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Using fisheries-dependent data to investigate landings of European lobster (*Homarus gammarus*) within an offshore wind farm

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Abstract

The need for alternative strategies to assist in the monitoring and sustainable management of fisheries' resources is becoming increasingly important. In recent years, greater utilization of fishers' knowledge has been advocated as a potentially valuable source of data that could be applied to fisheries management issues. In the current study, we addressed this by investigating the landing per unit effort (LPUE) of European lobster (*Homarus gammarus*) from within an offshore wind farm using a fisheries-dependent commercial fishing logbook. The logbook was provided by a single fisherman who targeted lobsters within the wind farm between 2015 and 2022 using single pots deployed in association with individual wind turbines. Generalized linear mixed modeling was used to investigate changes in LPUE over temporal scales and as the result of the presence of scour protection at turbine locations. LPUE was found to be significantly higher at turbine locations where scour protection was present compared to those turbines where it was not. Predictions from modeling suggested LPUE was nearly 1.5× greater at turbines where scour protection was present. Significant differences in mean monthly and yearly LPUE were detected with this variation likely to reflect seasonal changes in lobster activity and the effect of introducing fishing into a previously unfished area. This work highlights the potential for fishing logbooks to be applied in fisheries management. Our results also demonstrate potential fishing opportunities arising from the development of offshore wind farms and the potential for these opportunities to be enhanced.

Keywords: offshore wind energy; landing per unit effort; fisheries dependent; homarus gammarus

Introduction

Traditionally, fisheries management across Europe has been heavily dependent on top-down control, whereby fishers' are not directly involved or consulted during the process of data collection or the subsequent legislation of management measures. This is particularly true for small-scale fisheries and has led to the exclusion of small-scale fishers' from policy and management decisions that directly impact their livelihoods (Pearson et al. 2020). Alternatively, fishers' and fisheries scientists can collaborate to enhance our understanding of how fisheries resources are being utilized (Johannes et al. 2000, 2007, Eddy et al. 2010, Stange 2016, Stephenson et al. 2016, Rees et al. 2021, Davies et al. 2022). For example, Wahle et al. (2013) worked alongside fishers' from Narragansett Bay on Rhode Island (USA) to investigate changes in the abundance and distribution of juvenile lobsters following extreme summer conditions. On the east coast of the United Kingdom, the Holderness Fishery Industry Group employed researchers who collaborated with offshore wind farm (OWF) operators to better understand the impact of OWF development on nearby lobster populations (Roach et al. 2018, 2022). Some of the benefits of this approach include reduced costs, increased sampling frequency, and the opportunity to strengthen communication and trust among fishers' and scientific groups (Conway et al. 2006, Hart et al. 2008, Feeney et al. 2010).

