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Spatial conflict in offshore wind farms: Challenges and solutions for the commercial fishing industry

C.L. Szostek [a,c,*], S.C.L. Watson [a,c], N. Trifonova [b], N.J. Beaumont [a,c], B.E. Scott [b]

[a] Plymouth Marine Laboratory, Prospect Place, Plymouth, Devon, PL13DH, UK
[b] School of Biological Sciences, University of Aberdeen, Tillydrone Avenue, Aberdeen, AB24 2TZ, UK
[c] The UK Energy Research Centre, UK

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ABSTRACT

The offshore wind (OW) energy industry is growing exponentially. Coastal seas provide a wealth of ecosystem services and national regulators face the challenge of managing co-location and spatial conflict between multiple marine industries. Due to its prominent position in the global OW energy market, we use the UK as a case study through which to investigate interactions between the commercial fishing industry and OWFs. This study presents views from the fishing industry gathered through a structured survey and one-on-one interviews, and reveals the major issues and concerns facing fishermen in respect of current, and future developments. The majority of fishermen surveyed feel their fishing grounds and livelihoods are threatened by OWFs, with social, wellbeing and economic impacts felt across vessel sizes (5–50m in length) and fleet sectors (represented by 11 types of fishing gear). A small minority identified potential benefits, and most suggested potential solutions and opportunities for mitigation of impacts. We summarise the findings, outline conflicts and opportunities, and converge these into policy recommendations with the aim of supporting increased collaboration and equity between commercial fishermen and energy companies in future offshore leasing rounds, and provide insight and best practice to other global nations developing offshore wind energy.

1. Introduction

1.1. Increase in the spatial footprint of offshore wind

Our seas support multiple activities, including aggregate dredging, shipping and maritime industries, commercial and recreational fisheries, aquaculture, and offshore renewable energy. Frequently, multiple activities overlap in space and there are environmental and socio-economic trade-offs associated with such large-scale development of the seabed (Guşatu et al., 2022). Activities must also align with regulation for area-based management, conservation objectives, and Net Zero targets (Putuhena et al., 2023). Spatial competition is an increasing pressure on commercial fishing in particular (Jentoft and Knol, 2014; Chaji and Werner, 2023; Dunkley and Solandt, 2022), and both OWF and fisheries have similar spatial preferences: shallow seas, softer sediment, and proximity to coast. Globally, the number of installed OW turbines has doubled since 2017 and there will be an estimated 7-fold increase in the pace of deployment going forward (Paolo et al., 2024). Northern Europe and China have dominated the market thus far, accounting for 52% and 45% respectively, up to 2021 (Paolo et al., 2024). Other major economies such as the USA and Australia have emerging industries (GWEC, 2024). This rapid expansion of the industry brings challenges to regulators and requires a significant increase in understanding of both environmental and socio-economic consequences.

1.2. Conflicts between offshore wind farms and commercial fisheries

Studies of socio-economic impacts of OWF developments on commercial fishing span the last two decades (e.g. Mackinson et al., 2006; Alexander et al., 2013; Lee et al., 2010; Hall and Lazarus, 2015; Hooper et al., 2015; Reilly et al., 2015; Schupp et al., 2021). Although, literature repeatedly cites that affected communities and stakeholders should be consulted as early as possible in planning stages for large offshore infrastructure (e.g. Hall and Lazarus, 2015), whether responding to consultations has a tangible impact on decisions is not clear and a greater emphasis is needed on social sustainability in the development of fisheries policy (Gómez and Maynou, 2021).

* Corresponding author. Plymouth Marine Laboratory, Prospect Place, Plymouth, Devon, PL13DH, UK.
E-mail address: csz@pml.ac.uk (C.L. Szostek).

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In the UK, fishing is not excluded from within operational wind farms, due to the following law: "a public right of navigation and of fishing in the sea and rights ancillary to it" – *Halsbury op cit, para 243*. However, the practicalities of co-existence are disputed (Mackinson et al., 2006; ABPMer, 2022), with safety concerns over interactions of fishing vessels and gear with turbines and subsea cables (Rouse et al., 2020). In Europe it is common to completely exclude certain types of fishing within wind farms, e.g. in Belgium, Germany, Denmark and the Netherlands (EC, 2020). Under EU legislation, a 500-m safety zone excluding fishing activities and navigation can be implemented around construction zones, and a 50-m zone around the turbine bases during operation (FLOWW, 2014). This avoids the risk of fishing gear snagging and damaging cables, and ship strikes to turbines. In China, regulations propose that areas should be excluded from OWF development if designated for other commercial uses such as fishing (DeCastro et al., 2019).

OWF construction, operation and decommissioning also have ecological outcomes (Galpasoro et al., 2022; Szostek et al., 2024; Watson et al., 2024); which can potentially impede or enhance the ability to meet marine conservation targets, or lead to societal consequences including impacts on commercial fishing. Potential ecological benefits include vertical habitat creation on sandy seabed, the artificial reef effect (Degraer et al., 2020; Vivier et al., 2021; Lemasson et al., 2024), and de-facto marine protected area effects (Lindeboom et al., 2011; Ashley et al., 2014). Ecological benefits can be sought intentionally through Nature-based Solutions (NBS) such as colocation of shellfish or seaweed farming with OWF (Rendle et al., 2023; Amazon, 2023). Potential negative ecological impacts include noise from pile-driving and construction, episodic impacts from seismic surveys and impacts from electromagnetic fields (EMF) (Gill et al., 2009; Love et al., 2017; Scott et al., 2018; Hutchison et al., 2020a; Hutchison et al., 2020b). Opportunities and potential benefits of offshore installations to the fishing industry focus largely around decapod fisheries that use static fishing gears (Hooper and Austen, 2014; Roach et al., 2018; Thatcher et al., 2023, 2024), or the secondary de facto MPA effect which could potentially lead to a localized increase in fish abundance (Ashley et al., 2014). Other potential impacts on target species populations are climate change, artificial light at night (ALAN) around turbines (Marangoni et al., 2022), impacts on marine stratification, turbulence, and primary production (Daewel et al., 2022). Although these remain largely unquantified at present, impacts are inevitable on an already strained sector.

