be interpreted carefully. Measurements recorded in literature indicate a deeper penetration.

Beam trawl gear penetration

Beam trawling is considered alongside dredging and otter trawling as one of the more penetrative demersal gears, displacing 70 times more sediment (m^3 per kg landed fish) than trammel nets (Polet *et al*., 2010; Depestele *et al.,* 2016; Eigaard *et al*., 2016). Observed penetration depths of beam trawls and components in the UK range from 0.7 to 20 cm (Houghtoon *et al.,* 1971; Grieve *et al.,* 2014). These depths largely depend on the nature of the seabed, as gears can generally penetrate deeper in fine, softer sediments (Linnane *et al.,* 2000). Beam trawling generally penetrates deeper in soft sediments, typically penetrating to a depth of around 6 cm in muddy and sandy bottoms (Lindeboom & de Groot, 1998; Paschen *et al.,* 1999; Polet *et al.,* 2010). The penetration depth of beam trawling is largest on very fine to fine muddy sand (Grieve *et al.,* 2014). There is mention of beam trawls penetrating sandy sediment to depths of 8 to 20 cm in several papers, inferred from observations of trawl tracks and the presence of benthic species which live at a known depth in the substratum (Houghtoon *et al.,* 1971; Margetts & Bridger, 1971). More recent studies suggest penetration is between 1 and 8 cm (BEON, 1990; Szostek *et al*., 2022), although this could be a factor of different sediment consolidation or compaction within sandy sediments. Investigations of beam trawling in muddy and soft sediments suggest penetration depths range from 0 to 10 cm (Bridger, 1972; de Groot, 1984; de Groot, 1995; Kaiser *et al.,* 1996; Szostek *et al.,* 2022). There is less research into the impacts of beam trawling on coarse sediment, however an average penetration depth of 4 cm has been estimated in subtidal gravel sediments (Szostek *et al.,* 2022). Regardless of sediment type, the maximum reported penetration depth of beam trawls in UK marine environments was between 10 and 20 cm (Houghton *et al.* 1971). However, these were experimental survey results inferred from the presence of benthic species which live at a known depth in the substratum.

Beam trawl component penetration

For a traditional beam trawl, the impact can be derived from the shoes of the beam, the ground gear and the tickler chain or chain mat of the trawl, if used (Eigaard *et al*., 2016). The use of tickler chains can lead to a penetration depth that is up to 10% deeper (Polet *et al.,* 2010). Tickler chains have been evidenced to penetrate the seabed to depths ranging between 0.2 and 10 cm in mud and sand sediments (Bergman *et al.,* 1990; Kaiser *et al.,* 1996; Paschen *et al*., 2000; Løkkeborg, 2005; Grieve *et al*., 2014; Depestele *et al.,* 2016). The penetration depth of tickler chains appears deeper in soft sediments (up to 10 cm) compared to a maximum penetration depth of 3 cm in firm ground and rough or mixed sediments (Bridger, 1972; Lindeboom and de Groot and, 1994; Kaiser *et al.,* 1996). Tickler chains penetrate deeper into the sediment than chain matrices, of which are used on rougher ground and penetrate to a maximum depth of 3 cm (Jennings, 2000; Grieve *et al.,* 2014).

Ground gear, of which includes ground ropes, sweeps and nets, has been evidenced to penetrate to depths between 0.1 and 8 cm in sandy environments (Kaiser *et al.,* 1996; Valdemarsen *et al.,* 2007; Greive *et al.,* 2014; Eigaard *et al.,* 2016; Oberle *et al.,* 2018). Beam trawl shoes, used at the bottom of beams, can penetrate the seabed to depths between 0.8 and 10 cm in all sediment types (Margetts and Bridger, 1971; Kaiser *et al.,* 1996; Depestele *et al.,* 2016; Eigaard *et al.,* 2016). The removal or modification of these gear components can reduce penetration depths (Szostek *et al*., 2022). The maximum penetration depth of beam trawl gear components recorded in UK commercial fishing is 10 cm.

Pulse trawl gear penetration

Pulse trawling is an adaptation of beam trawling, with the use of trailing electrodes instead of tickler chains or a chain mat. It is predominantly used by Dutch fishing fleets in UK waters. The pulse emitted from the electrodes stimulates fish to rise up into the path of the trawl, with minimum seabed disturbance (Seafish, 2022). Pulse trawls lack the heavy tickler chains associated with other demersal trawling therefore reducing seafloor penetration and fuel costs (Van Marlen *et al.,* 2014; Depestele *et al.,* 2016). Towing speed is often reduced for pulse trawling, further reducing seafloor penetration. The penetration depth of pulse trawls ranges from 0.8 to 2.5 cm (Grieve *et al.,* 2014). However, the average penetration depth has reduced over time to an average of 1 cm (Grieve *et al.,* 2014).

The impact of separate components of pulse trawls can vary. For example, the nose of pulse trawls can penetrate sediment to a depth of 6 cm (Grieve *et al.,* 2014). Other components are less damaging in nature with ground gear, shoes and electrodes penetrating to a depth of 0.35, 0.6 and 0.5 cm, respectively (Depestele *et al*., 2016). The addition of tickler chains can increase penetration depths to 2.2 cm (Grieve *et al.,* 2014). The maximum penetration depth associated with pulse trawling is 6 cm (Grieve *et al.,* 2014).

3.1.7.2. Otter trawls

Otter trawls also consist of bridles or sweeps used to expand the area of seabed swept by the gear (Seafish, 2022). These trawls can be towed by a single boat as singular, twin or multiple trawls or by several boats in the case of pair trawls (He *et al*., 2021). Otter trawls are one of the most penetrative bottom gears and generally penetrate deeper into the seabed than beam trawls (Eigaard *et al.,* 2016).

Otter trawl gear penetration

The use of otter trawls in benthic environments can create visible paths and furrows, even on substrates dominated by pebbles (Freese *et al.,* 1999). In coarse sediment, such as gravel, it is estimated that otter trawling can penetrate down to an average depth of 1.7 cm (Szostek *et al*., 2022). The penetration depth is slightly deeper in sand, with a maximum observed depth of 5 cm (Buhl-Mortensen *et al.,* 2013; Szostek *et al.,* 2022). Softer sediments, such as mud, can be penetrated down to 15 cm (Lindeboom and de Groot, 1998; Sciberras *et al.,* 2018; Szostek *et al*., 2022). For example, *Nephrops* otter trawling in the Irish Sea has been observed to penetrate to a depth of 14 cm in muddy sediments (Lindeboom & de Groot, 1998). Globally, otter trawl penetration can vary from a few centimetres up to 30 cm deep (Jones, 1992). This difference could be due to the presence of 'fine mud' in areas such as the Baltic Sea, which has a low density and shear strength, and is rare in the UK (Bohling, 2005). Twin otter trawling, two trawl nets towed by one boat, has been observed to penetrate to a depth of 0.9 cm (Grieve *et al.,* 2014). Otter trawls, unlike beam trawls, can be used in rough environments due to the use of rock hoppers, however penetration depth data for this sediment type is scarce (Linnane *et al.,* 2007). Regardless of sediment or otter trawl type, the maximum observed overall penetration depth of otter trawls in the UK marine environments was 15 cm.

Otter trawl component penetration

Trawl doors are designed to be towed through the water at an angle as this causes them to spread away from each other and open the net in a horizontal direction. In order to keep the gear on the seabed, the trawl doors must be heavy (Seafish, 2022). It is for this reason that trawl doors penetrate the seabed more than the sweeps and ground gear components of the trawl (Gilkinson *et al.,* 1998; Grieve *et al.,* 2014; Eigaard *et al*., 2016). In general, the penetration depth of trawl doors is deeper than that of that of all beam trawl components (Grieve *et al.,* 2014; Eigaard *et al.,* 2016). It is hypothesized by Grieve *et al.* (2014) that trawl doors penetrate deeper into sediments than scallop dredges, however results from this literature review suggest penetration depths are similar. In sandy sediments, the penetration depth of otter trawl doors ranges from 0cm to 10 cm (Ivanovic *et al*., 2011; Buhl-Mortensen *et al.,* 2013; Eigaard *et al.,* 2016). In softer sediments, such as mud, trawl doors can penetrate up to 15 cm (Kaiser *et al*., 1996; Eigaard *et al.,* 2016). The maximum estimated penetration depth of trawl doors in coarse and mixed sediments is 10 cm, however reported depths range reach up to 6 cm (O'Neill *et al.,* 2009; Eigaard *et al.,* 2016). A maximum depth of 35 cm has been reported, based on industry surveys, literature and subsequent calculations (Eigaard *et al.,* 2016).

Otter trawl sweeps have the least impact on the seabed, with a penetration depth of just a few centimetres (Buhl-Mortensen *et al.,* 2013). The maximum penetration depth of otter trawl sweeps and bridles is 2 cm in sand and 5cm in mud (Buhl-Mortensen *et al*., 2013; Eigaard *et al.,* 2016). The maximum penetration depth of otter trawl tickler chains is 5 cm in sand, coarse and mixed sediment (Bridger *et al.,* 1970; Kaiser *et al.,* 1996; Eigaard *et al.,* 2016). There is no data regarding the penetration depth of tickler chains in muddy sediments. Ground gear, including bobbins and ropes, penetrates the sediment to a maximum depth of 2 cm in sand, 8 cm in mixed sediments and 10 cm in mud (Kaiser *et al.,* 1996; Buhl-Mortensen *et al*., 2013; Eigaard *et al.,* 2016). Roller clump weights, often used for twin trawling, are more penetrative than some other ground gear components, penetrating up to 15 cm in sand and mud (O'Neill *et al.,* 2009; Ivanovic *et al*., 2011; Eigaard *et al.,* 2016). The maximum penetration depths of otter trawl components ranges between 15 and 35 cm (Kaiser *et al*., 1996; Eigaard *et al.,* 2016).

3.1.8. Dredges

Dredges are cage-like structures with a robust metal frame that are often equipped with teeth or scraper blades and are pulled or towed in order to dig biota out of substrate and into the cage (He *et al*., 2021). Dredges target biota living at the surface of the substrate or fauna found within it (Grieve *et al*., 2014). Dredging gear generally penetrates to a similar depth or deeper than other demersal gear such as beam trawls and otter trawls, depending on the sediment type (Eigaard *et al*., 2016; Hill & Tyler-Walters, 2016; Sciberras *et al.,* 2018 andEigaard *et al*., 2016). Dredges operate from boats and include two main types; towed dredges and mechanized / hydraulic dredges (He *et al.,* 2021).

3.1.8.1. Towed dredges

Towed dredges are towed steadily behind a boat across the seabed and can include a series of small dredges attached to a single towing bar (He *et al.,* 2021). The penetration depth of dredges is dependent on target species and sediment type (Grieve *et al.,* 2014). Typical target species include scallops and oysters, and the dredge teeth are adapted to suit the target species and sediment type (Grieve *et al.* 2014). Towed trawls, of which the target species were not provided, have been evidenced to penetrate to 7 cm in gravel, 3 cm in sand, 5 cm in mud (Sciberras *et al.,* 2018; Szostek *et al*., 2022).

Scallop dredges have been observed to penetrate the seabed to depths between 2 and 10 cm (Chapman *et al*., 1977; Grieve *et al.,* 2014; Stewart & Howarth, 2016). Penetration in sandy habitats can be deeper, reaching 15 cm in some cases (Bullimore, 1985; Eleftheriou & Robertson, 1992; O'Neill *et al*., 2009; O'Neill *et al*., 2013; Eigaard *et al.,* 2016). Scallop dredger penetration depths have also been studied in maerl beds where dredging was found to penetrate down to 10 cm (Hall-Spencer, 1995). Attachments and fastenings have also been observed to penetrate to 10 cm in rough ground however (Kaiser *et al.,* 1996). Literature studying scallop dredging is generally focused on the gear as a whole and information regarding gear components is lacking. Oyster dredging has also been studied; however, literature and data is sparse. In gravel, oyster dredging has penetrated to depths of 15 to 20 cm (Southern Science, 1992). The maximum documented penetration depth of towed dredges is 20 cm.

3.1.8.2. Mechanized dredges

Mechanized, or hydraulic, dredges use extensive accessory gears such as hoses and pumps and are towed or winched. The gear consists of a large metal cage equipped with a cutting blade. A high-pressure hydraulic jet pump is used to fluidize the substrate and wash out biota from the sediment into the cage (He *et al.,* 2021). Mechanized dredging is one of the more penetrative gears (Sciberras *et al.,* 2018; MMO, 2022). In mud and soft sediments, mechanized dredges can penetrate to between 16 and 21 cm (Sciberras *et al*., 2018; Szostek *et al*., 2022). Modelled penetration depths for coarse sediment and sand are 29 and 11 cm respectively, however these values may not be as reliable as observed penetration depths (Szostek *et al*., 2022). Another type of mechanized dredging, water jet dredging, has been documented to penetrate up to 15 cm into sandy sediments (Fisheries Research Services, 1998; Tuck *et al*., 2000). From the discussed literature, the maximum estimated penetration depth of mechanized dredging is 29 cm into sandy sediment.

3.1.9. Gillnets

Gillnets consist of long rectangular walls of netting that catch fish through gilling, wedging, snagging, entangling or entrapping methods. These nets can be used on seabed and are often anchored. Set gill nets are fixed to the seabed and used to catch any fish that come into contact. Trammel nets, also anchored, consists of three layers of netting including two outer layers of larger mesh netting and one inner layer of small mesh netting (He *et al.,* 2021). In general, gillnet seabed impacts are very localised with little abrasion (Montgomerie, 2022). The anchors and weights fixed at the ends of the nets can dig into the sediment or be dragged through the seabed when the gear is hauled. The surface impact, however, is considered to be small (d'Avack *et al.,* 2014; Grieve *et al*., 2014). No data or literature investigating the penetration depths of gillnets and associated gear components in the UK are currently available. There is little evidence on the penetration of the anchors and lead lines of gillnets, however they are estimated to have a negligible penetration depth, of up to 0.2 cm, based on expert judgement (Grieve *et al*., 2014). The impact of gillnets on the seabed is considered to be far less than other demersal gear and penetration of the seabed is considered negligible. For example, beam trawling displaces 70 times more sediment per kg of landed fish than trammel nets (Polet *et al.,* 2010).

3.1.10. Traps and pots

Traps / pots are stationary structures into which fish are guided, pushed by current or drawn into. Bait or other attractants are often used and the shape and size of traps can vary. Traps are usually anchored or fixed to the seabed and intercept and trap crustaceans, fish and cephalopods during daily movement or migration. The entrance of traps allows the entry of mobile fauna whilst preventing or delaying their escape (He *et al.,* 2021). The use of anchors enables the traps to be fixed to the seafloor. These anchors can dig into the sediment and potentially drag through the seabed during retrieval or when subject to strong tides, currents or storm activity (Hall *et al*., 2008; Stephenson 2016) although the surface area affected is relatively small (Grieve *et al*., 2014).

Traps are generally less impactful to the seabed than other mobile gear (Macdonald *et al.,* 1996; Hall *et al*., 2008; Grieve *et al*., 2014). For this reason, traps are considered to be a relatively sustainable fishing method with minimal seabed impact (Kinnear *et al.,* 1996; Eno *et al.,* 2001; Coleman *et al*., 2013). For example, analysis of fishing activity data in the UK found that most habitats were highly sensitive to fishing gears such as trawling and dredging, but only three were sensitive to potting (Eno *et al.,* 2013). Literature and data assessing the penetration depth of traps and pots is minimal. One study, undertaken in the Celtic Sea, observed penetration depths of light and heavy traps between 0.02 and 1 cm (Kopp *et al*., 2020).

3.2. Data collection and comparison

3.2.1. Methodology

In order to provide verification to the measurements recorded in literature, trawl depth measurements were analysed from existing geophysical datasets in the North Sea (Southern and Central) and Irish sea, between water depths of 25 and 75 m below MSL (mean sea level), providing fishing gear penetration values for the typical sediment types and water depths of ORE projects. These datasets were derived from previously undertaken surveys and not from surveys undertaken as part of this project. Measurements relating to all mobile fishing gear (trawls and dredges) scars were analysed to provide maximum penetration depths. These tabulated data are presented in Appendix 2.[3]

In total, 22 areas of visible seabed fishing gear penetration were observed in four different sediment types. Mobile fishing gear scar widths and depths were measured from high-resolution multibeam echosounder (MBES) data (0.5 m resolution). Fishing activity attributed to static gear were not observed with only bottom trawling scars evident, in the datasets analysed.

In order to distinguish mobile fishing gear scars from other seabed scars, for example, anchor scars, the parallel distance between trawl marks was recorded and screenshots of each trawl mark taken. These were then verified by a commercial fishing expert, using Seafish guidance (2020) and regional knowledge of fishing practices to determine the fishing method used. Sediment types were obtained using EMODnet broadscale habitat distribution data overlain onto MBES data in a Geographical Information System (GIS). These sediment types were verified by a geophysicist using sidescan sonar (SSS) data, where applicable.

3.2.2. Limitations

A key constraint to these data is the unknown age of the seabed scars relative to the date of seabed survey. With differing deposition, sediment composition and sediment re-working rates the measurements recorded are expected to generally underestimate the scar depth, compared with that of very recent fishing activity. To distinguish older mobile fishing gear scars from more recent records, where areas of sediment infill or reworking were evident, these were noted for each entry. Sediment infill or reworking was identified as less defined furrows caused by trawl doors/shoes penetration.

Another key constraint is the limited number of fishing activity scars and measurements taken. A total of 22 measurements were taken which may not be considered representative of the whole of the UK sediment types and fishing methods. Fishing gear penetration depths vary depending on factors such as configuration, gear components, target species, tide / currents, weight of catch and power of the vessel in use. The number of measurements collected may not account fully for this variability and

[3] In addition to the data collected, one developer shared data illustrating trawl scars over cables found through survey work at two operational wind farms, but it could not be incorporated in the calculations due to limited detail in the data.

maximum penetration depths. A larger dataset would provide more comprehensive results; however, available data were reviewed to provide validation to literature and data availability was limited.