One form of collaboration between fishers' and fisheries scientists involves the analysis of information gathered as part of fishing logbooks. Fishing logbooks generally include where, when, and how many of the targeted species are caught per unit of effort (e.g. per tow or per string of pots). Fishing logbooks are recorded for multiple reasons with varying levels of detail included. In some cases, fishing logbooks are designed by fisheries scientists to gain information on a specific issue and are voluntarily used by fishers' who are often financially compensated (e.g. Lunneryd et al. 2005, O'Donnell et al. 2012, Sari et al. 2021). In the United Kingdom, it is mandatory for all vessels to maintain comprehensive records of their landings and utilization of ICES rectangles. These logbooks are used as a tool in the enforcement of fishing regulations and to ensure compliance with resource management controls, but data collected as part of these schemes can also be analyzed for fisheries management purposes (e.g. Bastardie et al. 2010, Murray et al. 2013). Lastly, personal fishing logbooks may be recorded by fishers' of their own accord to inform future fishing efforts and, in some cases, are voluntarily shared with fisheries scientists (Reis-Filho et al. 2021). While personal logbooks are frequently used in the management of recreational fisheries (e.g. Nunes et al. 2012, Jansen et al. 2013, Grilli et al. 2021), there are few examples of this approach being used in the management of commercial fisheries. This is likely to be the result of the disconnect between commercial fishers' and fisheries scientists and is exacerbated by the fact commercial fishers' logbooks are highly sensitive and, if used inappropriately have the potential to threaten their livelihoods (Reed et al. 2020). However, those studies that have used this type of logbook have produced valuable results. For example, Reis-Filho et al. (2021) were able to identify important areas for permit (*Trachinotus falcatus*) spawning aggregations along the Brazilian coast with data collected from personal logbooks being used to inform the basis of a permit management plan. Another example involves the analysis of haul-by-haul catch data from a 10-year personal fishing dairy to investigate the distribution and relative abundance of common megrim (*Lepidorhombus whiffiagonis*) in the North Sea. These data were compared to data from fishery-independent sources. From the fishing diary, an increase in the relative abundance and dispersal of megrim closer to the shore was identified, aligning with the findings from the fishery-independent data (Macdonald et al. 2014). While both of these studies conclude that there are a range of challenges associated with using personal fishing logbooks, such as the potential for a lack of consistency, time-consuming nature of extracting catch data, and they often lack spatial and temporal coverage. Both also suggest that providing the data within the logbook is suitable for the aims of the study personal logbooks from commercial fishers' have the potential to make important contributions towards fisheries management. This is particularly true for data poor and declining fisheries, where a lack of information does not allow fisheries scientists to make properly informed decisions in the timeframes required (Giglio et al. 2015, Saldaña et al. 2017). The need for fisheries-dependent data generated as part of logbooks to help inform fisheries management is highlighted in the recent Proposed Fisheries Management Plans for Crab and Lobster in English Waters (DEFRA 2023), where the importance of developing and implementing efficient fisheries-dependent data is featured as part of the research plan.

Increasing activity from a range of sectors within the marine environment is contributing to a phenomenon known as "spatial squeeze," whereby established sectors, such as fishing are competing for marine space with new and emerging sectors (Heery et al. 2017, Stelzenmüller et al. 2021, 2022, ABPmer 2022). In the UK, plans to increase the total installed capacity of offshore wind energy from 13.6 to 50 GW by 2030 as part of reaching net-zero targets are expected to make significant contributions towards "spatial squeeze" (British Energy Security Strategy 2022). The proliferation of OWFs can lead to reduced access to traditional fishing grounds forcing a displacement of fishing activities, which has the potential to cause economic loss and impacts on coastal communities (Stelzenmüller et al. 2021, 2022). Further, in some cases, the introduction of artificial hard substrates as part of OWFs has the potential to change the local habitat characteristics and, therefore, species presence leading to mixed effects for the fishing industry (Van Hoey et al. 2021). For example, the presence of commercially important species such as lobsters [*Homarus gammarus* (hereafter referred to as "lobster")] or edible crab (*Cancer pagurus*) within OWFs could lead to fishing opportunities (Hooper et al. 2014, 2015). However, the electromagnetic fields and noise generated during the construction and operation of OWFs may have negative effects on commercially important species, including crabs and lobsters (Öhman et al. 2007, Mooney et al. 2020). Given the scale at which OWF development is planned, it is important to investigate the fishing opportunities arising from their construction to promote co-location of this sector with commercial fisheries (Hooper et al. 2015, Stelzenmüller et al. 2021). A better understanding of these factors may contribute towards mitigating the negative effects of OWF-induced "spatial squeeze" and work towards compensating fishers' for any negative impacts of OWF development on commercially important species (ABPmer 2022). Thus, there is real scope for personal fishing logbooks to provide valuable data that would help fisheries scientists work towards these goals in a suitable timeframe.

Here, we use a unique 6-year personal fishing logbook to investigate LPUE of lobsters within an OWF. In so doing, we demonstrate the potential for personal logbooks to be used in the management of small-scale emerging fisheries and the prospective fishing opportunities that may arise from the continued development of fixed-turbine OWFs.