1.3. The UK as a case-study for marine spatial competition

In 2022, the UK provided 45% of the European OW energy capacity and 24% of global capacity (Crown Estate, 2022). The first two wind turbines in the UK were installed in the UK in the year 2000. Fishermen's concerns towards fifteen proposed Round 2 wind farm sites (with up to 250 turbines each) are documented (Mackinson et al., 2006). By 2022, there were 3197 turbines operating or under construction in UK waters. The UK is considered a global leader in OWF and installations are increasing exponentially, as too is the impact on fishing communities competing for ever-reducing marine space (Putuhena et al., 2023).

In 2021, there were 4269 active fishing vessels in the UK, with 6835 employed fishermen, and additional employment in fish processing (17,971 FTE in 2022). Turnover of the UK fishing fleet was £802 million in 2021, with a profit of £222 million (Seafish, 2023, 2024), with Gross Value Added (GVA) to the UK economy of £461 million. The UK OW industry directly employed 17,000 in 2023, but 88,509 jobs are forecast to be required by 2026 (OWIC, 2023). Although the ownership of wind farms around the UK is multi-national, the gross value added (GVA) to the UK per GW installed, given 32% UK content, was estimated at £1.8bn in 2017 (Noonan and Smart, 2017). While the OWF industry exceeds fisheries in monetary value, these figures do not account for the cultural heritage value of fisheries, vital to many coastal communities and important in fisheries policy development (Acott and Urquhart, 2014; Gómez and Maynou, 2021). The figures also don't reflect the distribution of employment and profit, which in the case of fisheries may be found within lower resilience communities.

This study aims to evaluate how attitudes, perceptions and impacts have evolved in light of increasing numbers of OWF installations, and in combination with other pressures impacting the fishing industry such as spatial competition, the Covid-19 pandemic (Ruiz-Salmón et al., 2021), Brexit, increased fuel costs, changes in visa requirements for foreign crew, and regulatory changes (Seafish, 2023). We present a case-study of the socio-economic impacts of OWF developments on commercial fisheries operating around the UK, including adjacent seas and nations. An enhanced understanding of the full extent of these impacts can help to facilitate a rapid, but sustainable and fair energy transition. We also reinforce existing calls for policy recommendations (e.g. Schupp et al., 2021) and make further proposals, to improve outcomes for the coexistence of offshore wind energy and commercial fishing.

2. Methods

2.1. Surveys

A semi-structured online survey was developed (supplementary material 1) and was open for online responses in December 2023 and January 2024. The survey was distributed using a weblink and QR code, through social media channels, industry press and through direct contact to fishing industry representatives and organisations. Anyone involved in commercial fishing in UK waters was invited to take part in the survey. Ethical approval was awarded by the University of Plymouth Ethics Committee (project ID 4649).

Opening questions gathered background information such as: the respondent's status in the fishing industry, details on vessel size, engine size, home port, landing ports, gear types used and species targeted during different seasons of the year. Maps of wind farms either operational or under construction (Fig. 1), and of future planned wind farms at the time of the study (Fig. 1) were presented and respondents asked to identify which, if any, wind farms had impacted on their fishing activity (or if they expect them to in future). A series of multiple choice and Likert-style questions with the following themes investigated what outcomes respondent had experienced (positive or negative) due to existing OWF, with the questions repeated for future planned developments:

- distance travelled to fishing grounds;
- OWF sites of impact;
- responses to displacement;
- impacts/outcomes of displacement;
- benefits of OWF;
- compensation payments;
- co-location of fishing and OWF;
- additional comments

Respondents were invited to leave contact details to be contacted for a follow-up interview.

2.2. Interviews

Sixteen respondents were interviewed over the telephone with interviews lasting between 20 and 45 min. Interviews were semi-structured, first asking respondents to elaborate on any comments made in the survey. Then each respondent was asked for comment on four topics (although the scope and focus of the interview was also guided by the information offered by the respondent):

- government **consultations;**

Fig. 1. Map of wind farms in UK territorial waters that was presented in the online survey. Operational or under construction OWF (yellow), or future planned OWF (grey). Data from Crown Estate Open Data, as of November 2023. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

- measures that might enable **co-existence** of OWF and commercial fishing;
- **solutions** that could help improve outcomes for fishermen in relation to OWFs,
- their experiences around monetary **compensation** following displacement.

2.3. Data analysis

From the survey data, the relationship between the number of times a wind farm was cited as having an impact on commercial fishing and other variables were investigated with linear regression. Other variables included the capacity of the wind farm, and the year the wind farm became operational. Differences in responses to questions based on vessel size (under 15m/>15m in length) and between mobile/static fishing gears are evaluated and described. Thematic analysis (Braun and Clarke, 2012) of interview scripts was conducted to reveal prevalent issues and concerns. Each script was coded using an inductive process, whereby each comment or statement was assigned a topic code. Topic codes were then grouped into broader categories to highlight topics of most interest and relevance to fishermen.

3. Results

3.1. Survey results

3.1.1. Respondent characteristics

There were 52 complete responses to the survey, with the majority (73%) from skippers. This represents around 1% of fishers in the UK. Other respondents included fleet managers (13%), crew (4%), industry representatives (8%) and a single retired fisherman (2%). There were 26 respondents using mobile fishing gears (trawls and dredges), 24 that used static gear (pots, creels, including rod and line), and two respondents that either used both gear types or did not specify gear type. A range of vessel sizes and fishing gears were represented (Table 1). Twenty responses represented a single gear type, while the remainder represented multiple gear types, reflecting different target species assemblages and seasonal variation in fishing activity throughout the year. Respondents home ports were located around the British Isles and the Netherlands (Fig. 2). Three hundred partial responses, whereby people had followed the link to the survey but not entered information beyond the first question regarding consent, were removed from analysis.