In addition, the measurement of fishing activity scars does not necessarily account for repeated fishing in one area. If an area with pre-existing trawl scars is fished, the fishing gear may penetrate deeper due to the accumulation of multiple trawling events. Recovery can take several years depending on habitat and substrate type and therefore may not be possible in areas of sustained fishing (Foden *et al.*, 2010).

3.2.3. Results

Of the 22 measurements of fishing activity scars recorded around the UK, 10 were identified in 'sand', six in 'sandy mud', five in 'mixed sediment' and one in 'gravel'. Figure 13 shows a comparison of data collected as part of the literature review (Appendix 1) alongside the data observed as part of this study (Appendix 2). To align dataset sediment types, 'gravel' observed in this study was compared with 'coarse sediment' from literature, and 'sandy mud' observed in this study was compared with 'mud' from literature. Also, measurements made in 'gravelly muddy sands' and 'gravelly sands' were compared with 'mixed sediments' from literature review data. Sediments labelled as 'rough' in literature were omitted as no comparative sediment type was identified in the observed dataset, further these values did not exceed those in the sediment unknown category, included in the analysis.

The data shows a higher degree of variance within the literature dataset collated, which, with the exception of mixed sediment, recorded higher maximum values than the values derived by this study. The average measurements recorded for each respective sediment type showed a general good degree of correlation between datasets, where comparable. The largest variance observed between datasets was for the 'gravel/coarse sediment', however only one datapoint for this sediment type was recorded in the data analysed, therefore only low reliance can be placed on this comparison. Further, in the literature derived data, results for 'gravel/coarse sediment' were somewhat skewed by two outlying fishing gears of Mechanized and Oyster Dredges which recoded depths of 29.4 and 17.5 cm, respectively, and although still relevant in UK waters, these gear types are considered rare.

The deepest fishing gear penetration was observed in mud sediments in both the literature and measurements recorded in this study, although maximum depth observed in literature was more than twice that of this study (30 cm), the average mobile fishing gear scar depths for 'sandy mud/mud' were both similar at 7.5 cm for this study, and 10 cm for literature.

Sand showed the least amount of variance with a mean average of 5.6 cm in the literature and 5.1 cm for this study, with 5.5 cm difference in the maximum recoded values. Similarly, mixed sediment shows an overall similar pattern with a mean average of 3.4 cm in this study and 5.7 cm in literature, and 12.1 and 10cm maximum depths, respectively.

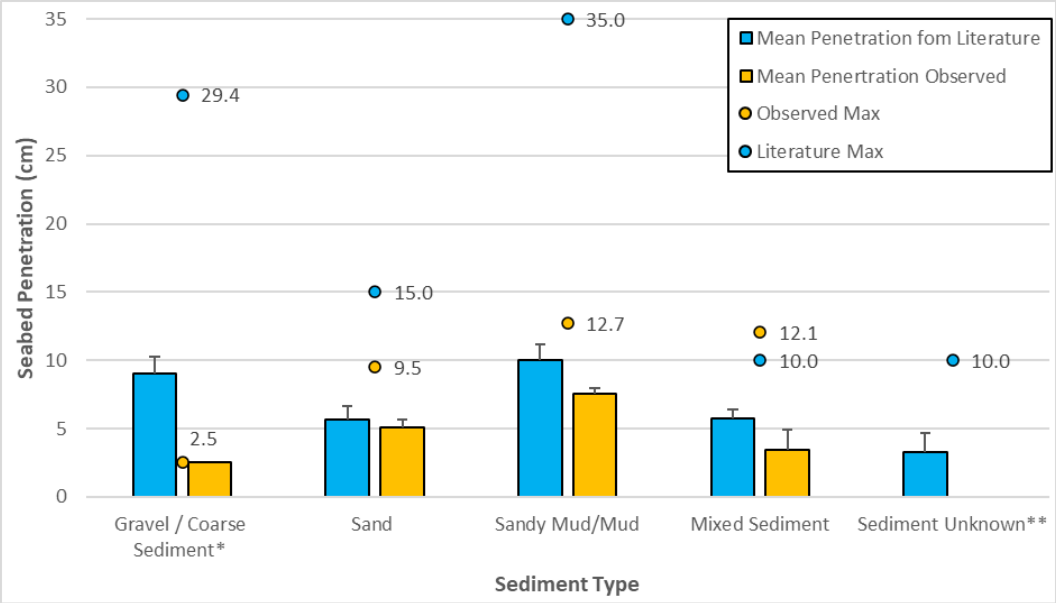


Figure 13: Mobile fishing gear scar comparison between literature review (Europe) and observed measurements (UK only).

Note: * Only one data point was recorded in 'observed' data set. ** No 'sediment unknown' data points were recorded in 'observed' data set.

In order to remove broadscale geographical bias, Figure 14 only presents a comparison between the UK data from both the literature review and observed data. This comparison did not present any comparable data for 'mixed' and 'unknown sediment', with comparisons between 'gravel/coarse sediment' and 'sand' the same as above. However, the variance for 'sandy mud/mud' sediments was reduced, showing very similar mean averages at 7.7 cm for literature records and 7.5 cm in the observed study dataset.

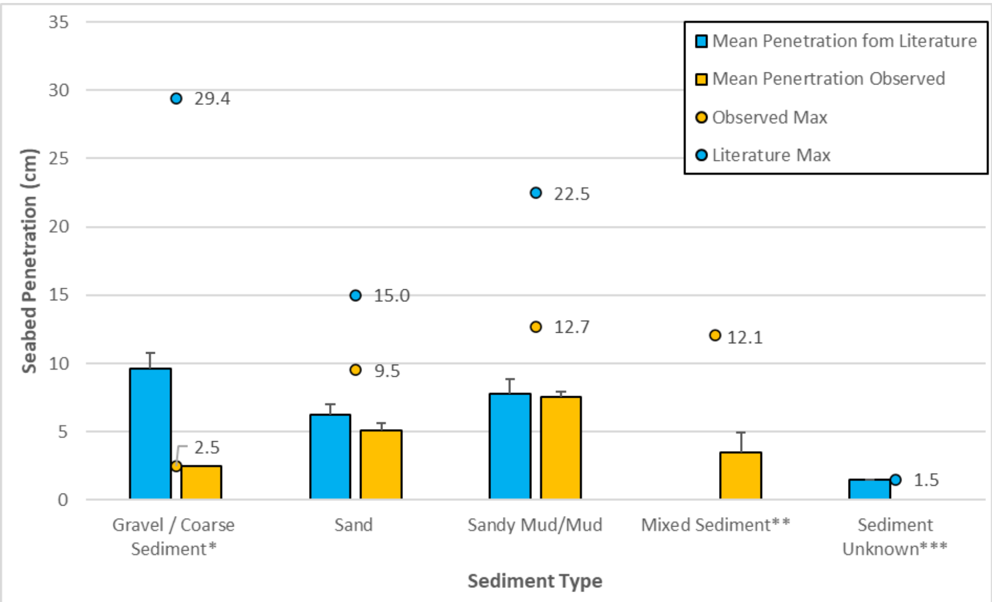


Figure 14: Mobile fishing gear scar comparison between literature review (UK only) and observed measurements.

Note: * Only one data point was recorded in 'observed' data set. ** No 'mixed sediment' data points were recorded in 'literature' data set. *** Only one data point was recorded in 'Literature' data set.

3.2.3.1. Statistical analysis

In order to quantify the similarity between the measurements recorded in literature with those observed in this study, a Welch T-test (for uneven sample sizes) was undertaken. Data used for comparisons can be found in Appendix 1and Appendix 2. Results are presented in Table 7.

Table 7: Sediment correlation between literature and observed mobile fishing gear scar measurements.

Welch's T-test					
Sediment type	***T* Value**	***P* Value**	**Degrees of freedom**	**Effect size***	**Effect**
Coarse Sediment / Gravel	n/a	n/a	n/a	n/a	n/a
Sand	0.465	0.6477	17.5	0.125	Small
Sandy Mud / Mud	1.108	0.2811	19.8	0.315	Small
Mixed Sediment	0.8659	0.417	6.5	0.548	Medium
Sandy Mud / Mud (UK only)	0.08087	0.9367	13.6	0.032	Small

Note: * 0 = no effect, 1 = completely dissimilar. Red values show not significant *P* value >0.05.

Due to only one 'coarse sediment/gravel' record in this study, the test could not be performed for this sediment type. The results of all remaining sediment types did not calculate any significant probability (p) values, due to the limited sample size. The largest 'effect size'/variation observed between the mixed sediment type datasets and highest similarity observed between the mud and sandy mud measurements of the UK sector only data values, although these correlations were not significant and therefore lack robustness to draw conclusions from.

3.3. Cable protection measures

Submarine cable protection systems must be able to demonstrate a clear financial return over their operating life and have a technological advantage for as long as possible. To achieve this, the route must be engineered with the optimum method and level of protection (Allan, 1998). For offshore renewable energy projects, developers are assigned grid connection locations by authorities (this differs from offshore-hybrid assets such as interconnectors, which follow a different approach); they must then route cables to these points while considering various constraints and risks. Fishing gears, anchoring and sediment mobility risks at cable crossings, leads to a requirement for protection, and ensuring that protection measures are proportionate to the assessed risk and aligned with industry best practices.

Seabed mobility can threaten buried subsea cables, causing cable exposure. Once a deep trough from a migrating bedform moves into the area where a buried cable is present, it decreases the sediment cover, potentially exposing the cable and causing local scouring. Anchors are particularly damaging to cable protection measures and subsequently cables, as they are designed to penetrate the seabed more aggressively than fishing gear (Allan, 1998). Commercial fishing gears can also be a hazard to cables where fishing gear interacts with the seafloor.

The most reliable form of protection, for both asset owner and the fishing industry, is generally considered to be cable burial, where this is assessed to be a viable option. Fishing threats are considered to be reduced by burial; however, several cables are damaged by anchors / fishing gear every year (Carbon Trust, 2015), and industry associations strongly advise not to fish over subsea cables, buried or unburied (ESCA, 2022 and MCA, 2021). Where cable burial is not feasible, e.g. at cable crossings or over hard ground, external cable protection measures should be carefully considered. The growth in use of cable protection measures is thought to have reduced cable damage incidents form external threats.

A baseline overview of market available cable protection measures in the UK has been undertaken. Factors, such as cost, environmental impact, supply, and installation feasibility, also play a significant role in the selection of cable protection measures. However, this 'high level' overview is focused on cable protection with relevance to the risks to mobile fishing gear.

3.3.1. Cable protection options

3.3.1.1. Rock berm

Rock placement provides a physical barrier around cables, as well as stability, in the form of a continuous berm of graded rock. The geometry of berms and grading of the rocks in design, ensure sufficient cable coverage and can reduce potential for snagging from mobile fishing gears (Deltares, 2023). However, rock berms can themselves cause damage to trawl nets and rock berm damage, thought to be caused by trawling activities, has been observed, which can lead to cable exposure. Rock berms are designed to suit requirements on a case by case basis, however typically have a trapezoidal shape with a height of around 1.5 m and width of around 6 to 8 m at the seabed. Rock berms can become worn over time leading to cable exposure and an increased risk of snagging. An example of rock berm cable protection installation is shown in Figure 15.

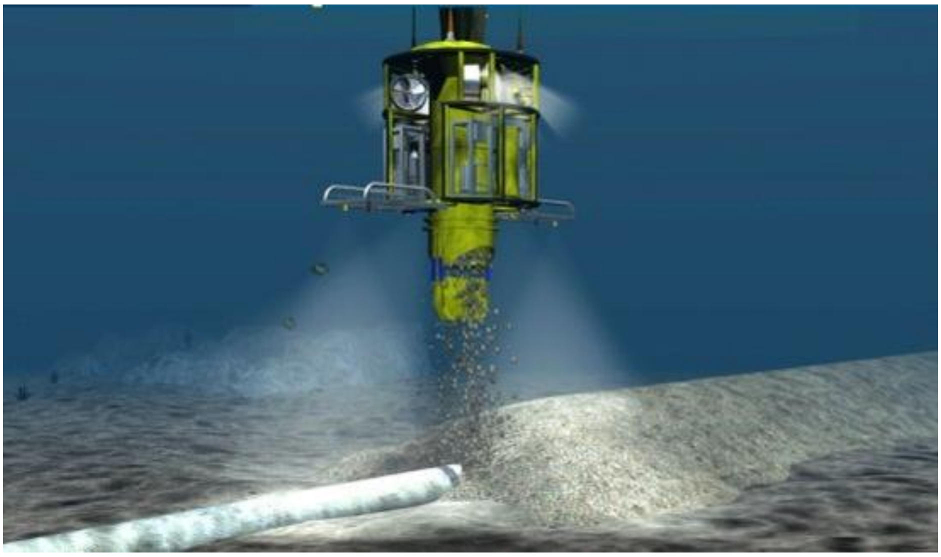


Figure 15: Example rock berm (Nordnes, 2017).

3.3.1.2. Mattresses

Anti-abrasion mattresses are commonly used for protecting infrastructure offshore, and can be manufactured from products including concrete, bitumen, and Marine Crete® (ARC Marine, 2024), however for cable protection the concrete option is the most commonly used material. Concrete mattresses are composed of interlinked sections of concrete that form a protective layer over subsea cables. This cable protection can be designed to reduce snagging, through tapering of edges and by offset layering the mattresses, however evidence supporting claims of reduced snagging, is scarce. The risk of snagging is also dependent on the angle of the approach of fishing gear, as corners of the mattresses can remain a snagging threat. Concrete mattresses can also be developed to have Nature Inclusive Design, promoting biodiversity (ARC Marine, 2024).

Concrete mattresses are not considered to be a good engineering solution for a cable protection as they do not offer the same protection as rock berms. However they may be more feasible for some projects due to their shorter cross-section profile.

Reports associated with OWF developments in the North Sea suggested that mattresses present a significant snagging hazard (Jee, 2015). In addition, a response to a planning proposal for a North Sea OWF stated that rock dumping and concrete mattresses are likely to present a significant marine hazard for trawlers under 10 m in length as fishing nets can be easily caught (HPS, 2014). It is therefore considered that the use of concrete mattresses does not eliminate the snagging threat (Nova Innovation, 2015). An example of concrete mattress cable protection is shown in Figure 16.

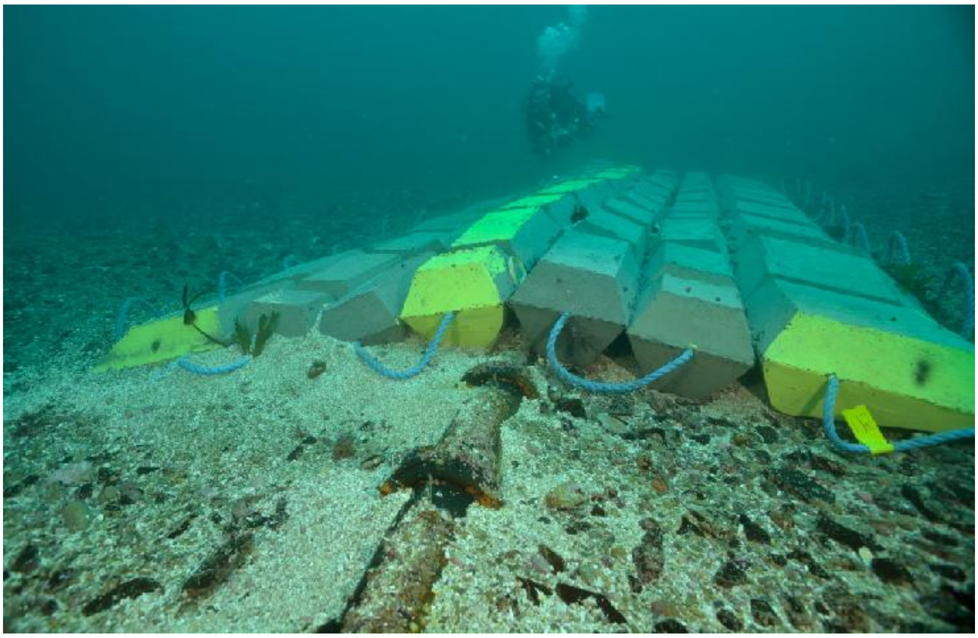


Figure 16: Example of a concrete mattress (Taormina, 2018).

3.3.1.3. Fronded mats

Fronded mats can be used alongside other cable protection methods such as rock berms and concrete mattresses. Polypropylene frond mats resemble seaweed beds and can be laid in order to slow down the local current, causing suspended particulate matter to settle. Further sediments accumulate over time, producing a sand or sediment bank that reinstates the seabed and resists further erosion (Langhamer, 2012). The weighted accumulation of sediments may increase the stability of concrete mats, if used alongside, potentially reducing the risk of snagging and may increase the level of protection. However, this type of cable protection can still be snagged by commercial fishing gear, leading to damage. Further, fronded matts require a suitable period of net sedimentation to provide a maximum level of protection. A study in the Southern North Sea showed significant sedimentation and formation of a sediment back after just 37 days of installation (SSCS, 2015). An example of fronded mats cable protection is shown in Figure 17.

Figure 17: Example fronded mat (Offshore Technology, 2025).

3.3.1.4. Cable protection systems

Cable protection systems (CPS) or articulated pipe are anti-abrasion bend restrictors, often manufactured from Cast Iron or Polyurethane and can be used to protect subsea cables. This solution is generally used in shallow water and not used by itself or where trawling activities are undertaken. These options can be used alongside other cable protection methods such as rock bags, grout bags and post-lay rock placement. CPS, combined with anchoring ballast (e.g. rock bags), can pose a snagging risk and lead to damage of commercial trawling gears unless avoided, as this protection measure is not designed to protect cables against trawling gears (Scottish Power Renewables, 2019). An example CPS is shown in Figure 18.

Figure 18: Example of cable protection system (CRP Subsea, 2025).