Materials and methods

Data protection and confidentiality

To protect the interests of the fishermen who supplied data for this study, the location of the offshore wind farm (OWF) will not be named, nor the operators of the site. Furthermore, no specific geolocations associated with catch data are included. At the request of the fisherman providing the logbook, values relating to the number of lobsters caught and therefore landings per unit effort (LPUE) have been transformed to relative arbitrary values. All data and confidentially measures were agreed with the fishermen involved before submission for publication.

Data preparation

The data used throughout this study was provided by a single lobster-potting vessel. This fisherman has provided logbooks relating to catches of lobster from a single OWF from 2015 to 2022. The minimum straight-line distance from this OWF to naturally occurring reef habitat where lobsters are also targeted is 4.63 km. Lobsters were targeted within the site using either a single or pair of side entry square parlor pots ($44 \times 22 \times 15$ cm) deployed within ~ 10–15 m of the edge of a single turbine location towards the edge of the scour protection where present. Generally, the pots were checked every 3–4 days; however, it's important to note that inclement weather conditions can influence this duration leading to variation in soak time. Over the entire logbook pots had been baited with a range of species including, but not limited to, salted Ballan wrasse (*Labrus bergylta*), and the carcasses of European bass (*Dicentrarchus labrax*) and Atlantic salmon (*Salmo salar*). For each pot deployment, the total number of legal landing-size lobsters (>92 mm in carapace length) was recorded together with the location (latitude and longitude) of where the pot was deployed (hereafter referred to as a "mark"). This information was stored within an Olex plotting system (Olex AS, Trondheim, Norway).

Data were exported from the Olex system, and we extracted all marks with a latitude and longitude found within the perimeter of the OWF site. The site's perimeter was established as the area extending 25 m from the outermost turbines. Each mark was then assigned to the turbine location each of the pots was deployed closest to. Distance between the turbines within the OWF is ~720 m. Forty-five percent of these turbines are surrounded by a continuous layer of scour protection made up of rocks and boulders (~40–100 cm diameter) extending a maximum of 30 m from the base of the turbine (Fig. 1). The scour protection was put in place between April 2013 and January 2015 (Robberts 2023, pers. comm). The habitat surrounding the scour protection and the turbines lacking scour protection is made up of gravel and sand sediment. Each mark was classified as either "scour protection present" or "no scour protection," depending on whether artificial hard substates were present at the base of the turbine at which the pots were deployed. Individual turbine codes, the presence and amount (total area at each turbine, calculated from post-installation bathymetric surveys) of scour at each turbine, and GIS data relating to the positions of all wind farm-related structures within the site were provided by the site operators.

Landings per unit effort

All data exploration, manipulation, and analysis were carried out using R version 4.2.2 (R Core Team 2023).

Due to the lack of replication in 2015 compared to the rest of the dataset this year was removed from the following analysis.

LPUE was calculated by dividing the number of lobsters landed at each turbine by the number of pots deployed at the same turbine (adaption from Davies et al. 2015). LPUE was used to infer the relative abundance of lobsters at particular turbine locations (Maunder et al. 2006, Hubert et al. 2007).

Both monthly and yearly LPUE were found to be non-normally distributed (Shapiro-Wilk's test < 0.05); therefore, 2 separate Kruskal-Wallace tests were used to investigate differences in LPUE between months and years at turbines with scour protection, and 2 separate Kruskal-Wallace tests were used to investigate differences in LPUE between months and years at turbines with no scour protection. Significant differences highlighted by these tests were further investigated using post-hoc pairwise Wilcoxon tests.

Modeling catches of lobster

Since the data collection was not designed for statistical analysis several steps were taken to ensure it was suitable for modeling: (i) visual analysis of frequency plots indicated the number of pots used at each turbine location (effort) was not normally distributed. Therefore, to meet the assumptions of normality and homogeneity of variance, a square root transformation was applied to the number of pots (effort) deployed at each turbine across the whole dataset (Jasen et al. 2015); (ii) data from 2015 was considerably lacking in comparison to the other years (17 marks vs. an average of 427 marks for all other years) and therefore removed from any further analysis to balance the data; and (iii) as the number of pots deployed at certain turbines increases unevenly throughout the years of the catch logbook (likely influenced by ease of access to particular turbines or previous catch numbers leading to preference or otherwise for particular turbines), any occurrences of 10 pots being deployed at a single turbine in a single year were removed to balance the data between turbine locations. This decision was informed by visual analysis of boxplots and histograms, revealing that the inclusion of heavily fished turbines would introduce excessive variability.