3.1.2. Impacts from present and future wind farms

Of the OWF currently in operation or under construction, 'Seagreen' (north eastern Scotland) was cited most frequently as impacting fishing activities (n = 11; [mobile = 7, static = 4]), which at the time of the survey was the most recent to become operational (in 2023), and also

Table 1
Characteristics of vessels represented by survey responses (s.d. = standard deviation).

Characteristics of respondents	Value range
Vessel length (m)	5-50 (mean 16; s.d. 10.3)
Engine size (hp)	25-4000 (mean 544.6, s.d. 816.4)
Nationality	English, Welsh, Scottish, Northern Irish, Irish, Dutch, Manx (Isle of Man)
Number of different gears used	Single (n = 20), multiple (n = 32)
Types of mobile gear used	otter trawl, demersal trawl, pelagic mid-water trawl, semi-pelagic trawl, scallop dredge, long-lines
Types of static gear used	Pots, creels, fixed nets, gill-net, rod and line
Species targeted (mobile gear)	queen scallops, king scallops, bass, cod, skate, spurdog, cuttlefish, dover sole, turbot, brill, plaice, haddock, herring, mackerel, horse mackerel, blue whiting, pollock, red mullet, hake, lemon sole, *Nephrops,* mixed non-quota species
Species targeted (static gear)	Brown crab, spider crab, velvet crab, lobster, *Nephrops*, whelk

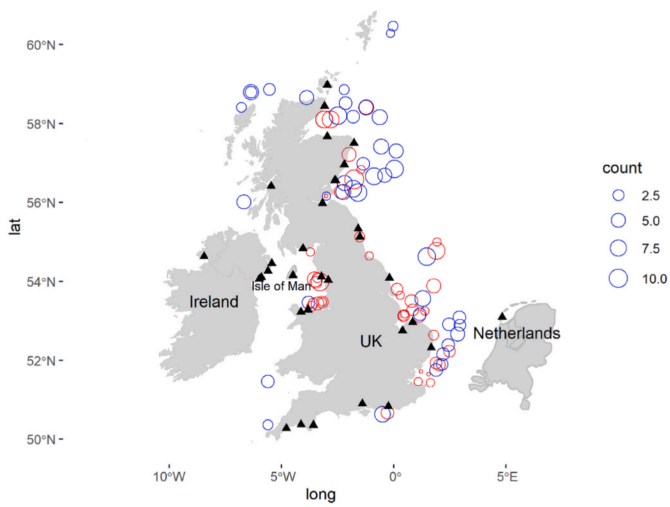

Fig. 2. Frequency that respondents cited impacts to commercial fishing from wind farms currently operational or under construction (red circles), pre-construction or proposed (blue circles) as of November 2023, and home ports of survey respondents (black triangles). (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

the deepest fixed-base turbine wind farm in the UK (Fig. 2). Other wind farms frequently cited as impacting fishing activities were Barrow (western Irish Sea), Dogger bank (North Sea), Beatrice, Moray East and West (West coast Scotland) and Walney (Irish Sea). The frequency of selection of a wind farm by respondents (Fig. 2) does not equate to the magnitude of the impact on the UK fishing industry, due to the relatively small sample size of respondents, but indicates that fisheries impacts do occur in those locations. Two respondents said they were not impacted by any wind farms in construction or operational phases; these respondents used static gear fishing up to 12 NM from the shore. Gunfleet Sands, London Array and Methil Demo were not indicated as impacting by any of the respondents. This could be due to the geographical distribution of respondents or the size of the wind farms (Gunfleet Sands 2 Environmental Statement states that 21 fishing vessels would potentially be impacted; Methil is a small demonstration site). The capacity (MW) of installed wind farms has increased between 2000 and 2023 ($r^2 = 0.315$), but there is no correlation between the date a wind farm became operational and the number of times it was cited as having an impact on commercial fishing ($r^2 = 0.129$). There is a weak trend in the capacity of the wind farm (MW) and the number of times it was cited as having an impact on commercial fishing ($r^2 = 0.228$). In relation to the expected impact of pre-construction or proposed wind farms (as of January 2024), all were expected to have an impact on commercial fishing. Bellrock, Berwick Bank and Caledonia (eastern Scotland) were cited most frequently.

Responses to the Likert scale questions are presented below, with additional comments from respondents in supplementary material 2.

3.1.3. *Response to displacement (current)*

Around three-quarters (n = 40) of respondents reported specific responses to displacement by an operational OWF. The most common response (n = 35; [mobile = 20, static = 15]) was using different fishing grounds. Some respondents supplemented their income in other ways (n = 7): six of these related to static gear fishing vessels <15m in length. Other responses included; changing gear or target species (n = 6), changed or modified vessel (n = 3), or left the fishing industry (n = 1). Some respondents cited more than one response to displacement.

3.1.4. *Response to displacement (future)*

If all wind farms that are planned or proposed (as of December 2023) are built, most respondents would consider leaving the industry (n = 35). Other potential responses are using different fishing grounds (n = 25), supplementing income through other employment (n = 13), modifying fishing gear (n = 5), changing their target species (n = 4) and change or modify their vessel (n = 2). Some respondents cited more than one response.

3.1.5. *Ability to maintain catches/profitability (current)*

Responses were very negative or negative (n = 35), neutral (n = 4), positive (n = 1), or no response (n = 11). One neutral response was in relation to negative impacts for one target species (pollack), counteracted by positive impacts on a different target species (lobster).