3.3.1.5. Rigid concrete cable protection

This protection measure is more commonly used for pipeline protection; however, this can be custom designed to suit cable protection and geographical requirements. This includes dropped object and trawl board protection. Custom designs can include the addition of fronded mats for sediment retention as well as tapered edges and specific layering which may reduce risks to/ from mobile fishing gear. In addition, sand may be re-instated over time, offering more cable protection. If not designed correctly, or if rigid concrete protection blocks become dislodged, this can lead to snagging and the damage of commercial fishing gear. As these remain rigid with no flexibility, such as those of concrete mattresses, where a snagging incident does occur this is more likely to result in the protection system becoming flipped or the nets to 'come fast', therefore resulting in an increased severity of incident / damage. An example of rigid concrete protection is shown in Figure 19.

Figure 19: Example of reinforced concrete subsea protection systems (Subsea Protection Systems, 2025).

3.4. Limitations and knowledge gaps

3.4.1. Literature review

The analysis of literature and data has provided information for all relevant commercial fishing gears in the UK that are known to interact with, and potentially penetrate, the seabed. It should be noted that literature for some fishing gears and sediment types was minimal or scarce and only commercial fishing gears used in the UK continental shelf was considered.

There is no documented scientific literature regarding the penetration depth of boat seines. However, this is considered less penetrative than other demersal gears, such as trawling, due to the lighter weight of the boat seine ground gear and lack of trawl doors (Eigaard *et al*., 2016).

Unlike beam trawls, otter trawls can be used in rough sediments due to the use of rock hoppers (Linnane *et al*., 2007). However, penetration depth data for otter trawling in rough grounds is scarce. Penetration of this gear type is generally deepest in fine and soft sediments (Lindeboom and de Groot, 1998; Grieve *et al.,* 2014; Eigaard *et al*., 2016; Sciberras *et al.,* 2018; Szostek *et al.,* 2022).

Therefore, the penetration depth of otter trawls in rough ground is unlikely to exceed the penetration depths observed in soft sediments.

Literature studying scallop dredging is generally focused on the gear as a whole rather than individual components. There is, however, sufficient information regarding the penetration depth of the gear as a whole. Conversely, literature and data regarding the penetration depth of oyster dredging is sparser. Penetration depths between 15 and 20 cm have been observed in gravel (Southern Science, 1992), with penetration in softer sediments unknown. This is likely due to fishers targeting firm seabed which oysters inhabit (Perry, *et al*., 2023). It can be assumed that oyster dredging may have similar penetration depths as scallop dredging, in these sediments, however more information may be required to confirm this scenario.

No data or literature investigating the penetration depths of gillnets and associated gear components in the UK are currently available. The impact and penetration depth, however, is considered to be negligible and far less than other demersal gear (Grieve *et al*., 2014). For example, beam trawling displaces 70 times more sediment per kg of landed fish than trammel nets (Polet *et al*., 2010). Therefore, further investigation is not recommended.

Literature and data assessing the penetration depth of traps and pots is minimal, however one study observed penetration depths of traps between 0.02 and 1 cm (Kopp *et al*., 2020). Traps are generally less impactful to the seabed than other mobile gear and associated anchors are considered more likely to penetrate the sediment (Macdonald *et al.,* 1996; Hall *et al*., 2008; Grieve *et al*., 2014). These could however present a snagging risk from cable protection measures, which could be investigated further.

The description of sediment type or class within literature can vary with no standard sediment classification used. General categories such as sand, mud, coarse sediment and mixed sediment are used throughout literature however further descriptive terms such as 'muddy sand' or 'soft sediment' are used in some literature and not others. This makes comparison difficult and terminology inconsistent. Furthermore, very few studies describe the sediment strength or consolidation which could impact the penetration depth of commercial fishing gear. For instance, sediment parameters such as water content density and shear strength can vary significantly within the same sediment class, e.g., 'mud', and these will all impact the penetration of fishing gear and can therefore induce variability in results, if not accounted for. It is therefore recommended that future investigations and studies record sediment qualities and use a common reference of seabed criteria, for instance British Geological Survey (BGS) modified Folk triangle (Folk, 1954).

Where the classification of sediment type is used in literature, it is not clear to what vertical depth this sediment type is recorded. Surface sediments can often differ to those deeper down, and it is not uncommon for a surface veneer of sediment in the top 10 to 15 cm (infauna zone) to differ from sediments below (NIVA, 2006). It is therefore recommended that future studies assess seabed penetration based on a sediment profile which may differ in sediment composition. These data can be provided through core sampling or sediment profile imaging.

3.4.2. Observed data measurements

The fishing gear penetration measurements, derived from MBES data as part of this study, were limited by not having the key information as to when the fishing activity took place. This therefore ensures that measurements undertaken are a likely underestimation of the true penetration depth, due to factors such as sediment infill. A more robust dataset for maximum fishing gear depth penetration can be achieved by undertaking demersal trawling in a variety of sediments and recording penetration measurements soon after. Or in some cases the use of AIS data could be cross referenced with a geophysical dataset to provide an indication of when this area was fished, this would be most applicable in areas of low fishing activity where seabed scars and fishing activity can be more easily linked.

Data availability for undertaking depth measurements was also limited, as data of a sufficient quality was required to determine accurate measurements, and data covering different regions, sediment types and fishing methods were also required to provide a representative data sample. Therefore, the 22 measurements may not be considered comprehensive and may not fully account for variability of fishing gear penetration. A larger dataset could potentially provide more statistically robust results. Furthermore, the measurement of fishing activity scars does not specifically account for repeated fishing in one area. If an area with pre-existing trawl scars is fished, subsequent fishing activity may penetrate deeper due to the accumulation of multiple trawling events.

Seabed depth measurements collected using MBES data, as part of this study, were originally collected for the purpose of ground investigation. These data are potentially limited in resolution as opposed to infield measurements. Alternative data collection techniques such as synthetic aperture sonar have proven to provide far greater resolution of mobile fishing gear scars. However, no available datasets could be used as part of this study, as this emerging technology is not a standard requirement for site surveys.

3.4.3. Cable protection measures

There are very limited publicly available sources of over-trawl studies on cable protection measures to establish accurate results of damage to equipment by either party. Also, different circumstances may lead to different outcomes, for example, continued trawling over assets may dislodge cable protection measures, leading to a temporal increased risk to fishing.

Further collaboration of operators in presenting their results of over-trawl studies, including unexpected instances of damage, will further support conclusions. Alternatively undertaking commissioned over-trawl studies over out of service assets could provide useful data. In addition, future investment into the design and manufacture of cable protection measures, with regards to reducing risk to fishing activities while maintaining asset protection, could be considered. However, this is unlikely to change present guidance which strongly advises against fishing where there are subsea cables.

Future investigations could consider the relationship between fishing gear penetration depths for different gear types and the risks to the cable protection measures reviewed, to provide a comprehensive assessment of threats to submarine cables from different fishing gears.

4. Survey and trial evaluation

4.1. Surveys

This section focuses on a review of marine survey methods which are used to survey subsea cables associated with Offshore Renewable Energy (ORE) developments. These data are used to feed into the assessment of risk to a subsea cable from threats such as fishing activity.

Surveys play a vital role in the pre-construction, construction, monitoring and decommissioning of offshore renewable projects. Surveys can provide information regarding the composition of the seabed and sub-seabed, seabed obstructions and hazards, and areas of environmental sensitivity. Surveys can also provide measurements of the location, extents, and depth of penetration from fishing in differing types of seabed. On a temporal basis, survey data can also help to understand seabed dynamics and cable burial over time.

One of the biggest risks to a buried subsea cable, and subsequently to fishing gear, is cable exposure and loss of supporting material from underneath the cable, known as a free-span. A free-span can present a significant hazard to mobile demersal fishing gear as well as anchors (Figure 20) and can cause damage to the cable as well as damage or loss of fishing gear.

Free-span occurrence is most common in areas of high sediment mobility. At the pre-installation stage, the use of survey data and modelling can be used to help identify areas of high seabed mobility and identify options to reduce the risk, such as identifying alternative cable siting, increased burial depths, where possible, and/or to highlight areas or particular risk for future monitoring.

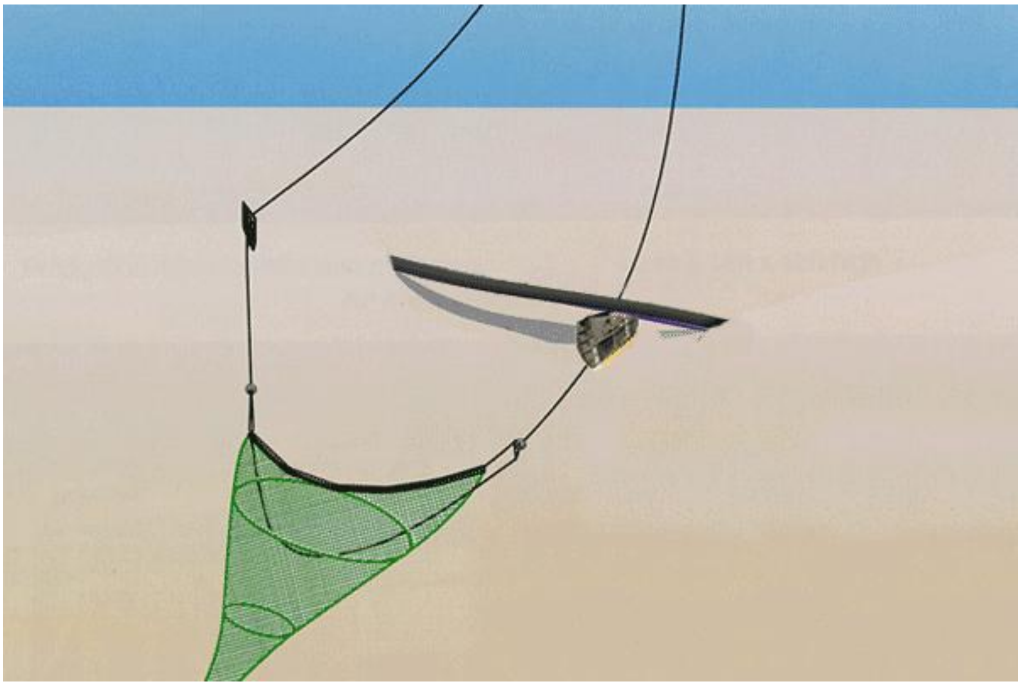


Figure 20: Subsea cable free-span with trawl door entangled (KIS-ORCA, 2024).

4.1.1. Advice from regulators and industry

The scope of pre-construction/installation surveys is established in accordance with engineering requirements and with environmental surveys designed to fulfil the regulatory requirements of a site, based on the expected receptor sensitivities.

For environmental surveys undertaken in relation to ORE and other marine developments, Statutory Nature Conservation Bodies (SNCBs) provide some guidance, as listed below, for the UK;

- Joint Nature Conservation Committee (JNCC; 2018) Monitoring guidance for marine benthic habitats;
- Natural Resources Wales (NRW; 2022) Benthic habitat assessment guidance for marine developments and activities. Guidance Note: GN030;
- NatureScot (2011) Guidance on survey and monitoring in relation to marine renewables deployments in Scotland; and
- Centre for Environment, Fisheries and Aquaculture Science (2012) Guidelines for data acquisition to support marine environmental assessments of ORE projects.

These documents act as useful guides for determining the appropriate environmental survey design and data analysis techniques to support Environmental Impact Assessment and future monitoring surveys. It is recommended to consult with relevant SNCBs on survey design prior to survey, to comment on the application of their guidance.

In the UK, guidance for geotechnical and geophysical surveys at a regulatory level is scarce, with engineering and environmental requirements a key consideration for survey design. In 2022, the Society of Underwater Technology (SUT) published "Guidance Notes for the Planning and Execution of Geophysical and Geotechnical Ground Investigations for ORE Developments" (SUT, 2022), a revision to the 2014 Guidance Notes to account for the growth of ORE projects. These provide guidance on different geophysical and geotechnical investigation considerations for current and future ORE development. Similar guidance notes for environmental surveys are being prepared by SUT members. Other geophysical and geotechnical guidance documents aimed at ORE projects include:

- Bureau of Ocean Energy Management (updated in 2020) Guidelines for providing geophysical, geotechnical, and geohazard information pursuant to 30 CFR Part 585;
- Carbon Trust (2020) Guidance for the geophysical surveying for Unexploded Ordnance (UXO) and boulders supporting cable installation;
- Gribble, J. and Leather, S. (2007) Offshore geotechnical investigations and historic environment analysis: Guidance for the renewable energy sector. Commissioned by COWRIE Ltd; and
- International Cable Protection Committee/Society for Underwater Technology (2002) Recommendation – Minimum technical requirements for the acquisition and reporting of submarine cable route surveys.

4.1.2. Survey equipment overview

4.1.2.1. Multibeam echosounder

Multibeam Echosounder (MBES) is a type of sonar that is used to map the seabed. It emits acoustic waves in a fan shape beneath its transceiver. Multibeam systems are usually hull mounted to a vessel, to achieve good swath width, however, they can also be mounted to a Remotely Operated Vehicle (ROV) or Autonomous Underwater Vehicle (AUV) which acquires higher resolution data at a lower altitude relative to the seabed, while reducing the swath width. The data are used for bathymetric mapping and providing information on seabed features.

Backscatter can also be computed from MBES data and provides information on the relative hardness of the seabed. This can be used to distinguish between different sediment types and hard substrates such as subsea infrastructure.

MBES can be an effective tool used to help distinguish areas of cable free-span.

4.1.2.2. Light detection and ranging

Light Detection and Ranging (LiDAR) is a remote sensing system which uses laser scanning to accurately measure topography. It is often used as an airborne source, commonly on drones in recent years, and is used at landfall locations and in shallow (non-turbid) water depths. The 3D images produced can be used to determine suitable cable landfall locations and for post installation surveys, can be used to monitor coastal erosion and potential cable exposure.

Due to its limitations in relation to water depth and clarity, it has only limited use in cable monitoring with regards to vessel deployed fishing gear, but could be important in shallow areas where intertidal shellfish fisheries are present.

4.1.2.3. Side-scan sonar

Often used alongside MBES and SBP equipment, SSS systems emit a fan-shaped beam of sonar pulses directed at the seafloor, of which the acoustic reflections are detected. SSS systems are usually towed behind the vessel at an altitude of around 10 to 15 m. This altitude provides good swath coverage (up to 400 m). The data can be used to determine seabed objects and sediment types, including areas of scour and cable exposure.

4.1.2.4. Synthetic aperture sonar

Synthetic Aperture Sonar (SAS) is a relatively new technology. Data acquisition is similar to SSS, however, these systems acquire ultra-high resolution across the swath range (up to 400 m), along with simultaneous bathymetry. Resolutions are around ten times higher than traditional SSS. The higher resolutions are achieved by transmitting continuous overlapping sonar pulses and combining returned pulses, therefore receiving multiple measurements of a single location at once (NOAA, 2024).

While SAS is not applied as standard in geophysical surveys, the level of detail which they acquire provides key information where mobile fishing activities are present. The detail of trawl scars can help define the fishing gear type in an area, as well as any other threat, e.g., anchor scars. The technique can provide more accurate seabed penetration depth measurements.

4.1.2.5. Magnetometer

A magnetometer measures a variation in the earth's magnetic field, to identify ferrous anomalies, such as cables, pipelines and unexploded ordnance (UXO), as well as geological features. These are often used alongside other geophysical survey sensors, or as a dedicated standalone survey. Dedicated magnetometer surveys generally consist of arrays with several magnetometers, which provides wider coverage of an area, whereas when towed alongside other survey sensors usually only one or two (gradiometer) magnetometer units are used. Magnetometers are towed at an altitude above the seafloor, dependant on the target size of the magnetic anomaly, e.g., approximately 15 kg of steel or Iron is detected from a distance of around 10 m, and 1 ton, detected from a distance of around 30 m (Geometrics, 2005).

4.1.2.6. Sub-bottom profiler

Sub-bottom Profilers (SBPs) are used for determining the sub-surface geology. Most systems use low frequency acoustic pulses which penetrate the seafloor and record the returns. They can also be a useful tool in establishing depth of burial of assets. Depending on the desired outcome (data resolution and seabed penetration) SBP can take different forms from hull mounted sensors, towed sparker, or boomer systems with mini streamer. While surface mounted sensors can be useful in determining large assets, such as pipelines or to verify a subsea power cable's depth, a profiler closer to the asset is generally required, particularly in deeper waters. Therefore, such systems are typically mounted to a Work Class Remotely Operated Vehicle (WROV), AUV, or other tethered and towed survey vehicle.

4.1.2.7. Cable and pipe trackers

Cable and Pipe Tracker Systems are often used mounted to WROV and flown above assets. Some systems use a SBP method of detection, and some systems use a pulse induction system. This works in a similar way to a metal detector by emitting small current pulses from the coils, and if there are any metal objects within the range of the coils, they will emit a return signal as eddy currents. The eddy currents detected in each of the coils are then processed to give a position or range. These data can then be used to determine cable location and depth of burial data as well as cable fault locations.

4.1.2.8. General visual inspection

General Visual Inspection (GVI) is often used for monitoring surveys, either in combination with the above methods, once an area of interest has been identified, or as a standalone survey method. Undertaken by an ROV, or other tethered vehicle, it involves the recording of video and or still photographs along a cable route to identify areas of cable exposure, condition of cable protection measures, areas that may require repair, or maintenance and areas of future concern. Configurations can vary, some ROVs can be mobilised with several cameras including those on remotely controllable boom arms which allow a different camera angle very close to the seabed or asset, as well as a drop down/oblique camera angle which is more standard. Recorded video footage is often commentated by an engineering who will log video transects.

4.1.2.9. Geotechnical

Geotechnical surveys provide ground truthing data of the shallow geology including assessment of sediment type and sediment characteristics. These data are essential for Cable Burial Risk Assessments (CBRAs), burial assessment studies, as well as sediment mobility modelling which can be used to assess areas of high or low risk to cable exposure. Data are predominantly acquired through coring and boreholes, as well as Cone Penetration Tests (CPTs). Core samples are logged in the field and samples tested in a laboratory to determine their physical properties e.g., shear and compressive strength, bulk density, plasticity, moisture content, Atterberg limit, specific gravity, and particle size distribution. CPT data provide *in situ* measurements of sediment within cable burial depths, including shear strength, friction, pore water values, and, where applicable, thermal conductivity measurements.