Generalized linear mixed effects modeling (GLMM) with a negative binomial distribution and log link function from the *glmmTMB* package (Brooks et al. 2017) was used to investigate LPUE of lobsters at single turbine locations (response variable) as a function of the presence of scour at each turbine location (fixed effect), fishing effort (*n* pots deployed at each turbine location: fixed effect), year (random effect), and turbine (random effect) (Table 1). Turbine was included as a random effect to account for the nested nature of the design (Buyse et al. 2022). Month was not included as a fixed or random effect as separating the catch logbook by turbine, year, and month resulted in a lack of replication at a number of turbine locations. Visual analysis of distribution plots suggested no interactions between the factors; therefore, no interaction terms were included as part of the model. A negative binomial distribution was selected over a Poisson distribution to handle overdispersion detected using the check_overdispersion function from the *performance* package (Lüdecke et al. 2020). Model simplification was carried out using Akaike Information Criterion (AIC). Following the rules of parsimony, the model with lowest AIC score was selected. Following AIC selection, model validation based on Pearson residuals was carried out (Supplementary Fig. S1). After carrying out back transformations using the exp() function (Base R), this model was used to predict differences in LPUE at turbines with scour protection vs. turbines lacking scour protection. This prediction was calculated using the ggpredict function from the *ggeffects* package (Lüdecke 2018).

Results

Data summary

Following the removal of marks collected in 2015 and balancing data between turbines, a total of 2155 marks recorded within the perimeter of the offshore wind farm (OWF) were carried forward for further analysis. The data utilized in the analysis included marks that had been recorded from 09/01/2016 to 30/05/2022. The highest number of marks were recorded during 2018, the least during 2016 (Supplementary Table S3). Across all years, the greatest number of marks were recorded during July and the least during November (Supplementary Table S3). Marks had been recorded in association with 159 of the 160 turbines present within the OWF. Of these 159, no scour was present at 88, and scour was present at the remaining 71 (Fig. 2).

Temporal trends in LPUE

Landing per unit effort (LPUE) was found to vary between months and years. For turbines with scour protection, LPUE was calculated to be lowest during 2018 and highest during 2020 (Fig. 3A). Significant differences were found between years [Kruskal-Wallace (K-W): $\chi^2 = 24.04$, $P = < 0.001$], with post-hoc pairwise tests revealing that LPUE during 2018 and 2019 was significantly lower than during the first year of fishing (2016). There were no other significant differences among years for turbines with scour protection.

While an overall increase in LPUE at turbines without scour was observed from 2016 to 2022, statistical analysis indicated there were no significant differences between years (K-W: $\chi^2 = 6.77$, $P = 0.34$).

LPUE among months was found to be significantly different at turbines with and without scour protection (K-W: $\chi^2 = 242.24$, $P = < 0.001$; $\chi^2 = 73.13$, $P = 0.02$, respectively). Generally, LPUE was higher in summer months (June, July, and August) compared to winter months (November, December, and January). However, at turbines where scour pro-