3.1.6. *Ability to maintain catches/profitability (future)*

Most respondents expected a very negative or negative impact from future planned or proposed wind farms (n = 49). A few were neutral (n = 3). Comments repeated concerns over impacts such as displacement, increased time at sea and operating cost, or fishing unknown grounds.

3.1.7. *Spatial competition (current/future)*

Most respondents strongly agreed or agreed that displacement had caused spatial competition with other fishers (n = 32, [mobile = 14; static = 18]). Some remained neutral (n = 6), representing fishing activity for *Nephrops* in the Irish Sea, beam trawls in the North Sea and creels in Scotland. In disagreement (n = 2), were fishermen involved with trawling and long-line activity on the English south coast. Most respondents (n = 48) strongly agreed or agreed they would expect to experience spatial competition in future if all planned and proposed wind farms were built. Other responses were neutral (n = 2), representing a >15m scallop dredging vessel and an <10m vessel mixed-gear fisherman.

3.1.8. *Distance travelled to fish (current/future)*

Most respondents (n = 38) said they travelled further than normal to fish due to displacement from wind farms; 0–12 NM further (n = 11, [mobile = 5; static = 5, both = 1]), 12–50 miles further (n = 17, [mobile = 9; static = 7; both = 1]), up to, or greater than 100 NM further (n = 8; [mobile = 7, static = 1]) (Fig. 3). Some respondents did not have to travel further to fish (n = 11, [mobile = 4, static = 6, both = 1]). One of these respondents stated they would travel less distance if displaced to waters closer to home, although that would not be their preferred fishing ground and any fuel savings may be cancelled out due to a reduction in catch per unit effort (CPUE). Thirty-eight respondents would expect to have to travel further to fish in future (majority (n = 14) 12–50 NM further).

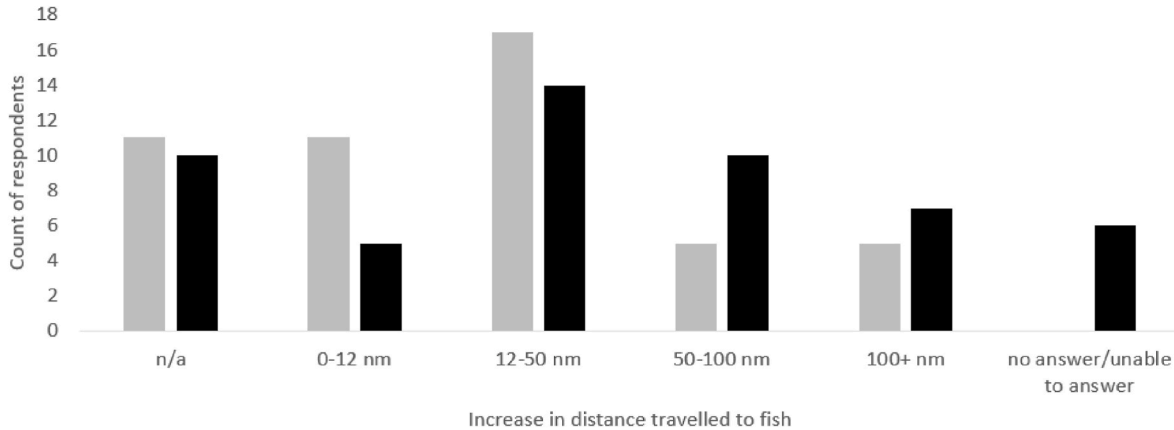

Fig. 3. Increase in distance that respondents had to travel to fish due to displacement by offshore wind farms. Grey bars = current situation, black bars = expected based on future planned developments.

3.1.9. *Financial implications of displacement (current/future)*

Most respondents (n = 37; [mobile = 19, static = 18]) strongly agreed or agreed that they had experienced negative financial implications, while some remained neutral (n = 5). All but one (n = 51) respondents strongly agreed or agreed that they expected to face negative financial implications in future. One respondent remained neutral and commented that it would depend on whether larger vessels were displaced to their preferred fishing grounds.

3.1.10. *Safety implications (current/future)*

The majority of respondents cited safety implications due to wind farms and displacement (n = 30; [mobile = 17, static = 13]), while others remained neutral (n = 9). One respondent strongly disagreed.

Specific safety implications cited are:

- Increased steaming time required leading to longer periods at sea, increased fatigue and associated risks
- Needing to travel further offshore in less favourable conditions and with less shelter to maintain catch levels
- Navigational dangers at night time due to poorly lit turbine arrays
- Lack of experience on unknown grounds e.g. unknown seabed obstructions
- Risk of collision with turbines if tide or weather changes
- Snagging cables that could lead to gear loss or vessel capsize
- Accidents/interactions with wind farm vessels reported
- Reports of wind farm vessels travelling at speed past fishing vessels retrieving static gear

In future, more respondents agreed or strongly agreed that they would expect to experience safety implications (n = 39), while some remained neutral (n = 10). Two respondents disagreed or strongly disagreed. There were comments about array design, uncertainties related to future floating offshore wind farms (FLOW) and search & rescue operations.

3.1.11. *Benefits of offshore wind farms (current/future)*

Few respondents (n = 5) reported benefits from wind farms relating to fishing opportunities, compensation and community benefit schemes (all static gear fishers, vessels <15m length). More respondents (n = 25) cited no benefits. Two respondents expected benefits from future OWF, including potential benefits to marine biodiversity and sources of employment (static gear fishers, <15m vessels). Most (n = 48) expected no future benefits.

3.1.12. *Compensation*

Some respondents (n = 17, [mobile = 2, static = 14, both = 1]) had received compensation payments from energy companies either during seismic surveys pre-construction, or to move static gear for construction, although comments reflected frustration in the amount of money received or inequity of payments between individuals or fleet sectors. Only one vessel that received compensation was >15m length.