4.1.2.10. Environmental

Environmental surveys can be used in the assessment and delineation of environmentally sensitive areas which can be potentially avoided, or impacts minimised in the cable routeing, installation and decommissioning phases of a project. Grab sample data for surficial sediments and benthic infauna are frequently acquired as part of environmental baseline surveys. With the exception of Hamon grab samples, used in mixed and coarse sediments, samples are considered to have minimal disturbance to surface sediments, which are often under sampled in geotechnical coring where core catchers disturb this upper layer. Such data can also be used to inform CBRAs as well as sediment mobility models.

4.1.3. Evaluation

The requirement of different survey equipment and vessels is dependent on the data requirements of a project and its location. Nearshore surveys are usually undertaken by smaller shallow-draught vessels to reach shallow areas, whereas offshore surveys are often undertaken by larger vessel with longer endurance and lower weather sensitivity. A baseline offshore renewables project typically requires a full suite of geophysical survey equipment (SSS, MBES, SBP and magnetometer), as well as geotechnical and environmental sampling. However, a cable free-span identification survey may just require MBES and GVI. As well as the consenting and engineering need of a project, other considerations include weather sensitivity, cost, risk and data handling limitations.

4.1.3.1. Weather sensitivity

Weather plays a significant role in marine surveys. The main constraints from adverse weather conditions are possible risk of injury to personnel or damage to equipment and loss of data quality through excessive vessel movement. In order to minimise costly weather standby, mitigation includes planning surveys at a time of year when the weather is more favourable and also consideration of appropriate vessel size and weather handling abilities for the location.

AUVs do not depend on vessel movements when untethered and in operation. They can therefore provide high quality data in poor weather conditions, however, their launch and recovery is often reliant on a survey vessel, where AUV data are downloaded, and batteries recharged. As vessels can only work within certain weather parameters, the use of AUVs can therefore be limited in sustained periods of adverse weather.

4.1.3.2. Cost

Marine surveys represent a high cost to any development, owing to the vessel, fuel and equipment cost, as well and multi-disciplinary crews required to operate equipment and process the data. Also, availability of survey vessels can be highly limited, particularly at late notice. Therefore, in some cases, methods of cable monitoring, such as those described in Section 4.6.1, can often be preferable, in order to target specific areas which may be at high risk.

Typically, the more survey equipment that is required the more expensive the survey. MBES surveys are most frequently used for free-span monitoring. This is due to the hull mounted sensor offering a large swath of data acquisition while limiting the weather-related risks and crew required for over boarding sensors. WROVs, or other vehicles mobilised with cable tracking sensors, provide more detailed survey data, however, these options are often more costly as a larger vessel is required to launch and recover these relatively heavy vehicles.

As mentioned, while AUV surveys currently require a relatively large crew and large vessels in order to deploy and recover them, they can be used in simultaneous operations with other AUV(s) and/or survey vessel(s) which can ensure they are cost effective, particularly when maximising a workable weather window. Uncrewed Surface Vessel (USVs) can offer cost effective options of acquiring mapping and inspection data, particularly in nearshore areas.

USVs are now being professionally recognised and certified by Lloyds Register as an Unmanned Marine System (UMS). Controlled remotely from land, another vessel, or programmed autonomously, USVs are smaller and more agile than larger survey vessels, they burn less fuel (through onboard generator operation) and can have a reduction in crew. They can currently be configured with SSS, magnetometer, MBES, SBP as well as observation class ROV's. The technology is still relatively new and therefore not without issues, however reliability is improving on a year-by-year basis.

4.1.3.3. Risk

Any survey poses a risk to equipment, the environment, and/or personnel. Before mitigation, risks in the offshore industry are considered relatively high compared with similar industries on land. This is due to the dynamic nature of the marine environment, which often requires hardware which can be hazardous e.g. hydraulics, high voltage electrical systems, as well as lifting operations.

The survey industry, therefore, has very high standards of risk management with often stringent mitigation measures in place to ensure a safe workplace, which originates from the oil and gas sector. However, there is still a residual risk that can remain with certain operations.

The use of USVs for operations further offshore, i.e. optionally-crewed robotic vessels, such and the 78 m length Armada ships (Ocean Infinity, 2022), offer a low-emission solution to survey operations, with reduced numbers of crew onboard. This can be particularly effective for hostile environments of operations such a UXO relocation and/or detonation.

As with trawling, the towing of survey instruments can present a higher risk to operations compared with using hull mounted sensors in two main ways:

- Restricted manoeuvrability; and
- Snagging on uncharted objects.

The restricted manoeuvrability of vessels towing equipment limits a vessels ability turn or decrease speed with possible damage to towed equipment coming into contact with the seafloor or entangling with other towed sensors. Therefore, working in areas of high vessel activity can present higher risks if other vessels do not follow correct maritime regulations.

Snagging on unknown hazards is also a risk, particularly in areas where ghost fishing gear or unobserved static fishing gear is encountered. The risk presented often involves entanglement and increased weight on the towed sensor. The operation of unentangling equipment can be high risk and is often classed as 'over the side working' and may require cutting of tangled components. This practice requires additional mitigations, such as appropriate Personal Protective Equipment (PPE) and harnesses. The additional weight of entangled equipment and drag can also, in some cases, lead to the parting of tow cables and loss of equipment. While other objects, such as wrecks, do present a risk, these are often observed in the data during acquisition, allowing the operator to take avoiding action.

4.1.3.4. Data handling requirements

While technologies which provide very high-resolution data, such as SAS, are valuable in terms of what they can show, these higher resolutions come with an increase in data size. Where survey areas, such as export cable routes, cover large distances, the usability of such data sets may become restrictive, by requiring increased computing power to use full resolution data.

4.2. Over-trawl trials

Over-trawl trials can be requested as a consent condition to observe if any damage is caused to fishing gear, over areas of cable burial and cable protection. Over-trawl trials are intended to provide assurance to fishermen to resume fishing in the over-trawled area. However, they are considered by some to instil a false confidence of safety, as a risk of snagging and damage still persists after an over-trawl trial.

In the UK, there is presently no legislation to prevent fishing over subsea cables. Fishing in close proximity to subsea cables, of which are Critical National and International Infrastructure, presents a hazard which can result in the loss of communications and/or power. It is for these reasons that maritime industry associations advise against any type of fishing where there is a known and chartered subsea cable (MCA 2021, UKHO 2023 and ESCA, 2022). The use of over-trawl trials has been criticised in the offshore renewables industry with notable issues associated with the practice highlighted, including:

- Some areas of seabed are dynamic and a moving environment. If a cable is buried when an over-trawl was to take place, [where seabed conditions are dynamic with mobile sediments] it may not be buried to the same extent hours/days/weeks/months later. This is highly prevalent in the Southern North Sea and less so in Scotland.
- Offshore Renewable installations and other submarine cables are generally deployed with a design life of between 20 to 40 years, and longer in some cases. Over-trawl trials only demonstrate a 'snapshot in time' and risk of exposure can change over time.

- The depth of cover can be reduced from numerous over-trawling events, even when buried or protected. This can impair the integrity of any protection measures.
- Over-trawl trials could be seen as an endorsement of the undertaking of a recognised unsafe practice, with potential liabilities arising as a consequence.
- Undertaking over-trawl trials is not consistent with the responsibilities of the skippers of fishing vessels under the International Convention for the 'Safety of Life at Sea' (MCA, 2004).

4.2.1. Over-trawl trial uses

The request of over-trawl trials as a consent condition are decided on a case-by-case basis, they can depend on the policy framework underlining consent and are often driven by environmental conditions, stakeholders and consultation bodies. They are more prevalent for Scottish projects in comparison to OWF projects elsewhere in the UK.

Developers of ORE projects have worked alongside regulators and fishing associations to explore the use of over-trawl trials as a viable approach to coexistence between offshore wind and fisheries. This can lead to increased cross-sector understanding, improve coexistence opportunities and, potentially, improve understandings of snagging risks and fishing gear damage. By taking a collaborative approach, and using local fisheries representatives, for example, locations where over-trawl trials are particularly necessary can be identified and specific fishing gears targeted based on local fisheries. It should be mentioned that over-trawl trials can be considered by some to instil a false confidence of safety, as a risk of snagging and damage still persists after an over-trawl trial, irrespective of no damage occurring during the trial. These risks can be higher in areas of high fishing activity, where the seabed is mobile and/or in areas where there is limited cable burial.

4.2.2. Over-trawl trial examples

Over-trawl trials have been completed at several offshore windfarms in the UK:

- Neart na Gaoithe (NNG) OWF
  - Undertaken in two phases, the first phase involved prawn fishing gear and resulted in no observed damage to gear.
  - The second phase involved prawn fishing gear over rock protection and other areas of the cable, no damage to fishing gear was observed.
- Beatrice OWF
  - Over-trawl trials were carried out post-construction in areas of rock placement.
  - No indications of gear snagging were detected during the trial.
- Seagreen OWF
  - The trial focused on *Nephrops* trawling as this replicated what was used most frequently in the vicinity of the OWF, and covered areas where full burial depth hadn't been achieved as well as rock protection.
  - No snagging or damage to gear was observed during the trial.

- Moray East OWF
    - The trial involved prawn and squid fishing gear.
    - One incident of damage to the trawl net was recorded, with all other crossings completed with no damage recorded.

The areas that were surveyed were certified by SFF Services as allowing fishing activity to continue in these areas, except for those at the Moray East OWF which was not considered safe to allow normal fishing operations to proceed.

4.2.3. Method evaluation

The over-trawl trials investigated did not provide data on all potential trawl angles or all fishing gear used in the area to represent local fisheries and fishing methods. Although some of the trials investigated more than one gear type, other fishing gears, such as dredging and bottom seine fishing, are also documented to be used in the vicinity of the Seagreen, NNG, Beatrice and Moray East OWFs (EMODnet, 2024). There is evidence that dredging penetrates deeper than bottom trawling (Eigaard *et al*., 2016), which could present a higher risk of damage to a cable or fishing gear, not represented in the commissioned trial. In all areas where over-trawl trials were undertaken, dredge fishing activity was also prevalent but not used as a fishing method in the trials (EMODnet, 2024). The inclusion of a variety of fishing gears and trawl angles in over-trawl trials could improve the confidence of results, however, the associated high costs may not make this approach viable for most projects and will still present risks to safety and potential very costly damage to subsea cables.

Another factor in the usefulness and confidence of the over-trawl trials is timing and frequency. The majority of over-trawl trials discussed were undertaken on one occasion only. The results of these trials provide an indicator of snagging/damage risk at the time of survey. This cannot necessarily be used to assume a similar outcome in future trials or fishing events. Snagging risk is dependent on numerous factors such as fishing intensity and fishing activity type. Even after undertaking over-trawl trials, the risks of trawling/dredging over the lifetime of the cable, and associated cable protection measures, will remain unclear. This is particularly key in areas of mixed fishing methods, such as the Irish Sea, where methods such as scallop dredging can relocate rocks and boulders to grounds which are also fished by less robust fishing gears, such as otter trawls, subsequently increasing the risk of damage to fishing gear and possible cable exposure or cable damage.

Location is another important factor in over-trawl trials. Robust trials will be done to a sufficient level of detail to cover a variety of locations along the cable. The Seagreen trial was relatively detailed and targeted a range of locations, including areas of importance to local fishermen as well as locations where full cable burial was not achieved, and rock protection was required. This level of detail, and inclusion of trawling over cable protection measures, can improve the accuracy of the outcome of over-trawl trials, however it is usually unfeasible and unnecessary to over-trawl all of a subsea cable. Investigations into areas of importance to local fishermen ensure that the trials are more targeted, relevant and applicable to trials.

Over-trawl trials should also be representative of the various sediment types present along the cable corridor. No discussion of sediment type was included in any of the over-trawl trials, although this would be useful. The lack of sediment data and information reduces the comparability of trials, noting the depth of penetration of commercial fishing gears and associated risk of snagging and damage is dependent on sediment type (Eigaard *et al*., 2016). If the cable corridor seabed consists of various sediment types, more robust trials will investigate these.

Presently, there are limited documented over-trawl trials that have been conducted in the UK to fully understand the effectiveness of over-trawl trials and confidence in the results. Those that have been undertaken involve similar methodologies; however, they were not delivered on a standard basis. All trials investigated bottom trawling gear which was known to be used locally, surveyed transects across cable locations and assessed outcomes based on speed and towing tensions, as well as conditions of towing gear and nets. However, inspections of fishing gear and nets were not carried out at a standard frequency, and design of the trails regarding angle approach to the subsea cable varied, as well as number of types of gear assessed. Some studies also investigated areas of importance to local fishermen whilst others did not, and only one trial was undertaken in stages.

Over-trawl trials can be associated with high costs due to the use of vessels, fuel, equipment and crew members. Increased survey effort which may lead to more robust results are directly correlated with increased trial costs, which may be prohibitive for some projects. Further, the longevity in the value of results will remain a concern from both a fishing risk and asset protection perspective.

4.2.4. Trial effectiveness and limitations

4.2.4.1. Effectiveness

Over-trawl trials can be effective at providing an overview of the potential for snagging of cables from a fisheries coexistence perspective. Trials can be designed and adapted to target specific sediment types and fishing gears present in the study area. Over-trawl trials are perceived by some to be useful to highlight critical areas where snagging and damage are more likely, of which can be mapped and fishers made aware.

Over-trawl trials could be an approach for establishing potentially lower risk fishing corridors where no infrastructure is present. In Norway and Germany, Marine Spatial Plans (MSP) are used to manage different marine activities (OECD, 2020). Therefore, demersal fishing is more restricted in ORE development areas. However, fishing can be undertaken within designated areas over export cables, sometimes as alternative compensations for loss of fishing grounds (Danish Energy Agency, 2018). Both designated areas and restricted fishing areas could be established to improve coexistence and manage the overlap in space. This would require the establishment of potentially lower risk fishing corridors using over-trawl trials and could improve the coexistence of offshore renewables and commercial fishing. Examples of coexistence include bottom trawling over export cables connecting Horns Rev 2 OWF and Danish West Coast (Danish Energy Agency, 2018). It should be noted however that despite over-trawl trial results, long term risk levels of fishing over any subsea infrastructure will be elevated compared with undeveloped grounds.

4.2.4.2. Limitations

There are several limitations to over-trawl trials. Firstly, the outcomes of over-trawl trials are limited to the fishing gear used in the study as well as any modifications. A trial can indicate that the use of that specific fishing gear is unlikely to lead to any snagging or damage to the subsea cable under the same conditions. The trial, however, does not demonstrate this for other fishing gears, or account for changes over time which may increase risks. Over-trawl trials undertaken are not necessarily representative of all regional commercial fishing practices which varies from controlled trials. Such variations include gear modifications, sea conditions and towing speeds. The outcome of over-trawl trials can only be relevant to fishing undertaken at the same towing speeds used during the trial. Any fishing conducted at higher or lower speeds may have different snagging risks.

Over-trawl trials are an indication of potential for snagging at the time of survey and cannot be relied on to demonstrate future risks. Seabed conditions can be dynamic, with cable burial depths and risk of exposure changing over time. This is especially true in areas of sandwaves, which can be mobile and migrate over the seabed. Over the lifetime of the cable, infrequent storm events and sediment mobility can affect sandwave profiles, leading to reduced cable burial and potential cable exposure (Whitehouse *et al*., 2000; Burley *et* al., 2023). This is not accounted for in over-trawl trials which only demonstrate a small period of time. Improved confidence of trial results can be achieved through repetitive surveys over time.

Some of the discussed over-trawl trials surveyed over rock protection. The profile of rock protection can become worn over time leading to cable exposure and an increased risk of snagging. Furthermore, trawling over rock protection can cause wear to the protection measures impairing its integrity and limiting its effectiveness. These factors are not accounted for in singular over-trawl trials.

Over-trawl trials are also location specific. Certificates provided in previous trials state that the swept areas are considered 'safe' to allow normal fishing operations to proceed, indicating that only the swept areas, and no other locations along the cable route, are considered safe; however, it should be noted that where the terminology states that it is 'considered safe' to fish an area, this is the opinion of one organisation and is often disputed as some element of risk will always remain.

Over-trawl trials could be useful for establishing designated fishing corridors but cannot eliminate all risk of fishing over subsea cables.

Over-trawl trials can also cause disturbance to seabed habitats where the trials could be seen as unnecessary damage to the area as the catches are not landed. The undertaking of any trials should be considered in any environmental assessments associated with cable installation.

4.2.4.3. Recommendations

While over-trawl trials remain a controversial practice, there are several recommendations that could improve the confidence and usefulness of the results. These are based on ensuring scientific robustness of trials and it should be noted that the commercial viability of proposing such recommendations to ORE developers for future trials, may be deemed unproportionate.

- Phased or repeated surveys with targeted locations (such as areas of importance to local fisherman) could improve trial confidence and an understanding of results over time.
- Trials investigating different fishing gear types used in the local fishing fleet, on different cable protection measures could help establish more robust results and give a better understanding of the risks from different fishing gear and how different cable protection measures perform.
- Sediment type has not been studied in previous over-trawl studies, but can affect fishing gear penetration and the risk of snagging and damage.

- The evaluation of over-trial trawls highlighted a lack of standardisation. There are limited documented over-trawl trials and several knowledge gaps. As more studies are undertaken, standardisation of trial methodology, per gear type, may be useful for some regions.
- As discussed, over-trawl trials do not demonstrate that any type of fishing gear is 'safe' to be undertaken over subsea cables, either buried or with external protection. Over-trawl trials can be required as a consenting condition, predominantly in Scotland, helping to reassure stakeholder concerns. The use of geophysical data acquired from post installation monitoring surveys can provide detailed information on the status of cable burial and external protection measures which over-trawl trials do not offer. The availability of this data in a useable format to fisheries stakeholders could potentially provide sufficient information to inform decisions regarding fishing in such areas as an alternative to over-trawl trials. However, this suggestion is not agreed by all stakeholders.