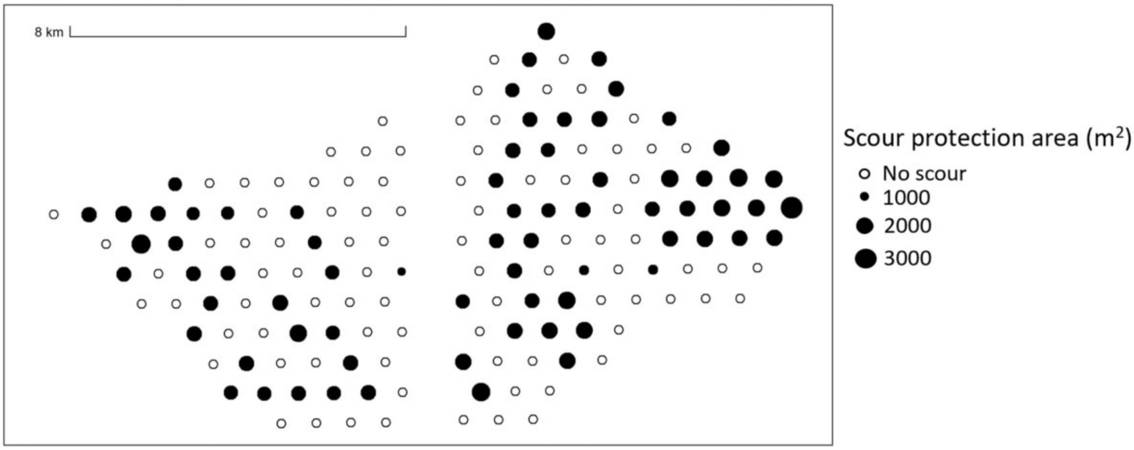

Figure 1 Turbine layout at study site. Axis labels (latitude and longitude) and north arrow have been removed.

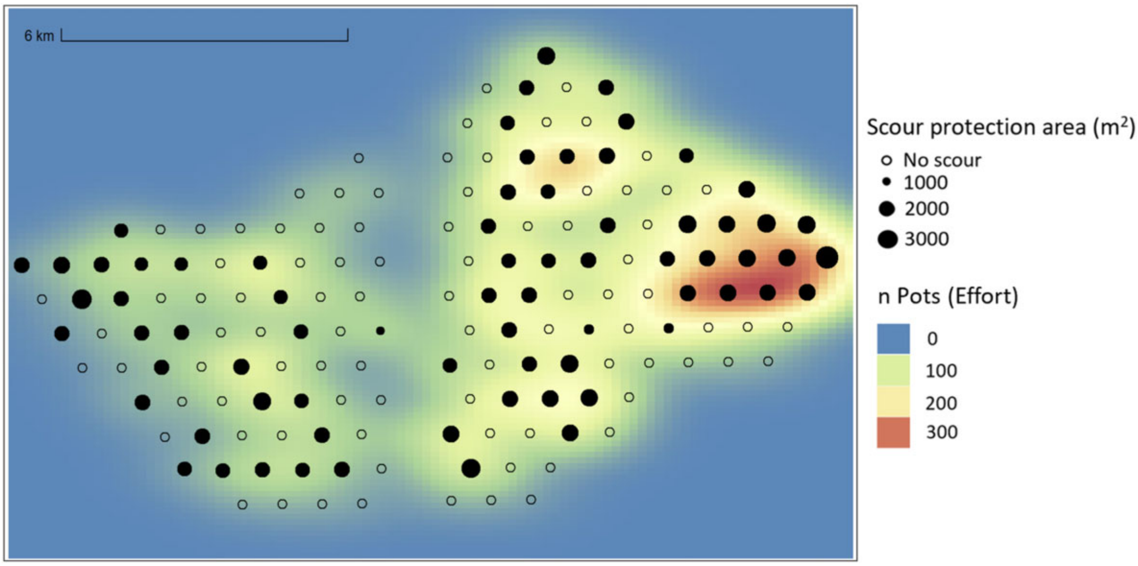

Figure 2 Heatmap showing location and total number of pots deployed across the OWF from 2015 to 2022. Axis labels (latitude and longitude) and north arrow have been removed.