3.1.13. *Potential for co-location of offshore wind and commercial fishing*

Thirty respondents commented on the potential for colocation of OWFs and commercial fishing. Three were pragmatic or optimistic, while the remainder were largely negative. It was suggested that in certain circumstances, colocation could occur but this was in relation to specific gear types and conditions, and many respondents confirmed they would not fish in wind farms, even where allowed to do so. Concerns were voiced that fixed-based wind farms are often cited in shallow areas over softer sediments, representing prime fishing ground or spawning areas.

3.1.14. *Additional comments*

Thirty-two respondents provided additional comments, relating to alterations of the marine habitat from construction activities, impacts from EMF, impacts on maritime traffic, cabling routes, impacts of seismic surveys on marine life and significant loss of fishing grounds.

3.2. *Interview results*

Questions centred around consultations, coexistence, solutions and compensation. Responses are grouped into 15 themes and are ordered in importance (the number of times raised):, Compensation, Cables, Solutions, Ecological Impacts, Other impacts, Displacement, Communication, Planning, Wellbeing, Consultations, Licensing, EIAs, Safety, Benefits and Coexistence (Table 2), with details of points raised found in supplementary material 3.

4. Discussion

This study demonstrates that most wind farms in planning or operation in UK waters are causing impacts on commercial fishing, most likely due to fishing activity being widely distributed across UK waters. Even relatively small areas can be important to fishermen on a seasonal basis if they represent prime, historical fishing grounds. Although this study reflects the views of a relatively small number of fishermen, it highlights key concerns that have been echoed by earlier and recent studies and reports. Expanding the sample size in future work could be beneficial. A broad range of vessel sizes, gear types and respondents are represented in this study, indicating that impacts of OWFs are not limited to a particular fishing sector, fleet or gear type. Although the

Table 2
Table of themes derived from interviews with fishermen and industry representatives. Themes and sub-themes are ordered in the frequency discussed, in order of most to least frequent.

Theme	Sub-themes
Compensation	Inadequate, inequity, knock-on effects, intimidation, benefits, international fishermen, challenges, evidence, framework, anglers
Cables	Fisheries, EMF, burial depth, extent
Solutions	Compensation, vessel decommissioning, turbine array design, fisheries enhancement, collaboration, spatial management, pile-driving, employment, indemnity, cable burial
Ecological Impacts	EMF, fisheries, habitat, pile-driving, seismic survey, cumulative
Other impacts	Socio-economic, fishing behaviour, safety, marine protected areas, supply chain, decommissioning of turbines
Displacement	Knock-on effects, spatial squeeze, avoidance, quota availability, intimidation, loss of ground
Communication	Inadequate, intimidation, mis-communication
Planning	Fisheries, marine traffic, economics
Wellbeing	Employment, Loss of crew, financial
Consultations	Lack of resource, ineffective, consultees
Licensing	Enforcement, lack of process, evidence
Environmental Impact Assessments (EIAs)	Evidence, inadequate, lack of resource
Safety	Navigational hazards, search & rescue
Benefits	Ecological, Community fund
Coexistence	Challenges, benefits

survey was not actively promoted outside of the UK, two responses from Dutch fishermen indicate that impacts are experienced by neighbouring nations fishing in UK waters.

In 2005, the OW industry was in it's infancy, with just three operational wind farms in the UK. In 2024, there are 52 operational wind farms in UK waters and a further 1000 km^2 of seabed under consideration for development in round 5 (Crown Estate, 2023). Concerns raised two decades ago (Mackinson et al., 2006) and in 2015, (Hooper et al., 2015), are echoed in this study (e.g. displacement, socio-economics, ecological effects, safety and trust in decision-making). This suggests that, little has been done to effectively address or mitigate impacts and concerns. We note that subsea cables are perceived to cause as much impact as the turbines themselves, due to the extent of the footprint, and safety or ecological concerns.

4.1. Impacts of displacement

More than half of respondents cited that spatial conflict and displacement were impacting them at present, with this increasing to 'most respondents' in relation to future developments. Although a common response to displacement or spatial conflict is to travel further to fish, this brings with it a host of economic and safety implications cited by respondents – increased fuel costs lead to reduced profit, increased carbon footprint (Scherrer et al., 2024), fishing on unknown or less productive grounds reduces yield and therefore profit, and safety considerations (see below). Travelling further to fish (12–100+ NM was reported mostly by mobile gear fishers and larger vessels, that have greater capacity to do so than smaller vessels. Impacts included being unable to pay crew due to reduced catches, and significant reduction in the value of their vessel as the fishing industry declines, or losing crew due to having to relocate to a distant landing port during the period of displacement. All of these factors combined, mean that actions to mitigate the impacts of displacement are difficult to balance with economic and logistical viability. The knock-on effects of displacement ripple up and down the coast from the point of impact, as fishers displaced from one location lead to increased fishing pressure and spatial squeeze in a different location (MMO, 2024). Displacement to less productive fishing grounds also requires more fishing effort to land the same catch quantity, thereby increasing environmental pressure on the ecosystem. OWF can impact commercial vessel traffic and it is likely ferry routes will be affected by planned developments in the Irish Sea. This may impact commercial fishermen if set gear is towed away or damaged by more OWF operation and maintenance vessel traffic transiting through.

More static than mobile gear fishers are more likely to change or modify their fishing gear, or supplement their income through other means in response to displacement. This is also reflected by vessel size, as mobile gear fishers tend to operate larger vessels (>15 m) and more frequently travel further from shore to fish. This indicates smaller vessels are more likely to seek adaptations or alternatives to fishing, rather than simply fishing elsewhere. New, FLOW developments sited further offshore in deeper water may have greater impacts on larger vessels.