4.3. Fishing gear trials

Fishing trials undertaken as part of ORE projects can help to understand and mitigate potential impacts an OWF or fishing practice may have on the other. In the past, fishing trials have been used to look into alternative and less damaging fishing methods for bottom dredging as well as to investigate the feasibility of alternative fishing methods within an OWF area. These data can potentially be used to help facilitate sustainable coexistence and provide valuable data for informed decision-making in planning and marine resource management.

4.3.1. Moray offshore renewables king scallop dredge design

In 2013, Moray Offshore Windfarm (East) Limited (Moray East), Scotland, agreed a Commercial Fisheries Mitigation Strategy (CFMS) with the SFF in consultation with Marine Scotland. After receiving consent on the finalised design, this strategy was revised in 2022. One of the conditions of consent for the scallop industry was "should it be deemed necessary by the MFOWDG-CFWG (Moray Firth Offshore Wind Developers' Group – Commercial Fisheries Working Group), investigations into alternative gear for the scallop fishing industry in the Moray Firth must form part of the CFMS". Under this condition, Moray East commissioned Bangor University to conduct a study into alternative scallop dredge gear types that may penetrate the seabed less than the traditional Newhaven dredge type, in aid of coexistence and reduction of risk to buried cables (Moray East, 2022).

Work undertaken by Bangor University "documented interactions between scallop dredgers and underwater cables; current dredge designs that could potentially mitigate the risk of cable snagging and provide environmental benefits; and changes required to use an alternative dredge design under UK fisheries legislation." This resulted in identification of three scallop dredge designs that achieved good commercial catch rates while reducing damage to the seabed/organisms. This was achieved in one design through the use of individually sprung tines that replaced the fixed dredge teeth (Catherall and Kaiser, 2014). No empirical testing was undertaken as part of the study, however, tests previously undertaken on a beach, showed a reduced disturbance to the sediment. Data on the potential reduction of snagging for each design was not available.

Field trials for such designs in the Moray East region were decided not to be undertaken by the MFOWDG-CFWG in 2018, due to a change in position by the scallop industry at this time (Moray East, 2022).

4.3.2. Low impact scallop innovation gear

In 2022, Herriot Watt university undertook trials looking into Low Impact Scallop Innovation Gear (LISIG), funded by the UK Seafood Innovation Fund. In recent years bottom trawling and dredging has come under increased scrutiny and considered by some as not a sustainable practice, due to disruption to natural carbon cycles and damage to benthic ecosystems (Howarth & Bryce, 2014). Disruption to the carbon cycle is achieved by exposure of underlying anaerobic sediments and damage to carbon sequestering organisms, as well as drag caused by penetrating the seafloor increasing fuel consumption and therefore carbon emissions. The trials aimed to reduce environmental impacts associated with the spring-toothed Newhaven dredge by looking into gear innovation.

The results of the study showed that marketable catch of a skid dredge was either higher or had no significant difference. However, results were variable on a site-by-site basis, with above and below minimum landing size scallops, bycatch and debris recording higher catch volumes or no significant difference with a skid dredge, compared with the standard Newhaven dredge. Damage to scallops remained similar and damage to bycatch varied species to species (Sciberras *et al*., 2022). Damage to seabed fauna was reduced with the skid dredge design which had a reduced seabed footprint. However, fuel efficiency showed no significant difference, thought to be due to an increased weight of the skid design offsetting the fuel efficiencies of decreased drag. A number of future recommendations for gear development and data collection had resulted from this study (Sciberras *et al*., 2022):

- Reductions of undersized scallop catches may be achieved by using alternative dredge teeth such as N-Virodredge, or by increasing the spacing between the dredge teeth and/or the size of the belly rings.
- The addition of artificial lights on the tow bar and/or chain bridles may reduce bycatch of highly mobile species such as flatfish.
- Further gear comparison trials on how gear performance differs with seabed rugosity and topography and sea state will strengthen the evidence base for commercial viability of the skid dredge.
- Bycatch survival rates are generally poorly quantified for scallop dredging and future work could help to understand this knowledge gap.
- Further study on gear footprint and seabed impact for different belly bag fullness (i.e. gear penetration in the seabed) and tow length will help expand the evidence base.
- Mortality and damage in sites with different community composition will help to better understand impacts.
- Future gear improvement to provide fuel savings and reduced CO_2 emissions could look to use lighter weight materials for skid dredges.

4.3.3. Hywind static fishing gear trials

In 2022, Equinor commissioned the Marine Directorate of the Scottish Government to undertake a trial using static commercial fishing gear within the Hywind floating OWF. Three types of static fishing gear were trialled: fish traps, crab and prawn creels and electronic jiggers, between July to November 2022. The main focus of the trial was to understand the risk of static gear snagging in a floating OWF.

Operations were undertaken on board a fishing vessel which also worked as a guard vessel and therefore had familiarity to working withing offshore renewable sites. Operations were undertaken in three designated areas identified by the developer for the trial. These areas were a minimum of 200 m from turbines and dynamic sections of the export/inter-array cables, and at least 50 m from remaining infrastructure such as moorings or static inter-array cables (Wright *et al*., 2023).

All gear was successfully operated within the prescribed areas and no safety issues or gear snagging was encountered or fishing gear lost. Commercial viability was not assessed as part of the project; however, commercially valuable species were caught. As the area was not fished by static gear, catch quantities were not comparable to other static gear target areas.

Trials were undertaken where weather conditions to enter the site were deemed safe, this could cause a restriction to fishers in comparison to fishing in grounds that are not located around infrastructure, and therefore collision risks lower.

Future studies looking into the commercial viability of such fishing practices in areas of high fishery productivity would establish if this coexistence can be considered profitable for fishers in the long term. It is important to recognise that transitioning from mobile fishing grounds to static gear use is complex and an uncertain prospect. This shift would likely depend on factors such as significant changes in market conditions—where trap-caught fish would command considerably higher prices than those caught by nets, such feasibility would require thorough assessment.

The study identified several other key recommendations:

- Developer defined ‘fishing areas’ were seen to reduce the risk of fishing gear snagging, vessel safety issues and damage to wind farm infrastructure.
- Concerns over liability and insurance were not part of the project scope, but certainly a consideration for commercial projects.
- Accurate infrastructure diagrams made available for plotters, can assist fishers working in OWF arrays.
- Although not a statutory requirement, good communication between the wind farm control centre and any fishing vessels, greatly improves working relationships.

Other types of fishing methods which are representative of the local fishing fleet, will help to establish if coexistence is viable without change to local fishing practices.

4.3.4. Evaluation

Innovation of different fishing gears has shown to be an effective method of reducing impacts of fishing gear to the environment as well as potentially reducing risk to subsea cables. However, such changes are often difficult to quantify on a relatively short-term basis and results of increased catches and decreased impacts may be cofounded with other environmental issues, such as increases in bycatch and undersized species. The costs associated with vessel-based trials are relatively expensive and more extensive onshore testing, prior to field trials, is a good consideration for minimising cost.

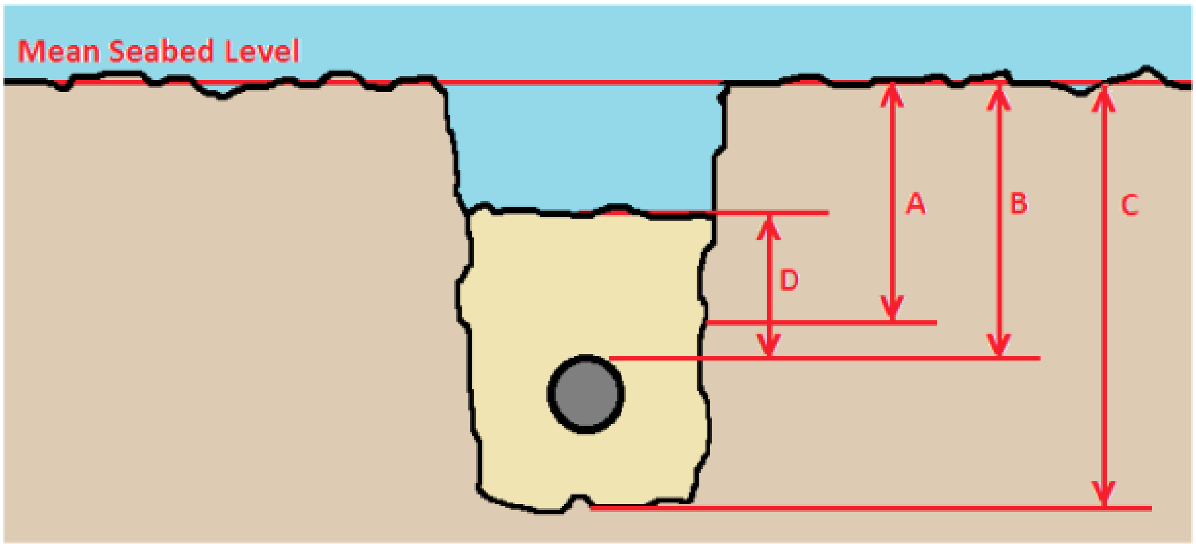
For a new fishing gear type, development outside of existing UK regulations needs to be accepted by Defra through a change of legislation. It has been noted through stakeholder engagement that this can be a time-consuming process which can hinder innovation in this sector. Therefore, a simplified process in recognising new fishing gear types may help to accelerate lower impact methods.

The colocation of static gear within OWFs is more established than mobile gear fishing. Although proven as operationally feasible, the commercial viability of replacing mobile fishing gear such as otter trawls with static gear such as fish traps, is not yet fully understood. By undertaking quantitative trials comparing both methods, it will help establish the commercial feasibility of a fishing gear type change by certain fishing fleets, as well as better understand the concerns of using mobile fishing gear in OWF areas.

4.4. Cable burial modelling

4.4.1. Cable burial guidance

Guidance regarding cable burial risk and the preparation of cable burial Depth of Lowering (DoL) has been produced (Carbon Trust, 2015). This guidance discusses the recommended minimum DoL, which is defined as the minimum depth recommended for protection from external threats (Figure 21). External threats include sediment mobility, submarine landslides, shipping and fishing gear, amongst others. With regards to fishing gear, where sufficiently detailed information on fishing grounds is available, or in areas where fishing is excluded, it may be possible to remove the requirement for burial for protection from fishing activity. However, the guidance recommends that given the limited information on fishing intensity, a fixed DoL should be applied in order to provide protection from fishing gear. The DoL is recommended to be based on the seabed strength and anticipated threats including types of fishing gear used in the region.



A Recommended Minimum Depth of Lowering
B Target Depth of Lowering
C Target Trench Depth
D Depth of Cover

Figure 21: Definition of trench parameters (Carbon Trust, 2015).

Recommended minimum depth of lowering

Recommended Minimum Depth of Lowering (RMDoL) is the minimum DoL recommended for protection from the external threats. It is the direct output of the fishing risk assessment and the probabilistic anchor risk assessment and includes a Factor of Safety (FoS).

Target depth of lowering

Target Depth of Lowering (TDoL) is the depth that will be specified as the target depth to the cable installation contractor. TDoL is a depth which makes best use of what is achievable by industry standard burial tools to gain additional depth beyond RMDoL without incurring a step change in costs. TDoL is also a practical application of depth which considers the effect burial depth has on tool stability.

Target trench depth

Target Trench Depth (TTD) is the trench depth cable installation contractors determine is required to meet TDoL. This is driven by cable properties and the selected trenching tool and is usually the diameter of the cable plus between 10 and 50 cm beyond the TDoL.

Depth of cover

Depth of Cover (DoC) is the thickness of material on top of the cable after trenching. It is not normally required for cable protection; however, it may be required by some consenting authorities.

Factor of safety

It is also recommended that a Factor of Safety (FoS) is calculated and applied to fishing gear penetration depths. No specific FoS is suggested, and it is recommended that stakeholders review their own acceptable risk profile based upon the accuracy of the data used for assessment.

It should be noted, however, that it is not always possible to achieve the recommended cable burial depth due to factors such as sediment type, underlying geology and installation tool limitations. Therefore, shallower cable burial may need to be considered on a case-by-case basis.

4.4.2. Cable burial risk assessments

The objective of a CBRA is to obtain an overview of the risks to cables. The CBRA calculates the required DoL of the cable to minimize the probability of damage from external factors such as vessel anchors, fishing and trawling. Following this, the residual risk for the buried cable is estimated.

The Carbon Trust's definition of trench parameters and proposed CBRA methodology is often used with primary steps presented in Figure 22 (Carbon Trust, 2015).

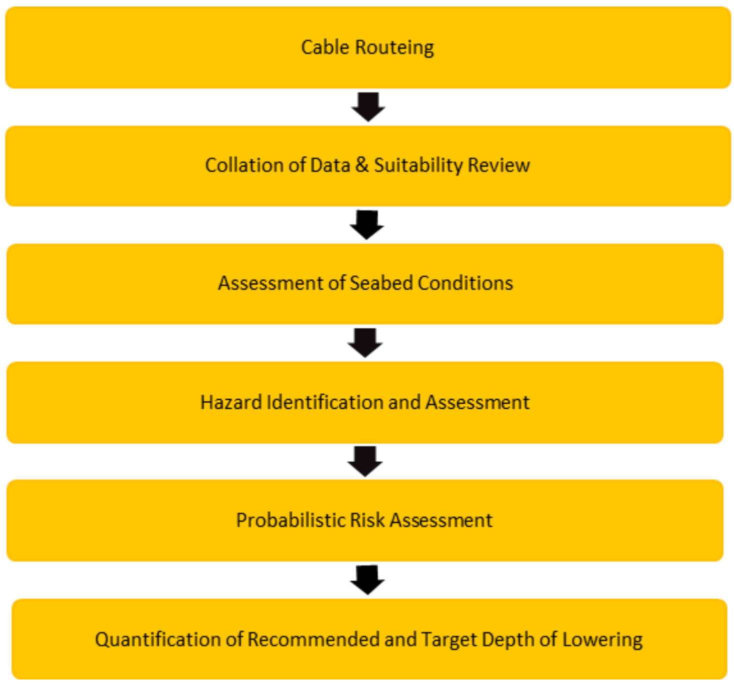


Figure 22: CBRA method in line with Carbon Trust guidelines.

4.4.2.1. Collation of data

The first step of a CBRA is the review of the cable route with respect to the available data at the time. Following this, data regarding the cable route, geophysical data, fishing data and geotechnical data is collected from surveys and/or publicly available resources and reviewed. Fisheries studies are often included in CBRAs for improved information and accuracy. These are often undertaken prior to CBRAs and include data regarding vessel type, surveillance and sightings, fishing gear and components, relevant ports, length of gear, fishing periods and duration, catch data, target species, and the capacity of vessels to engage in additional fishing methods. The cable route is then segmented based on seabed conditions including soil profile, sediment type, bathymetry, seabed features such as sandwaves, possible habitats, geo-hazards and crossings with other subsea infrastructures.

Analysis of geophysical, geotechnical and available fishing data is undertaken and a burial protection factor applied according to the threat to the cable. Factors such as orientation of the cable, vessel direction of travel and drift direction are considered. Fishing data is also collated to highlight areas of unacceptable risk that will have an increased TDoL and/or additional protection (i.e. rock protection or mattresses).

4.4.2.2. Assessment of seabed conditions

A breakdown of the cable route is undertaken based on distinct seabed conditions characterised by the review of the available geotechnical and geological data. Seabed sediment classifications are used such as clay, silt, sand, gravel and bedrock. Shallow geological features are also identified and characterised. Undrained shear strength parameters and classifications are interpreted and soil relative density classification provided.

To understand the seabed geology, geological datasets are then combined to create a geological ground model. This model can be used to create a geological seabed breakdown with seabed sediment assumptions.

4.4.2.3. Hazard identification and assessment

To specify an appropriate DoL, a risk identification and assessment is undertaken to consider both the likelihood and severity of all external threats to the cable. This includes natural risk such as sediment mobility, geohazards, outcropping bedrock, waves, currents and extreme weather. Anthropogenic risks including shipping (errant anchoring), dredging, aggregate extraction, subsea mining, dumping, third-party infrastructure and fishing gear interaction are also considered.

4.4.2.4. Probabilistic risk assessment

As part of a CBRA, a probabilistic assessment is undertaken to evaluate the risk to the cable after burial options are completed to a specified depth. Risk is defined according to likelihood and severity based on cost and performance and is project specific, however, the DNV guidelines for the risk assessment of pipeline protection are used as a starting point for most projects (DNV, 2010). Mitigation measures, such as concrete mattresses, rock placement, and CPS, are then considered. The final route is then segmented according to changes in risk profile resulting from changes to seabed geology and external risk factors.

If any of the cable route is present in mobile and static fishing areas or is within a water depth range in which mobile fishing gear could take place, it is recommended that the cable is given sufficient protection from potential fishing gear interaction.

4.4.2.5. Quantification of recommended and target depth of lowering

The literature used in Carbon Trusts' guidance indicates that penetration of fishing gear into the seabed is limited to a maximum of 30 cm penetration even in soft sediment based on previous literature research (Linnane *et al*., 2000; Carbon Trust, 2015). In most scenarios, a FoS of two is added to account for measurement errors and deformation of soil beneath fishing, giving a RMDOL of 60 cm. This is discussed further in Section 3.

4.4.3. Method evaluation

4.4.3.1. Effectiveness

CBRAs can offer reduced costs associated with subsea cable installation and design and also offer a comprehensive approach. CBRAs are a significantly improved method compared to the previous Burial Protection Index (BPI) that was adopted as Best Practice guidance for submarine cables over ten years ago (Carbon Trust, 2024). This approach was limited due to its conservative approach. The introduction of CBRAs has improved estimates of risk through reducing undue conservatism as it aims to agree an "acceptable level of risk". This ultimately reduces the installation and insurance costs for subsea cables.

CBRAs offer a standardised, repeatable and quantitative method to improve risk management of subsea cables. This method is used widely by industry and is comparable between projects. CBRAs are a useful approach to highlighting fishing and fishing gear use in the area and the risk of interaction between subsea cables and commercial fishing. The results and conclusions are often detailed and specific to the site and fishing area. The results of CBRAs can be used to define recommended target burial depths of which are both practically and economically achievable, whilst providing adequate protection.

An additional advantage of the current CBRA methodology is that it can be used multiple times during the cable's lifetime. This includes determining DoL during design stages and determining the change in risk profile and requirement for mitigation if the DoL is not achieved. Survey data can be used to update the CBRA to assess the impact of changes to the seabed profile and, at the point of decommissioning, CBRAs can be used to assess the viability of leaving cables in place long term. The monitoring of subsea cables, as part of a CBRA, can be useful for identifying areas of cable exposure. This can prevent or reduce the likelihood of interactions between cables and fishing gear as well as any subsequent damage. The identification of exposed sections of cables or shallow burial can be used for hazard mapping and plotting in services such as KIS-ORCA to help prevent snagging incidents. CBRAs and cable monitoring can benefit developers and commercial fisheries by identifying cable hazards and reducing the risk of snagging. Additional tools, such as 'Distributed Acoustic Sensing' (DAS) and 'Distributed Temperature Sensing' (DTS) of which quantifies the health of subsea cables (Section 4.7.6), can enhance the effectiveness of CRBAs and cable monitoring (Indeximate, 2023).

The inclusion of fisheries studies in CBRAs can improve data and knowledge base as well as the accuracy and longevity of results and conclusions.

4.4.3.2. Limitations

Although the CBRA approach is less conservative than previous methods, it may still result in overly conservative DoL, in some cases. This is due to changes in fishing gear use and techniques since Linnane *et al*. (2000) was published. Greater penetration is avoided by fishers, where possible, in order to reduce wear on gear, reduce drag and reduce fuel usage. In addition, there have been developments in the design of trawl boards and beam trawl gears.

Although CBRAs provide a comprehensive and less conservative approach than previous methods, they should be only part of a holistic risk mitigation plan. Regular surveys, inspections and/or cable monitoring should be undertaken to ensure that optimal DoL is maintained, and any risk points are identified and mitigated. This can optimise initial project investments.

Regional marine liaison efforts and strategic guard vessel deployment could reduce or even eliminate the risk of anthropogenic cable faults and may be more cost-effective than opting for potentially overly cautious depths of burial. CBRAs can often forecast results of the probabilistic risk assessment based on assumed effect that new infrastructure will have on shipping patterns over the cable route, although, this cannot be fully relied on.

There are additional limitations, of which are acknowledged by the Carbon Trust guidance. Firstly, the guidance used to support CBRAs does not refer to the requirements of regulatory bodies who might prescribe a minimum DoL. In addition, there is no specification of methods or extent of survey data that should be required, these issues can lead to variations between projects.

There is also a limit of data availability. As discussed, data regarding fishing gear penetration and the relationship with seabed conditions is limited. In addition, there is a lack of detailed information available regarding the movement and intensity of smaller fishing vessels. This limits the effectiveness of any probabilistic approach, although should be accounted for in future iVMS data. The Probabilistic approach is also limited by the use of the Pincident factor that forms a major component of the equation to assess the probability of an anchor striking a cable. Pincident is the probability of an incident occurring that would require the deployment of an anchor in an emergency situation. It is difficult to quantify this figure, and it is often taken from historical incident reports from national agencies such as the Marine Accident Investigation Board (UK).

4.4.3.3. Recommendations

The current methodology used for CBRAs offers reduced costs associated with subsea cable installation and design and a comprehensive approach. This method is significantly improved compared to the previous approaches and includes a wide variety of factors and considerations. There are, however, recommendations for an improved methodology.

It is recommended that initial CBRAs are undertaken in early stages of projects, pre-application submission, to allow engagement with statutory authorities to discuss necessary use of cable protection measures and expected burial depths. This will help to prevent unnecessary cable protection measure volumes from being consented.

Although site specific considerations, based on baseline conditions, are recommended by the guidance, a precautionary approach may be more suitable to ensure safety for the full lifetime of the cable.

In addition, it would be useful to update the literature used in CRBA guidance and include more recent studies. As part of this, more studies and/or trials may need to be undertaken to inform this with a focus on commercial fishing gear penetration depths and the impact of sediment type.

4.5. Sediment mobility modelling

Sediment mobility modelling can be used alongside assessments such as CBRAs as useful tool to help identify high-risk areas for cable exposure and they can be used to support risk assessments, monitoring strategies, and appropriate installation methods. An overview of sediment modelling applications is provided in Appendix 4.

4.6. Cable monitoring data

4.6.1. Cable monitoring systems

Cable Monitoring is critical for the safety of subsea export cables. Technologies can find faults in the cable itself, monitor faults and temperature changes. Furthermore, cable monitoring systems can predict localised fishing and shipping vessel near cables limiting risks of trawling and anchor strikes. Finally, monitoring systems can detect when cables are exposed from burial. The three main cable monitoring systems are in this section.

4.6.1.1. Optical time-domain reflectometer

Optical Time-Domain Reflectometer (OTDR) is used to test the integrity and identify faults along a cable. Specifically, it can verify splice loss, measure length, and find faults, bends and connection points.

It works by inputting a high-powered light pulse into one end of the cable. Light is reflected through backscatter back to the OTDR port and is directed to a receiver attached. The return scatter and reflections are measured based on time taken to return to the OTDR port. Based on the return times and type of light reflected, the OTDR can create a display of the amount of backscatter on the receiver, displaying a point along the cable where a fault is present. An example of a trace is shown below in Figure 23; Table 8presents the positive features and limitations of the systems.

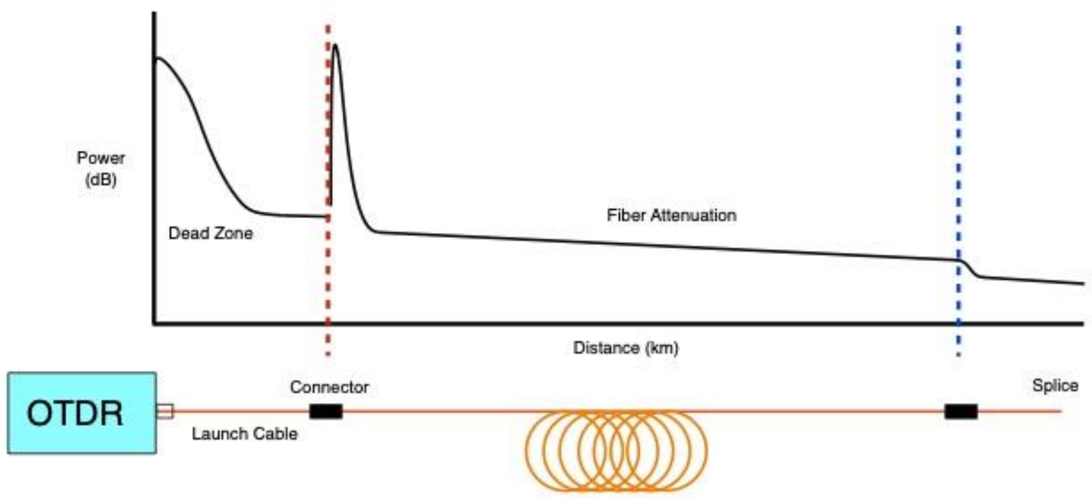


Figure 23: OTDR display trace and example (FOA Reference Guide, 2013).

Table 8: OTDR advantages and disadvantages.

Advantages of OTDR	Disadvantages of OTDR
Single end access – only one end of the cable is needed – useful when testing longer cables	Limited distance of measurement range for longer cables, a higher energy is required
Measurements of lengths and losses are accurate – Light reflection pulses allow for precise measurements and locations	High cost and complexity of equipment – initial kit is expensive and requires expertise in interpreting results
OTDR devices can store tests – useful for time-based monitoring of a cable. They also come in portable smaller sizes to be carried and used at any location.	OTDR struggles with shorter cables due "ghosts" arising from connections.

4.6.1.2. Distributed acoustic sensing

DAS is a method of identifying acoustic vibrations and sounds along a cable, detecting risks from nearby anchoring and fishing activities as well as general cable risk monitoring.

The method is based on Rayleigh scattering – finite laser pulses are sent along the cable allowing back scatter to occur. This happens within the cable when vibration or strains events arise, reflecting light back towards the DAS unit. The backscattered light travels back up the fibre towards the unit where it is sampled at the Rayleigh frequencies. The time it takes the laser to reflect allows the event to be accurately mapped and located. A summary of this method is shown in Figure 24 below and positive features and limitations are shown below in Table 9.

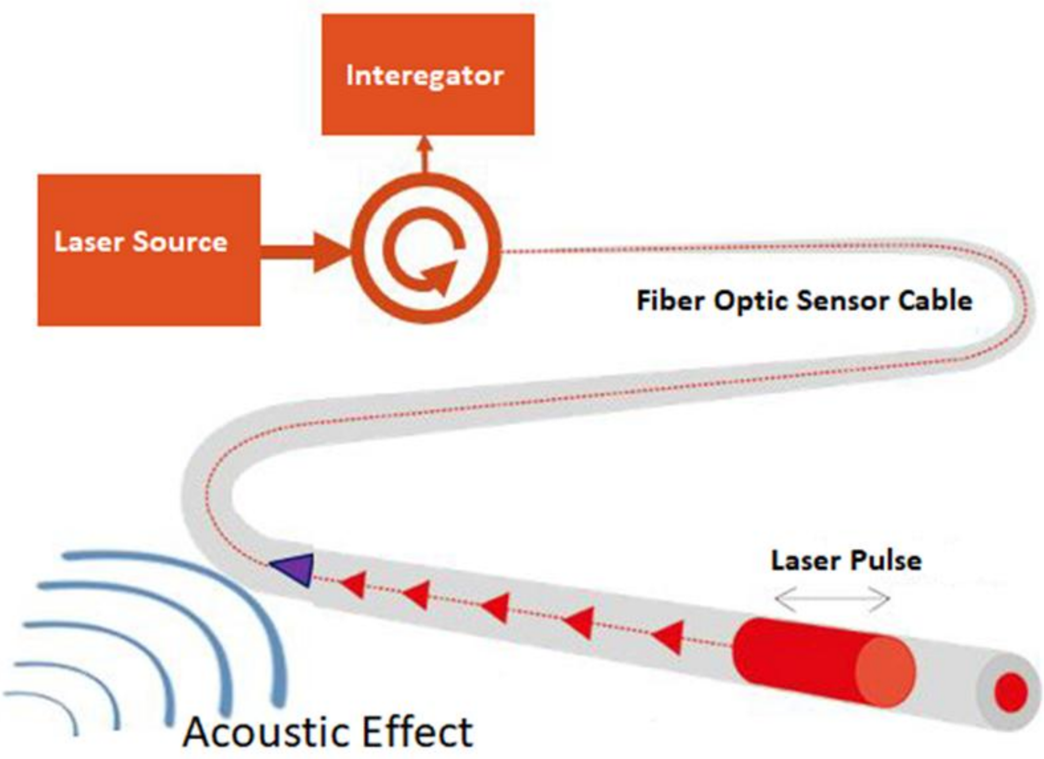


Figure 24: DAS method summary (FOTAS, 2024).

Table 9: DAS advantages and disadvantages.

Advantages of DAS	Disadvantages of DAS
Real time and continuous monitoring, giving warnings of potential risks such as vessel anchoring and fishing activities as well as other acoustic threats such as earthquakes.	DAS signals can be affected by environmental factors, such as temperature changes, currents, and marine life.
Numerous display options, due to the other uses of DAS in the seismic industry.	Very large data volumes, especially for longer cables, up to Terabytes per day.
The system is cost effective, once installed compared to other monitoring systems, no inspections or other deployment of equipment is needed.	At longer ranges the spatial resolution of DAS may decrease, limiting monitoring accuracy, and application to longer cables.

4.6.1.3. Distributed temperature sensing

DTS uses common fibres within cables to measure and monitor temperature over a cable.

The system works similarly to DAS systems, a laser sends pulses of light into and through the cable. Light is reflected through Rayleigh scattering and Raman backscatter, that reflects a different wavelength and pattern The Raman backscatter changes its reflection pattern based on temperature changes. When the temperature changes along the cable, the scatter pattern intensity changes. Optical receivers are used to detect the patterns and measure the intensity and therefore the temperature distribution, displaying hotspot locations. A summary of the positive features and limitations are shown below in Table 10.

Temperature changes are important to monitor the cables overall health and are used as a method to monitor depth of burial and if any exposure has occurred.

Table 10: DTS advantages and disadvantages.

Advantages of DTS	Disadvantages of DTS
Provides a full and constant temperature profile of the entire cable in real time.	Environmental Interference / changing sea conditions can provide anomalous results.
Sensers can measure temperature changes to 0.01 degrees Celsius.	At longer ranges the spatial resolution of DTS can decrease, limiting monitoring accuracy, and application to longer cables.
DTS is non-intrusive, relying on the optical fibres within the cable, limiting need for other sensors and equipment that could damage the cable.	
Localised differences in temperature can help determine cable burial and cable cover.	

4.6.2. Other relevant cable monitoring methods

4.6.2.1. OceanBrain

National Grid developed the system called 'OceanBrain' which uses machine learning combined with data sources (including cable location, burial depth and seabed type) and fishing vessel AIS data to automatically quantify the risk of potential damage (National Grid Partners, 2024). While this real-time risk assessment currently provides useful information for asset protection it doesn't currently notify fishers of the potential risks automatically which could be a consideration for future developments.

4.6.2.2. Asset monitor

Systems such as 'Asset Monitor' track vessel AIS to provide warnings of potential interactions between fishing vessels and subsea infrastructure, which can be interpreted by an experienced Fisheries Liaison Officer, and the vessels contacted to be made aware of potential risks. While effective, the vessel is not contacted in real time and so this may not prevent asset or fishing gear damage on initial interaction.

4.6.2.3. Future methods of subsea cable monitoring

The future has the potential to use new technologies for subsea cable monitoring, with particular focus on AI.

The use of AI and machine learning could automate data analysis from the methods above, providing increased efficiency and identify potential issues before they become faults. Furthermore, AI has the potential to analyse subsea cable health and performance, based on cable statistics captured by the raw data.

Finally, AI is being developed to monitor real time AIS of fishing and shipping vessels, tracking pathways, and flagging if vessel activities are deemed too close to a cable.

Although systems and associated cable monitoring services have an upfront cost, in comparison with traditional marine surveys, used to determine cable burial, such systems can prove very cost effective at determining areas of potential high risk as well as fault finding and health monitoring.

Collaboration from industry service provides could provide focus and direction on the development of future monitoring techniques which may help to overcome shared solutions in fewer systems, and look to standardise their application.

4.6.3. Evaluation

Cable monitoring systems are currently used by developers to determine cable health and in the context of fisheries, determine risk to cables through detection of fishing activity and potential cable exposure, which could then be used to inform fishers of this hazard and to determine where a fault or damage to cable (potentially from fishing activities) is located. However, there are legal uncertainties associated with using such data to inform third parties about risk, which remain a challenge for developers.

OTDR systems were developed commercially in the 1980s, however, still have a purpose today in diagnosing cable faults over a large distance. From a fisheries perspective these systems can't be used to provide information on cable burial or nearby fishing activities. A decade later, DTS systems were used in the Oil and Gas industry and recently have been further developed to harness valuable information such as cable Depth of Burial State (DOBS), however long-range applications are currently limited with a decrease in accuracy with length, particularly after around 30 km length. While this may show a limited application for some Floating OWF developments, more recent technologies have shown a sensing range up to 100 km (Sabatier, 2019 & Lauber *et al*., 2018).

More recently, DAS systems have been used in the offshore industry offering information on vibration and mechanical disturbances, including potential risks from anchoring and some fishing activities. However, like DTS they are restricted in their effective range, with up to 50 km range typical of most systems. However, newer research has shown feasibility up to 170 km (Research Outreach, 2022), indicating a broader applicability for longer export cables and Offshore Hybrid Asset (OHA) Interconnectors. Both DTS and DAS have limitations with regard to environmental and marine industry interference, for example dredging activities and pile driving, this can reduce confidence in output of processed signals. However, both DTS and DAS can provide very useful information to determine both high risks areas of cables and determinate nearby activities (such as bottom fishing) which could present a high risk to both cables and fishers.

Future monitoring is set to look at predictive modelling of fishing activities combined with areas of shallow cable burial or exposures to determine high risk areas for fishing and provide an efficient disseminate of information to fishers, making them aware of risks in real time, facilitating fisheries coexistence.

4.7. Future considerations

4.7.1. Surveys

- The use of cable monitoring systems and advancement in technology looks to reduce the requirement for conventional vessel-based or AUV monitoring surveys in some cases.
- The use of USVs and optionally crewed vessels are currently operational and making large technological advancements in the industry, these will ensure cost effective and low risk solutions to certain projects however have limitations with regards to some equipment launch and recovery and maintenance which required vessel crew.
- SAS presents high resolution data which can be of great value in assessing areas of seabed which are not ground-truthed, or for areas of high commercial fishing activity. However, computer data handling for large volumes of data may be specialised and could reduce efficiency data use, for some projects.

4.7.2. Over-trawl trials

Over-trawl trials undertaken as a licence consent condition are often proportionate to the potential impact on commercial fisheries. Over-trawl trials are welcomed by some fisheries stakeholders. The review of highlighted the below considerations which will improve scientific robustness as an academic practice, however, may not be viable on a commercial basis:

- The evaluation of over-trawl trials highlighted a lack of standardisation. Factors such as speed, repetition and gear inspection frequency could be standardised to improve the comparability and replicability of trials.
- To improve the accuracy and applicability of over-trawl trial results, trials would need to consider all potential trawl angles and all gear used in the area, this may help improve the understanding snagging risks, however risks will always still remain.
- Many over-trawl trials discussed were undertaken on one occasion only and the results of these provide an indicator of snagging/damage risk at the time of survey. This cannot necessarily be used to assume a similar outcome in future trials or fishing activities.
- Future trials could investigate a variety of locations along the cable, and all types of cable protection measures used along the route, to give holistic spatial coverage. This will not eliminate risks to fishing in these areas though and risks will always still remain.
- Sediment type can affect fishing gear penetration and the risk of snagging and damage. Trials that are representative of the various sediment types present along the cable route may help to consider the impact of sediment type on fishing gear penetration depths.
- Over-trawl trials may not provide data above and beyond data acquired from post-installation monitoring surveys. Making post installation geophysical survey data available for fishers, in a useable format, could negate the need for over-trawl trials, although this is disputed by some fisheries stakeholders.