Other impacts reported were alteration to the seabed from construction activities including dumping of rock spoil, or cables not being buried to a sufficient depth (MMO, 2024). The layout of cables (for example in a fan shape from the turbines toward land) can impede fishing activity, where fishing has to take place in a particular orientation to tidal flow. There are presently an estimated 58,855 NM of subsea cables on the seabed around the UK (C. Warwick, personal comm.) Interviewees alleged that cables were not being buried to depths specified in licence conditions, the seabed conditions are not being monitored for changes, or that the licensed burial depth is inadequate for the hydrodynamic regime of the seabed. In areas of dynamic seabed conditions it is likely that cables are frequently covered and uncovered but this requires better monitoring and novel solutions to ensure that adequate burial is maintained. Impacts of multiple cable routes making landfall on a small area of coastline, that may pass through important nursery grounds, or potential pollution from the construction phase, were all raised as concerns. Static gear fishermen were most concerned about impacts from cables and electro-magnetic fields (e.g. cables routed through potting grounds, physiological impacts of EMF on target species).

4.2. Ecological outcomes

4.2.1. Underwater noise/pile-driving

This study reveals unease from the fishing industry over understudied, or little understood, impacts of pre-construction/construction activities such as seismic surveys or pile-driving on marine life. A mixed array of impacts are experienced by crustaceans; on foraging behaviour, egg development, reduction in growth and reproductive rates, or changes in haemolymph biogeochemistry (Scott et al., 2020). If these lead to negative population level impacts this could lead to reduced catches and instability in commercial fisheries. Effects are species-specific meaning there are still many data gaps to be filled. A number of respondents expressed concern over 'unknown' impacts of pile-driving on important commercial king and queen scallop stocks in the Irish Sea that lie within areas licensed for OWF development. Scallops, a sedentary bivalve, exhibit negative responses to noise from pile-driving, expressed as reduced gonadal growth and egg quality and a reduced pelagic larval phase (Gigot et al., 2024), and turbine monopile changes in water column mixing is likely to influence offshore scallop larval transport (Chen et al., 2024), which could both potentially cause a reduction in recruitment.

Respondents reported a reduction in catches of certain fish species including cod, gurnard and herring, attributed to either seismic surveys or pile-driving activities. Concern was expressed over disruption to spawning and nursery grounds (e.g. herring spawning in the Irish Sea) and subsequent impacts on stock recruitment and biodiversity (Bolle et al., 2012). A significant increase of dead crabs observed in pots following seismic surveys was reported by multiple respondents. Habitat disturbance from turbine and cable installation may lead to cumulative effects on populations, which are poorly understood (Willsteed et al., 2018). Although sensitive ecological periods should be identified in EIAs, it seems that there is no legal obligation for energy companies to cease operations during these times. The de-facto MPA effect that may occur from the exclusion of fishing in OWF may be countered by unknown ecological effects described above and further research is urgently needed to fully understand the impacts on marine life.

4.2.2. Electro-magnetic fields (EMFs)

In this study, respondents believe EMFs emitted from subsea cables are impacting seasonal fish migration and crab behaviour. There were specific reports that cables and EMF have impacts on migration patterns in sole, crab, herring, mackerel and Atlantic salmon. Respondents reported reduction in catches of whelk, crab, cuttlefish, and sole, attributed to EMFs, echoed by reports of a decline in sole and rays in areas of the southern North Sea (MMO, 2024). *Sabellaria* reefs and mussel populations were also reported as being negatively impacted on the East coast, due to construction activities and cable laying. The scientific literature reports mixed responses to EMF which are taxa and species specific (e.g. Scott et al., 2020; Wyman et al., 2018). Many different marine taxa use geomagnetic fields for orientation and our understanding of species-specific impacts on this remains limited (Nyqvist et al., 2020). Although a number of laboratory studies have investigated the effects of EMF on marine life, empirical field studies are needed to understand effects in-situ. Dynamic cables in FLOW developments will also introduce EMFs into the water column affecting pelagic species and marine mammals, cables will pass through multiple ecosystems *en* route to land, and cumulative effects from multiple interacting cable arrays will increase encounter rate and effect. There are currently no regulations or policies around EMFs in the marine environment.

4.3. Response to displacement

There was a notable increase in the number of fishermen that would consider leaving the industry now (n = 1) or in future (n = 35), if OWF expansion occurs at the proposed rate. This high change in response could be due to the 'protest vote' effect (Otjes et al., 2020), but the data in our survey certainly reflects a degree of frustration and perceived lack of prioritisation of commercial fishing in relation to other marine policies and developments.

Mostly static gear fishermen would expect to supplement their income through other employment due to future OWF developments. This is an adaptive approach and could be positive in enabling fishermen to learn skills in other industries but also has implications for wellbeing, particularly if individuals feel they have no choice. Modifying vessels and gear so that other species can be targeted is possible in some cases, but requires significant cost, investment and the ability to gain a quota for that species as well as new specialised skills and local knowledge.

With multiple pressures on fishermen including spatial competition, restrictions for conservation objectives, legislation, the Covid-19 pandemic and Brexit, many fishers are finding the financial viability of maintaining a vessel and retaining crew increasingly difficult. Fishers also face cumulative impacts of increasing loss of space to multiple wind farms, and fisheries are impacted beyond the boundaries of a wind farm (Berkenhagen et al., 2010). The UK fishing fleet is shrinking (Seafish, 2023), and changing in composition. Larger vessels (>15 m length) are more resilient compared to smaller vessels due to their nomadic style of fishing. Smaller vessels exploit inshore, local grounds, and lack options if preferred fishing grounds are lost, and are therefore more susceptible to impacts from OWF developments.

4.4. Safety

As well as direct safety concerns of fishing between turbines with the risk of losing power and drifting onto turbines, or snagging gear in exposed subsea cables, respondents cited increased risks in having to travel further leading to fatigue, having to fish further offshore in more exposed areas, navigational dangers at night when transiting through turbine arrays, unknown seabed features or hazards in unfamiliar areas and some turbines not having the required lighting, and potential difficulties in performing search and recovery operations within a wind farm. All of these factors mean that fishermen are unwilling to risk fishing within wind farms even if they are legally allowed to, combined with the fact that they are financially liable if any incidents occur within the wind farm. Most respondents expected similar safety concerns for future developments, in particular for FLOW, although there was uncertainty around the exact impacts due to the infancy of that technology.