4.7.3. Fishing gear trials

- Gear trials associated with ORE projects are often tied to the consent of an application. The undertaking of gear trials aimed at expanding the evidence base, that are not associated with a specific project may be more difficult to secure funding on.
- Gear modifications used commercially need to comply with UK rules guidelines, outlined by Defra. Changes in such legislation can be time consuming. The acceleration of allowing scientifically proven gear designs to be used commercially could help to drive innovation.
- The change of fishing gear type around ORE projects is not well-understood on a commercial basis. Static gear colocation is more established in OWF than mobile gears, however traditionally these target shellfish. The use of fish traps has been proven to catch commercially valuable species, but not at the same quantities as demersal trawls, on the small scale tested. Future commercial trials covering a wider time and space could be beneficial to understanding this coexistence on a socioeconomic basis.

4.7.4. Cable burial modelling

- The evaluation of CBRA methods highlighted that more studies and/or surveys may be required to fill knowledge gaps regarding fishing gear penetration and consider changes in fishing gear use and techniques.
- CBRAs were found to provide a comprehensive and less conservative approach than previous methods, however it was highlighted that this should be only part of a holistic risk mitigation

plan. It is recommended that future CBRAs are undertaken alongside surveys and inspections to provide a holistic approach and ensure optimal DoL is maintained and risk points identified. It is also recommended that regional marine liaison efforts and cable monitoring techniques are incorporated to reduce or eliminate the risk of cable faults.

- Although CBRAs are comprehensive and comparable between projects, a full standardised specification of methods is recommended to ensure CBRAs are comparable.
- The evaluation also highlighted that there can be a lack of data regarding the movement and intensity of smaller fishing vessels as this limits the effectiveness of any probabilistic approach. It is recommended that data availability is improved and that the evidence base for the Pincident factor is improved as it is difficult to quantify and often taken from historical incident reports.

4.7.5. Sediment dynamic modelling

- Sediment dynamic modelling methods are established and well-understood. They can be used to identify areas of high mobility and consequently areas of higher risk to cable exposure and free spans. However, their application is only worthwhile if suitable supporting data is available or will be made available, otherwise resultant models may lead to a misguided understanding of risk.
- In most cases the value of output data verses the associated high cost of models, ensures that they are not required, as ground truthing data can be used and interpreted by a subject matter expert. However, in areas of cable installation with high sediment mobility they should be a consideration.

4.7.6. Cable monitoring data

- The use of DAS and DTS is claimed to identify areas of cable exposure, which can be cost effective and a considerably quicker means of identification than traditional survey methods.
- AIS tracking of fishing vessels proves an effective tool for preventing incidences of fishing over high-risk areas of subsea cables.
- A combination of cable diagnostics, fishing vessel tracking and automated alerts to fishers could provide a quick and effective method for preventing incidents from occurring. This may be best achieved through collaboration of different cable monitoring service providers.

An evaluation matrix summarising key considerations survey, trial, modelling and cable monitoring methods is presented in Appendix 3.

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Appendix 1: Fishing gear penetration depth summary from literature sources

Table 11: Summary of penetration depths of UK commercial fishing gear in different sediment types (with minimum and maximum penetration depths for each sediment type highlighted).

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Hydraulic dredge	Water jet dredger		15						Fisheries Research Services (1998)	
Hydraulic dredge	Water jet dredger		15						Tuck *et al.* (2000)	
Hydraulic dredge								16.11 ± 3.35	Sciberras *et al.* (2018)	
Mechanized dredge		29.44 (gravel)	11.42	20.69					Szostek *et al.* (2022)	
Oyster dredge		15-20 (gravel)							Southern Science (1992)	
Scallop dredge	Tooth Bar and Belly Rings					≤ 10			Kaiser *et al.* (1996)	
Scallop dredge			2-4						Bullimore (1985)	Sandbanks

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Scallop dredge							3		Chapman *et al*. (1977)	
Scallop dredge			max 15						Eigaard *et al*. (2016)*	
Scallop dredge			3-4						Eleftheriou and Robertson (1992)	
Scallop dredge							2-5		Grieve *et al*. (2014)	
Scallop dredge							10 (maerl)		Hall-Spencer, 1995	Maerl beds
Scallop dredge			2-4						O'Neill *et al*. (2009)	Fine-medium sand
Scallop dredge			1						O'Neill *et al*. (2013)	
Scallop dredge							3-10cm		Stewart & Howarth (2016)	
Towed dredge								5.47 ± 1.28	Sciberras *et al*. (2018)	

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Towed dredge		7.15 (gravel)	2.77	5.02					Szostek *et al.* (2022)	
Set gillnets	Anchors						0.2		Grieve *et al.* (2014)	
Set gillnets	Leadline						Negligible		Grieve *et al.* (2014)	
Trammel net							Negligible		Polet *et al.* (2010)	
Boat seine	Ground gear								Eigaard *et al.* (2016)*	
Boat seine	Ground gear						1.8		Grieve *et al.* (2014)	
Boat seine	Seine ropes								Eigaard *et al.* (2016)*	
Boat seine	Sweeps						0.1		Grieve *et al.* (2014)	Assumed same penetration as otter trawl
Boat seine	Whole gear						0.11		Grieve *et al.* (2014)	
Fish trap			0.02-1						Kopp *et al.* (2020)	Muddy sand

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Beam trawl	Chain mat (12m)						2.3		Grieve *et al.* (2014)	
Beam trawl	Chain mat (4m)						2.6		Grieve *et al.* (2014)	
Beam trawl	Ground gear		1-8		0				Eigaard *et al.* (2016)*	
Beam trawl	Ground gear						1.8		Grieve *et al.* (2014)	
Beam trawl	Ground gear		1-8						Valdemarsen *et al.* (2007)	
Beam trawl	Net and ground rope						0		Kaiser *et al.* (1996)	Soft-firm sediment
Beam trawl	Shoe						0.8		Depestele *et al.* (2016)	
Beam trawl	Shoe	≤5-10	≤5-10	≤5-10	≤5-10				Eigaard *et al.* (2016)*	
Beam trawl	Shoe		0.8-10			1.5			Margetts & Bridger (1971)	Sandy ridged ground, muddy sand
Beam trawl	Shoes						Max 10		Depestele *et al.* (2016)	

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Beam trawl	Shoes						≤ 5-10		Kaiser *et al.* (1996)	Soft-rough sediment
Beam trawl	Sweeps						0.1		Grieve *et al.* (2014)	
Beam trawl	Tickler chain	≤3-10	≤3-10	≤10	≤3				Eigaard *et al.* (2016)*	
Beam trawl	Tickler chain (11mm)						0.2		Depestele *et al.* (2016)	
Beam trawl	Tickler chain (16mm)						0.7		Depestele *et al.* (2016)	
Beam trawl	Tickler chain (28mm)						0.9		Depestele *et al.* (2016)	
Beam trawl	Tickler chains							6	Bergman & Hup (1992)	
Beam trawl	Tickler chains						6		Bergman *et al.* (1990)	
Beam trawl	Tickler chains							≤ 10	Kaiser *et al.* (1996)	
Beam trawl	Tickler chains						"A few cms" to at least 8cm		Løkkeborg, 2005	
Beam trawl	Tickler chains						max 10		Paschen *et al.* (2000)	

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Beam trawl	Tickler chains & chain matrix						< 5-10		Kaiser *et al.* (1996)	Sandy-firm sediment
Beam trawl	Tickler chains (12m)						2.6		Grieve *et al.* (2014)	
Beam trawl	Tickler chains (4m)						2.7		Grieve *et al.* (2014)	
Beam trawl	Tickler chains, longitudinal chains					≤ 3			Kaiser *et al.* (1996)	
Beam trawl			4-8						BEON (1990)	
Beam trawl			6						Bergman *et al.* (1990)	Fine to medium hard sand
Beam trawl			"A few cm's"						Blom (1990)	
Beam trawl								Max 2.7	Bridger (1972)	
Beam trawl				0-2.7					Bridger (1972)	
Beam trawl			3	1					de Groot (1984)	

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Beam trawl			3	1					de Groot (1995)	
Beam trawl			2-4						Fonds (1994)	
Beam trawl							9.7		Grieve *et al.* (2014)	
Beam trawl							1.888		Grieve *et al.* (2014)	Two outrigger trawls
Beam trawl							0.693		Grieve *et al.* (2014)	Twin trawl
Beam trawl			10-20						Houghtoon *et al.* (1971)	
Beam trawl			10-20						Houghtoon *et al.* (1971)	
Beam trawl								6.5	Laban & Lindeboom (1991)	
Beam trawl			4-7					4-5	Laban & Lindeboom (1991)	Fine sand

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Beam trawl			5-6					4-7	Laban & Lindeboom (1991)	Fine sand
Beam trawl							1-8		Lindeboom & de Groot, 1998	
Beam trawl			6						Lindeboom & de Groot, 1998	Muddy sand
Beam trawl			8-10						Margetts & Bridger (1971)	Muddy sand
Beam trawl							1-8		Paschen *et al.* (1999)	
Beam trawl			2-4						Bergman & Santbrink (2000)	Fine to medium sand
Beam trawl							2-4		Bergman & Santbrink (2000)	
Beam trawl								2.72 ± 0.72	Sciberras *et al.* (2018)	
Beam trawl		4.24 (gravel)	1.64	2.98					Szostek *et al.* (2022)	

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Otter trawl	Bobbins			0					Kaiser *et al.* (1996)	
Otter trawl	Ground gear		0-2	0-10	1-8				Eigaard *et al.* (2016)*	
Otter trawl	Ground gear (rock hopper trawl)		0-2	5-10					Buhl-Mortensen *et al.* (2013)	
Otter trawl	Irish *Nephrops* trawl			14					Lindeboom & de Groot, 1998	Ireland
Otter trawl	Multi-rig clump		3-15	10-15					Eigaard *et al.* (2016)*	
Otter trawl	Net			0					Kaiser *et al.* (1996)	
Otter trawl	Otter boards						8.4		Grieve *et al.* (2014)	
Otter trawl	Roller clump of a twin trawl		0						Ivanovic *et al.* (2011)	
Otter trawl	Roller clump of a twin trawl		10-15						Ivanovic *et al.* (2011)	Muddy sand
Otter trawl	Roller clump of a twin trawl		3-4						Ivanovic *et al.* (2011)	

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Otter trawl	Sweeps		0-2	0					Buhl-Mortensen *et al.* (2013)	
Otter trawl	Sweeps and bridles		0-2	0					Eigaard *et al.* (2016)*	
Otter trawl	Sweeps chains		0-2	2-5					Buhl-Mortensen *et al.* (2013)	
Otter trawl	Sweeps chains		0-2	2-5					Eigaard *et al.* (2016)*	
Otter trawl	Tickler chains		"A thin layer of top substrate"						Bridger (1970)	
Otter trawl	Tickler chains	2-5cm	2-5		2-5				Eigaard *et al.* (2016)*	
Otter trawl	Tickler chains						2-5		Kaiser *et al.* (1996)	Soft-rough sediments
Otter trawl	Trawl door	5-6 (gravel)							O'Neill *et al.* (2009)	
Otter trawl	Trawl doors		2-5						Buhl-Mortensen *et al.* (2013)	

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Otter trawl	Trawl doors	5-10	0-10	≤15-35	10				Eigaard *et al.* (2016)*	
Otter trawl	Trawl doors			max 15					Eigaard *et al.* (2016)*	
Otter trawl	Trawl doors		5-6						Ivanovic *et al.* (2011)	Muddy sand
Otter trawl	Trawl doors			≤ 15					Kaiser *et al.* (1996)	
Otter trawl	Trawl roller clump		12						O'Neill *et al.* (2009)	Muddy sand
Otter trawl							0.941		Grieve *et al.* (2014)	Twin trawl
Otter trawl							1.010		Grieve *et al.* (2014)	
Otter trawl				max 30					Jones, 1992	Outside UK
Otter trawl				14					Lindeboom & de Groot, 1998	
Otter trawl								2.44 ± 0.69	Sciberras *et al.* (2018)	

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Otter trawl		1.74 (gravel)	0.67	1.22					Szostek *et al.* (2022)	
Pulse trawl	4.5 kn towing speed, small beam trawler						0.8		Grieve *et al.* (2014)	
Pulse trawl	5.5 kn towing speed, large beam trawler						0.9		Grieve *et al.* (2014)	
Pulse trawl	Electrodes						0.5		Depestele *et al.* (2016)	
Pulse trawl	Ground gear (parallel rubber discs)						0.35		Depestele *et al.* (2016)	
Pulse trawl	Ground gear (perpendicular rubber discs)						0.35		Depestele *et al.* (2016)	
Pulse trawl	Nose						6		Grieve *et al.* (2014)	
Pulse trawl	Shoe						0.6		Depestele *et al.* (2016)	
Pulse trawl	Ticklers and ground gear						2-2.2		Grieve *et al.* (2014)	

Gear	Component	Penetration (cm) and sediment type							Reference	Notes
		Coarse	Sand	Mud	Mixed	Rough	Not specified	Soft		
Pulse trawl							2.5		Grieve *et al.* (2014a)	

Table 12: Summary of fishing gear penetration depths by sediment type, recorded in literature.

	Sediment Type						
	Coarse (cm)	Sand (cm)	Mud (cm)	Mixed (cm)	Rough (cm)	Not specified (cm)	Soft (cm)
Minimum	1.74	0	0	*0**	1.5	0	2.44
Maximum	29.44	20	*35**	*10**	10	10	10
Average	9.06	5.63	10.03	5.7	4.83	3.28	6.19
Standard deviation	7.89	4.54	8.28	3.22	3.70	3.16	3.94
Coefficient of variation (%)	0.87	0.83	1.01	0.68	0.77	0.98	0.64

* Penetration depth estimated using European vessel size to gear size relationship and towing speeds.

Appendix 2: Fishing gear penetration depths for geophysical data sources

Table 13: Summary of penetration depths from fishing gear in different sediment types (with minimum and maximum penetration depths for each sediment type highlighted).

Estimated fishing gear type	Gravel (cm)	Sand (cm)	Sandy mud (cm)	Mixed sediments* (cm)	Width of scar (m)	Relative age	Shipping region	Water depth (m)
Beam trawl	2.5				1.6	Sediment infill / reworking evident	Dover	34
Twin-rig trawling				12.1	0.74	Recent	Forth	50
Unknown, numerous scars				<1	1.8	Recent	Dover	51
Twin-rig trawling				<1	3.4	Recent	Dover	40
Beam trawl				<1	1.4	Sediment infill / reworking evident	Dover	39
Beam trawl				3.6	2.6	Sediment infill / reworking evident	Dover	28
Twin-rig trawling			12.7		0.9	Recent	Forth	47
Twin-rig trawling			7		1.5	Recent	Forth	51
Single demersal trawl			6		2.6	Recent	Forth	52
Twin-rig trawling			5.1		0.8	Recent	Forth	53
Twin-rig trawling			6.8		3.1	Recent	Forth	56

Estimated fishing gear type	Gravel (cm)	Sand (cm)	Sandy mud (cm)	Mixed sediments* (cm)	Width of scar (m)	Relative age	Shipping region	Water depth (m)
Single demersal Trawl			<1		3	Sediment infill / reworking evident	Thames	13
Twin-rig trawling		9.5			3.2	Recent	Forth	58
Twin-rig trawling		8.4			4.1	Recent	Forth	60
Twin-rig trawling		6.6			2.5	Recent	Forth	61
Twin-rig trawling		4.4			2.2	Sediment infill / reworking evident	Dogger	77
Unknown		5.5			1.6	Sediment infill / reworking evident	Dogger	76
Twin-rig trawling		5.4			1.5	Sediment infill / reworking evident	Dogger	76
Unknown		2.5			1	Sediment infill / reworking evident	Dogger	70
Scallop Dredge or Beam Trawl		<1			1.2	Sediment infill / reworking evident	Irish sea	27
Scallop Dredge or Beam Trawl		1.4			2.3	Sediment infill / reworking evident	Irish sea	60
Scallop Dredge or Beam Trawl		2.2			0.6	Recent	Irish sea	62

Estimated fishing gear type	Gravel (cm)	Sand (cm)	Sandy mud (cm)	Mixed sediments* (cm)	Width of scar (m)	Relative age	Shipping region	Water depth (m)
Observed Min	2.5	<1	5.1	0.5	0.6	n/a	n/a	13
Observed Max	2.5	9.5	12.7	12.1	4.1	n/a	n/a	77
Observed Mean	2.5	5.1	7.52	3.44	1.98	n/a	n/a	51.86
Standard Deviation	n/a	2.78	2.99	5.02	0.98	n/a	n/a	16.69
Coefficient of Variance	n/a	0.55	0.39	1.46	0.49	n/a	n/a	0.32

Note: Mixed sediments comprise of Gravelly Muddy Sand and Gravelly Sand.

Appendix 3: Survey/trial comparison matrix

Table 14: Comparison of different survey/trial methods.