4.5. Benefits

Benefits were only cited by two <15m static gear fishers. These include: (i) short-term improvements in fishing opportunities; (ii) increased opportunities for lobster fishing around turbines; (iii) particular benefits provided by energy companies (including special buoys for static gear, community benefit schemes, rock armour tailored to encourage biodiversity). The artificial reef effect is context and design dependent meaning there is potential to design fisheries specific enhancements, but these must be combined with effective monitoring (Vivier et al., 2021). Benefits to lobster populations have been reported from temporary restrictions on fishing during construction (Roach et al., 2018) and empirical data reflects this (Thatcher et al., 2023). Evidence also suggests that certain fish species are attracted to offshore structures (Reubens et al., 2013; Lawrence et al., 2024), although these benefits need to be evaluated alongside any potential negative population level effects from OWF developments reported above. Potential sources of employment from OWF include retraining to take up specific opportunities, or guard vessel duties, although these opportunities are limited, training is costly and only certain vessels are suitable. There may be positive outcomes on commercial fish stocks from the de facto MPA effect of wind farms (due to a reduction of fishing with the wind farm), but this is a complex process that is context and species specific and potential benefits remain largely unquantified.

4.6. Compensation

A concerning lack of consistency and transparency regarding compensation payments for displacement of fishing activity was reported in this study. In the UK and other countries, there are no legal requirements for energy companies to pay compensation (not all energy companies offer compensation) with industry relying on recommendations for assessment for the potential economic, financial, social and environmental impacts of the projects (e.g. FLOWW, 2015; BOEM, 2022; NYSERDA, 2022).

Although three-quarters of respondents said they had been displaced by OWF in operation or under construction, only one-third (mostly vessels <15m) said they had received compensation payments from energy companies, with mobile gear fishers largely excluded from these payments indicating inequity in the process. Compensation payments were reported as not being consistent, with various methods used for calculating payments e.g. average annual earnings (which does not account for periods of peak yield); based on vessel size; or individual negotiations. There is a high level of dissatisfaction across the fishing industry with the amount of compensation provided or the fairness of payments compared to other vessels that needs to be addressed.

Data used to determine eligibility for compensation includes proof of area fished (from VMS, iVMS or plotter data) or financial records, although legal requirements for vessels <12m in length to have iVMS only came into force in 2024, meaning that many vessels will not have historical data (79% of UK fleet are <10m; www.gov.uk). In such cases, landings records and average annual earnings can be used to estimate losses from ground closures. However, respondents cited that some closures took place during the most productive season for the fishery and losses were therefore disproportionate and compensation inadequate, or seasonal movements between fishing grounds were not accounted for. Another issue raised is that compensation only covered temporary periods when surveys were taking place. Long-term ground losses and displacement, which are having a significant impact on the fishing fleet are not compensated for at present. Therefore, some respondents viewed compensation as a short-term problem, while accepting the inevitable decline of their business. It was reported that some fishermen had used compensation funds in a way that could negatively impact the local fishing industry, such as for purchasing a larger vessel, or buying more gear (to avoid paying tax on compensation monies), which creates greater ecological pressure in localized areas. Fishers impacted by displaced vessels moving onto their grounds are also not considered in compensation payments, but experience knock-on impacts (MMO, 2024).

Some respondents had been asked to sign non-disclosure orders to prevent them communicating any potential post-construction negative impacts from the OWF in order to receive compensation, demonstrating a lack of transparency in the process. Payments are made only to the vessel owner, but impacts can be experienced by the skipper, crew, processors and fishermen in areas where displaced vessels relocate to, including international fishermen. Shoreside businesses are not yet included in compensation payments in the UK, but are expected to be eligible for certain compensation schemes in the USA (Vineyardwind.com, 2024). In this study, a shellfish processing business owner reported that a lack of local supply during OWF construction caused severe financial difficulties for the business but they were not eligible for any financial assistance.

At the present time, it is up to the developers and fishermen to negotiate individual compensation payments, with many fishermen having little time, resource or legal support to object. Some fishermen reported being verbally threatened or intimidated by fishing industry liaisons. The best practice provided is advisory (FLOWW, 2015) and presents pathways to 'constructive discussions', however with no legal requirement, recommendations may not be implemented and are not enforced, leading to the inequity and issues highlighted above.

4.7. Solutions road map

Evidence presented here suggests that co-existence of commercial fisheries and offshore wind is considered largely unacceptable by the fishing industry operating around the UK, under the present regulatory regime. Fishing is not legally excluded from within operational wind farms in the UK, but fishing within turbines arrays is often not feasible for logistical, safety or liability reasons, particularly with mobile gear types, but also static gear depending on the length of the fishing gear deployed. Opportunities to fish close to wind turbines relate to static gear such as pots (Schupp et al., 2021) but there are a lack of solutions for mobile gear and no clear pathway to addressing this in the current legal landscape. Barriers to progress highlighted by Government representatives in the UK and Germany are; inadequacies of EIAs in relation to the impacts on commercial fishing, a lack of spatial fisheries policies, and non-statutory consultees (Schupp et al., 2021). Simply increasing the number of static gear fishers will not provide social equity or ecological balance, and limits fishing opportunities to invertebrate species. To address longer-term concerns for the fishing industry, we recommend that a defined legal framework for compensation is developed and embedded into policy. This framework should either provide mitigation and solutions where fishing is likely to be permanently impacted, or to provide vessel decommissioning schemes to enable fishermen to leave the industry where impacts are expected to be long-term (e.g. the expected lifespan of a wind farm is 20–30 years). The framework should also ensure equity, consistency, fairness and transparency. A Dutch decommissioning scheme in 2021 reduced the beam-trawling fleet from 72 to 35 active vessels. There were a number of pressures on the fleet that resulted in the scheme, including a loss of quota due to Brexit, environmental opposition to beam-trawling, and increasing spatial pressure from marine protected areas and wind farms (Hook and Net Magazine, 2023; Hamon et al., 2023). A decommissioning scheme will have knock-on impacts up the supply chain on fish processors, retail and food service sectors which will also need to be considered.