Method	Cost range	Availability of data	Weather sensitivity	Longevity of conclusions	Confidence in results	How can results be used in industry	Advantages	Disadvantages
Multibeam Ecosounder (MBES)	Mobilisation & Demobilisation: ~£10,000 - ~£50,000 Day Rate: ~£8,000 - ~£12,000 (approx.) (Based on manned vessel size around 20m)	This data acquisition is standard for pre-construction / installation projects as well as asset monitoring surveys. Although there are large volumes of data acquired, these are valuable and owned by the developer/offshore transmission owner, who may not wish to share data.	Weather sensitivity associated with vessel pitch and roll. Generally, a decreased weather sensitivity with a larger vessel. Considered less weather sensitive compared with towed sensors.	Provides data present at the time of the survey which can be subject to change through sediment mobility and geological events. Monitoring surveys can provide a time series of data increasing longevity of conclusions.	High confidence in results as is based on the actual site surveyed.	Can be used to monitor cable free spans. Can be used to determine damage to cable protection measures.	No over the side sensors. Doesn't necessarily require a large survey vessel and can be used from a day boat for nearshore work.	Resolution can be reduced with water depth. Data itself may not be clear and require ground truthing.
Side-scan Sonar (SSS)	Additional ~£300 - ~£500 per day	This data acquisition is standard for pre-construction / installation projects as well as asset monitoring surveys. Although there are large volumes of data acquired, these are valuable and owned by the developer/offshore transmission owner, who may not wish to share data.	Weather sensitivity associated with vessel pitch and safety risks associated with launch and recovery.	Provides data present at the time of the survey which can be subject to change through sediment mobility and geological events. Monitoring surveys can provide a time series of data increasing longevity of conclusions.	High confidence in results as is based on the actual site surveyed.	Can be used to monitor cable free spans. Can be used to determine damage to cable protection measures.	Maintains same altitude and resolution irrespective of depth, giving good quality.	Rarely used in a towed capacity in deep water due to the large amount of cable needed. Requires over the side working, which have some associated risks.
Sub-Bottom Profiler (SBP)	Additional ~£300 - ~£500 per day	This data acquisition is standard for pre-construction / installation projects. Although there are large volumes of data acquired, these are valuable and owned by the developer/offshore transmission owner, who may not wish to share data.	Weather sensitivity associated with vessel pitch and roll. Where SBP's are towed, there can be additional risks associated with launch and recovery.	Provides data present at the time of the survey which can be subject to change through sediment mobility and geological events. Monitoring surveys can provide a time series of data increasing longevity of conclusions.	Can be of limited confidence in observing small features such as cables when surface deployed /mounted in deeper water.	Provides valuable information for cable burial risk assessments. Where fitted to a ROV/AUV then can verify cable burial depth.	Gives very little information on cable burial unless suited to that purpose and fitted to a ROV/AUV. Can be highly weather sensitive.	Gives very little information on cable burial unless suited to that purpose and fitted to a ROV/AUV. Can be highly weather sensitive. Where surface towed requires Marine Mammal Observers and in some cases such as in certain special areas of conservation or in hours of darkness requires Passive Acoustic Monitoring (PAM). May also be subject to European Protected Species licencing.

Method	Cost range	Availability of data	Weather sensitivity	Longevity of conclusions	Confidence in results	How can results be used in industry	Advantages	Disadvantages
Remotely Operated Vehicle (ROV)	A small observation class ROV can be deployed from a standard survey vessel, from ~£1500 per day additional fee, increasing significantly with ROV size and complexity. Work Class ROV vessel (~80m) Mobilisation/demobilisation ~£200,000, day rate ~£40,000	This data acquisition is standard for monitoring surveys. Although there are large volumes of data acquired, these are valuable and owned by the developer/offshore transmission owner, who may not wish to share data.	Weather sensitivity associated with launch and recovery and large vessel movements, when deployed these can be less weather sensitive than other towed sensors and are generally deployed from large vessels with decreased weather sensitivities.	Provides data present at the time of the survey which can be subject to change through sediment mobility and geological events. Monitoring surveys can provide a time series of data increasing longevity of conclusions.	Very High confidence in results as is based on the actual site surveyed, with visual verification in real time.	Can be fitted with survey sensors such as MBES, SSS and SBP to provide the same information, and provide visual inspection data and can also be used in repair and intervention.	Provide real time data streaming so features can be observed *in situ*.	A large expensive vessel is usually required to launch and recover a Work-Class ROV.
Autonomous Underwater Vehicle (AUV)	Similar to ROV vessel cost. Mobilisation/demobilisation ~£40,000 - ~£200,000, day rate ~£40,000	Although a relatively new technology, this is becoming increasingly more popular for offshore renewables project, the data outputs are also very similar to crewed vessel operations listed above, albeit potentially higher resolution MBES and SBP data. Although there may be large volumes of data acquired, these are valuable and owned by the developer/offshore transmission owner, who may not wish to share data.	Weather sensitivity associated with launch and recovery, when deployed these can operate with only minimal sensitivity.	Provides data present at the time of the survey which can be subject to change through sediment mobility and geological events. Monitoring surveys can provide a time series of data increasing longevity of conclusions.	Very high confidence in results can be based on the actual site surveyed, with visual verification.	Can be fitted with survey sensors such as MBES, SSS and SBP to provide the same information, and provide visual inspection data.	Can provide high-resolution and multi-sensor data. When operational and not tethered, units operate underwater so are not weather sensitive.	Is a new technology and can suffer from reliability issues. Although these can be launched from the shore, a vessel is usually required to provide accurate positioning.
Synthetic Aperture Sonar (SAS)	Usually requires a Launch and Recovery System (LARS) and the towfish Mobilisation/demobilisation (excluding vessel) ~£5,000 - ~£10,000 Additional ~£4,000 to ~£5,000 per day (excluding personnel and processing)	This technology is not yet mainstream and so is scarce. These data are valuable and owned by the developer/offshore transmission owner, who may not wish to share data.	Weather sensitivity associated with vessel pitch and risks associated with launch and recovery.	Provides data present at the time of the survey which can be subject to change through sediment mobility and geological events. Monitoring surveys can provide a time series of data increasing longevity of conclusions.	Very high confidence in results due to the high resolution of data.	Provides detailed imagery of the seabed that can be used to determine the depth and pattern of trawl scars. Provides a detailed view of free spanning cables.	Provides very high-resolution data, this can minimise the requirement of ground truthing. Provides only seabed surface data and not subsurface data.	Considered quite rare and therefore expensive in the survey industry. Very long lead time for availability Requires high computing power to process and interpret at full resolution

Method	Cost range	Availability of data	Weather sensitivity	Longevity of conclusions	Confidence in results	How can results be used in industry	Advantages	Disadvantages
Uncrewed Survey Vehicle (USV)	Usually charged per project rather than per day. Approximate breakdown is: Mobilisation/demobilisation ~£20,000- ~£30,000, day rate ~ £18,000 - ~£25,000 More cost effective where numerous USV's can operate on one site.	Although a relatively new technology, this is becoming increasingly more popular for offshore renewables projects, the data output is also the same as crewed vessel operations listed above. Although there are large volumes of data acquired, these are valuable and owned by the developer/offshore transmission owner, who may not wish to share data.	USV's are generally small so can suffer from high weather sensitivity.	Provides data present at the time of the survey which can be subject to change through sediment mobility and geological events. Monitoring surveys can provide a time series of data increasing longevity of conclusions.	High confidence in results as is based on the actual site surveyed.	Can be fitted with survey sensors such as MBES, SSS and SBP to provide the same information.	Can be an environmentally friendly and cost-effective means of acquiring data. Can operate in hostile environments without risk of safety to personnel.	Limited application in deeper water. Are generally small and can be more weather sensitive than larger vessels. Is a new technology and can suffer from reliability issues.
Over-trawl trials	Typical vessel around 25m Length. ~£3,500 - ~£7,500 per day, charged for mob / demob days as well.	This isn't required for all OWF projects and can be proposed as a consent condition in some regions.	Methods are subject to weather sensitivities associated with relatively small vessel, however equipment robustness and launch and recovery procedures can minimise downtime compared with survey vessel of a similar size.	These provide a snapshot of over-trawl fishing gear at the time of the trial which can be subject to change with sustained fishing activity and sediment mobility.	Trials usually only include one gear type, confidence in results can only be applied for the same gear type, operated at the same speed in the same area as the trial, and they cannot not give temporal confidence in results.	Can be used to determine if an area of cable protection or possible cable exposure causes snagging and/or damage to fishing gear.	Can provide some assurances for fishers to fish an area after cable installation, helping facilitate fisheries coexistence.	It provides only a snapshot of results from when the trial was undertaken. May instil a false confidence to some fishers where risks to fishing gear still persist. Contradicts maritime safety advice.
Cable burial modelling	N/A for this work package, and highly project specific.	A Cable Burial Risk Assessment or they key results are often provided as part of the consent application for a project. However, it is not always a requirement to provide full details.	No weather sensitivity, although relies on data acquisition which is weather sensitive.	Based on site specific and ground-truthed data acquired at the time of survey, these can change in areas of seabed mobility. Once installed monitoring for cable exposures and reduced depth of burial is recommended.	Based on site specific and ground-truthed data providing high confidence, however feasibility of achieving target depth can be variable.	Assessment of external threats to subsea cables, providing a theoretical cable burial target depth to mitigate damage to a cable and recommend suitable cable protection measures.	Where correct burial is achieved can protect cables against expected potential threats.	Target / modelled burial depth is not always achievable, with installation tools, which can increase the risk or perceived risk of a cable in that location.

Method	Cost range	Availability of data	Weather sensitivity	Longevity of conclusions	Confidence in results	How can results be used in industry	Advantages	Disadvantages
Fishing Gear Trial	Typical vessel around 25m Length. ~£3,500 - ~£7,500 per day, charged for mob / demob days as well. Shore based trials will be significantly less.	Gear trails are usually undertaken as part or research where results are published giving good availability. However, not many gear trials have been undertaken to date.	Vessel based trials can be weather sensitive, where static gear is deployed weather windows can be used to maximise efficiency. Where trails do not include a vessel, e.g. shore-based dredge trawls these have only a limited weather sensitivity.	Results can have good longevity with innovation in this sector somewhat limited. However, confidence in long term commercial sustainability is more limited.	While gear trials can often be a result of sound research, there use both commercially and outside of a specific site can be limited, reducing confidence in results.	Can be used to determine the feasibility of alternative fishing gears use in OFW's. Can be used to improve fishing gear design to have reduced impacts and/or increased suitability to target species.	Can decrease the impact of mobile fishing gears on the seabed, potentially reducing seabed penetration and damage to the environment.	an be difficult obtaining approval for alternative fishing gears from Defra and there is no guarantee of acceptance, which can ensure no change to the industry, despite research efforts.
Cable monitoring data	DTS: ~£85k DAS: ~£100k Software with Database and Visualization: ~£8.5k Cable Rating and Ampacity Forecasting: ~£35k Depth of Burial detection: ~£50k Optional Servicing and support: ~£17-35k per year	Although there are large volumes of data acquired, these are valuable and owned by the developer/offshore transmission owner, who may not wish to share data.	No weather sensitivity.	Provides real time monitoring where patterns can be established providing good longevity of results.	Results can be subject to interference and interpretations which can reduce confidence. Manufacturer claims can be difficult to quantify.	Used to determine cable health, cable burial status and potential fishing / anchoring activity.	Can be cost effective means of acquiring burial status and vessel activity data.	Susceptible to environmental and industrial interference, which can provide misleading interpretation. Can lack resolution to provide accurate interpretation. Legal uncertainties associated with using the data to inform third parties. Security concerns associated with using the data to inform third parties.

Appendix 4: Sediment mobility modelling

1.1. Overview of sediment modelling applications

Numerical modelling can be a powerful tool for understanding the offshore environment. This understanding can be used to identify areas that may be at high risk, for example, of cable exposure, and therefore fishing activities. The information provided by models can therefore assist in mitigating such risks through engineered solutions or help to establish an appropriate monitoring strategy.

Models come in many different forms from simple steady-state models to complex dynamic models. These models can be used to replicate many different physio-chemical processes and features relating to hydrodynamics, waves, sediment morphology and movement, sediment and water quality, and two-way interactions between the marine environment and offshore structures and activities.

Before environmental models are applied in any study, it is important to consider a few points carefully:

- What outputs will the model produce? What outputs will it not produce?
- What data are required to construct, calibrate and validate the model?
- How will model outputs be integrated with other project activities and understanding?
- What inaccuracies are associated with model predictions and how will these be dealt with?

This section presents a high-level overview of some key considerations relating to the construction and application of environmental models for use in informing OWF developments, particularly in relation to sediment movement and cable free-spanning (and the consequent intersection with fishing activities).

1.1.1. Advantages of sediment modelling

Numerical models offer some key advantages when it comes to understanding the marine environment:

- They can provide full coverage of a large area without data gaps in a way that might not be possible with field surveys. For example, current velocities or suspended sediment concentrations can only be measured at a limited number of locations; a calibrated and validated model, conversely, can produce predictions of these parameters seamlessly covering large areas.
- Models can be run for long periods of time, out to decades or more. Field surveys generally cannot compete with these timescales, certainly within the typical timeframe of an OWF project.
- Models have predictive capability and can be used to simulate future conditions. This may cover an extension to existing conditions, or it may allow simulation of influences that are not yet in existence, such as the physical effects of a future OWF development or the consequences of long-term climate change.

- Modelling software can produce informative presentations (maps, animations, time series, statistics etc.) that can help to communicate study outputs to stakeholders.

1.1.2. Challenges of sediment modelling

Models have a number of inherent challenges and limitations that must be considered throughout the project: when deciding on the use of models; when selecting the model software, domain, resolution, physical processes and scenarios to run; and when interpreting the outputs. Key challenges include:

- While models are capable of simulating conditions across wide space and time scales, they cannot effectively simulate all scales at once. A small-scale, high-resolution model built to simulate local scour around a structure will not be suitable for assessing regional sediment transport pathways and budgets. Models are powerful but are also limited to the present scientific understanding. Model scales must be carefully selected to answer a specific question; if necessary, multiple models covering different scales may be required.
- Further to the previous point, models have an underlying spatial and temporal resolution. It is not possible to resolve features or processes that lie below this underlying resolution (other than by interpolation, which adds no new information).
- While numerical models are based on sound physical principles such as the equations of motion and empirically-derived formulae, it cannot be assumed that they will just 'work'. Models therefore need to be calibrated and validated using field data. The suitability of field data must take into account many factors including appropriate measurement sites/areas, timing and duration of surveys, sampling timestep, the parameters to be measured, measurement accuracy, limits of detection and more.
- Two common modelling aphorisms may help to highlight some of the challenges:
    - **Garbage in, garbage out (GIGO)**: In general terms, the output from a model can be of no better quality than the data that are used to construct, calibrate, validate and drive that model. Poor underlying data will necessarily lead to poor model outputs and misleading results.
    - **All models are wrong, but some models are useful**: A model is a representation of reality, not reality itself, and outputs will never be perfect (they are 'always wrong'). However, model predictions may be informative and helpful as long as their underlying limitations are acknowledged and accounted for, within the broader context of a study.
- The predictive capability of models is powerful, but predictions that lie beyond the limits of calibration – future post-installation or climate change scenarios, for example – can only be considered indicative since they cannot be directly tested against measurements.
- Sediment modelling, in particular, offers some unique challenges. Sediments are three-dimensional, can be highly variable in space, and evolve dynamically over time. It is not always obvious which processes are key to sediment morphology and evolution, particularly for future scenarios that cannot be directly tested (e.g. long-term climate change).

1.1.3. Types of sediment mobility modelling

Hydrodynamic model (currents and water levels)

Hydrodynamic models aim to simulate current velocities and water level changes. Around the UK, water movement is (as a rule) tidally dominated. Sedimentary features such as banks and sandwaves often reflect the regular, oscillatory nature of tidal currents, and their stability (or long-term migration) is often dictated by the tidal current regime. However, there are areas where tides are weak and non-tidal forcings (e.g. general circulation, density-driven, surge-related or surface wind-driven currents) are of equal or greater importance.

Wave model

Wave processes may also have an effect on sediment dynamics, especially in shallow water. Waves cause short-period oscillatory water movements parallel to the direction of wave propagation. These movements are a function of wave height and length, and decrease through the water column.

Wave-induced currents differ in some key respects from tidal currents. For example, they are not regular or (long-term) predictable, and will reflect the passage of weather systems (either local systems of more distant systems generating swell waves). They also act on smaller time and space scales than tidal currents, which means it may be difficult to construct a model that simulates both processes effectively.

Simple sediment transport model

Having described the movement of water using appropriate hydrodynamic and/or wave models, these may be used to drive models of sediment transport. Again, different levels of modelling are possible.

The following describes what is termed a simple sediment transport model. Near-bed forcing (from tidal, wave-induced or other currents) is used to calculate a boundary layer shear stress acting on the bed. The bed sediments themselves will have a critical shear stress above which they may be entrained, moved as bedload and ultimately suspended into the water column. This bed shear stress is a function of sediment density and – critically – the sediment particle size distribution. If the current-induced shear stress exceeds the critical shear stress, entrainment and movement will occur. Sediment remains in transport or suspension until the current speeds drop below a threshold and the sediment can settle out of the water column, a process which is also a function of sediment density and particle size distribution.

Dynamic morphological model

A more complex and involved type of sediment model is dynamic morphological modelling. This works on the same general principle as the simple sediment transport model (comparison of induced shear stress against critical shear stress), but it allows the model bathymetry to evolve as a result. For example, it may be used to simulate the long-term evolution and migration of sand banks. This type of modelling may be of interest over longer time periods (e.g. out to the lifetime of an OWF).

A dynamic morphological model is not something that is applicable to all projects. Given the need for high quality data with which to build and calibrate such a model, in most cases it may be more appropriate to base a cable risk assessment on an informed interpretation of the existing data carried out by a subject matter expert, with modelling considered for particularly complex or high risk areas.

1.1.4. Sediment modelling applications – review and recommendations

Models are a tool that can, if used properly, aid our understanding of the environment. However, they should not be used in isolation, but considered in conjunction with other approaches, particularly a data-driven review of morphological change and associated risks.

- Modelling should not be undertaken without a robust understanding and evaluation of the competing strengths and limitations of modelling-based approaches.
- It is important to understand what space and time scales need to be assessed, and to tailor modelling-based approaches accordingly.
- It is important to understand what physical processes are included in (or excluded from) the model, and whether these fully capture the desired outputs and study requirements.
- If suitable supporting data do not exist to construct, calibrate and validate all required models (hydrodynamic, wave, sediment etc.), there must be a financial and programme commitment to obtaining these data. Poor quality supporting data will lead to poor quality model outputs that may have little value – or, worse, lead to a misguided understanding of risk.
- Any sediment modelling-based study needs to be supported by the informed review of a qualified subject matter expert who can consider the model outputs within the wider study context and, in particular, interpret these model outputs through comparison with a data-driven review of morphological change, impacts and risk.

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