The offshore energy industry appears reluctant to encourage coexistence with commercial fishing, unless clear value is represented and risk excluded (Schupp et al., 2021). This suggests that there is unlikely to be progress towards improving the situation without a definitive legislative steer. However, if collaboration can be fostered there is opportunity to develop marine planning that reduces impacts on the fishing industry (e.g. https://www.nffo.org.uk/celtic-sea-offshore-wind-development-picks-up-pace/), such as spacing between turbines or the orientation/micro-siting of turbines, and the orientation/route of cables that can be designed to improve fishing access to sites. In the present study, fishers claimed that inaccurate or misleading data had been presented in EIAs (incorrect gear types for the local fishery, or non-local, generic data). This highlights that EIAs must include local knowledge and specific data, to move their functionality beyond a 'box-ticking' exercise. Fishery protection zones (areas highlighted as important to commercial fishing based on catch and effort data) could also be used in future as a tool to safeguard certain areas from OWF development (ICES, 2024).

Due to the planned exponential growth of the OWF industry, it is imperative that the novel data presented here is used to inform future policy and planning decisions to ensure that the fishing industry is supported through this time of inevitable transition. Failure to do this is likely to see a continued decline in the UK fishing fleet as more vessels struggle to complete with multiple spatial pressures, not just from offshore energy but also others cited above. We make the following recommendations below, which can be incorporated into future policy (Table 3).

5. Conclusion

Here we present a case-study of the perspectives from the commercial fishing industry around the UK and adjacent nations, and expect similar issues to be experienced globally. In the UK, we are more reliant on seafood imports (1.2 million tonnes of seafood annually) than seafood production (which represents <0.1% of national GDP) (Seafish, 2023). The consequences of increasing OWF development for communities in other regions of the world that are reliant on fish for food security, may be far more severe. Comparison of impacts in other nations deploying offshore wind presents future research opportunities.

This study has revealed the same issues that were raised by the commercial fishing industry 20 years ago, and with the global expansion of OW energy, the outlook for commercial fisheries, particularly smaller inshore vessels, is challenging, unless clear and decisive changes to government frameworks and policies, evidence collection and communication and collaboration are made. In order to promote a just renewable energy transition that includes consideration of other marine sectors such as commercial fishing we make the policy recommendations above and highlight the over-arching considerations below:

- Best practices guidelines are not effective – recommendations need to be embedded in legal policy frameworks.
- Whether inshore or offshore, wind farms impact the fishing industry due to the ripple effect of displacement, therefore the expansion of FLOW will lead to increase occurrences of the impacts highlighted in this study.
- Interventions are required without delay, to prevent a further decline in smaller, inshore vessels, with implications for food security and the resilience of coastal communities.
- The OW energy sector is forecast to grow globally, lessons learned in the UK and Europe can inform other countries where offshore wind is developing at pace.

With defined legal frameworks and enabling regulations by which

Table 3
List of recommendations for improving interactions between the commercial fishing and offshore wind industry.

	Mechanism	Recommendation
1.	Regulation and legal frameworks	Defined legal framework for compensation for interactions between OWF and commercial fishing, that accounts for different vessels and gear types, seasonal variation in fishing patterns and times of peak productivity by species.
2.	Regulation and legal frameworks	Stricter standards, regulation and enforcement for cable burial depth (e.g. min 1.5 m) including monitoring of burial state throughout the lifetime of the cable, and provide indemnity to fishers in the case of interactions with exposed cables.
3.	Regulation and legal frameworks	Regulations for levels of EMF in the marine environment
4.	Regulation and legal frameworks	Regulations on the timing of pile-driving and seismic surveys to legally restrict activities during periods of spawning or migration of marine species.
5.	Regulation and legal frameworks	Regulation and enforcement of speed limits for wind service vessels when passing fishing vessels or fishing gear.
6.	Communication and collaboration	Assign statutory consultee status to the fishing industry in all OW development consultations, giving fishermen the ability to contribute to decisions over the siting of OWFs.
7.	Communication and collaboration	Regional offshore energy/fisheries working groups to discuss and agree on evidence and solutions.
8.	Communication and collaboration	Include fishing industry representatives in the design of turbine arrays and cable layout to maximise fishing opportunities, post-construction.
9.	Communication and collaboration	Provide a statutory mechanism to report and ensure timely resolution of safety issues or breaches, such as lighting on turbines.
10.	Evidence	Mandatory inclusion of fishing industry data to conduct assessments of the economic and ecological importance of areas of the sea, prior to licensing.
11.	Evidence	Gathering of improved evidence on species-specific impacts of EMF and pile-driving on behaviour and migration to inform mitigation methods.
12.	Evidence	Use of local knowledge, seasonal and location specific data in EIAs for accurate assessment of ecological and socio-economic impacts

contrasting maritime industries can coexist, impacts on traditional fishing industries and local communities can be alleviated and addressed with open and transparent processes that provides each stakeholder a voice and a seat at the table.

CRediT authorship contribution statement

C.L. Szostek: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **S.C.L. Watson:** Writing – review & editing, Methodology, Conceptualization. **N. Trifonova:** Writing – review & editing, Methodology. **N.J. Beaumont:** Writing – review & editing, Methodology. **B.E. Scott:** Writing – review & editing, Methodology, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supplementary data

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Data availability

Data will be made available on request.

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