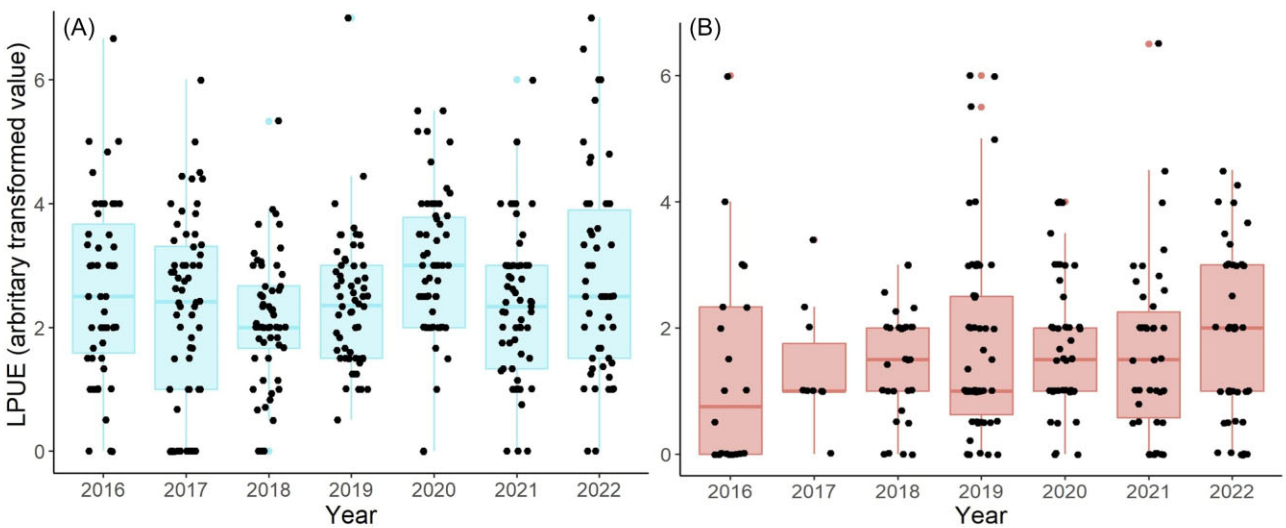

Figure 3 (A) Median, quartiles, and 95% confidence limits of yearly LPUE at turbines with scour protection and (B) Yearly LPUE at turbines without scour protection. Points represent observations in each year.

Table 1. Candidate linear mixed effect models to test the effect of effort and the presence of scour on LPUE at single turbines.

Model ID	Model notation	ΔAIC
Count models		
NB	*Catch ∼ sqrt(Effort) + Scour + (1|Year) + (1|Turbine)*	0
P	*Catch ∼ sqrt(Effort) + Scour + (1|Year) + (1|Turbine)*	102
Null	*Null model (no fixed effects)*	108
Zero-inflation models		
ZIP	*Catch ∼ sqrt(Effort) + Scour + (1|Year) + (1|Turbine)*	77
RSZIP	*Catch ∼ sqrt(Effort) + Scour + (1|Year) + (1|Turbine)*	52

Models ranked according to delta AIC scores. Selected model in bold. NB = Negative Binomial, P = Poisson, ZIP = Zero-inflated Poisson, and RSZIP = Random slope zero-inflated Poisson.

tection was present LPUE during December and January was similar to that observed in early spring and autumn. At both turbines with scour and those without scour, LPUE during May were found to be statistically different to that in June, July, August, and September (Supplementary Tables S1 and S2).

The effects of scour protection on LPUE

Generalized linear mixed effects modeling (GLMM) indicates that effort and the presence of scour protection were both significant predictors of the number of legal landing-size lobsters caught within the OWF (Table 2; $R^2 = 0.66$, $P = < 0.001$). The model suggests that both effort and the presence of scour have a positive effect on LPUE at individual turbine locations. However, increases in the number of pots are estimated to have a greater effect increasing LPUE by 1.22, whereas the presence of scour is estimated to increase LPUE by 0.31 (Table 2, Fig. 5). The R^2 values for the model suggest the fixed effects account for ∼63% of the variation observed in the model, while the random effects account for ∼3%.

Following back transformations, predictions from the chosen model (NB GLMM) indicate that LPUE of lobsters from a single pot at a single turbine, where scour protection is present can be expected to be 1.47 times greater than at turbine locations where no scour is present (Fig. 4A).

Discussion

These results provide an example of a cooperative project between fisheries scientists and commercial fishers' where personal fishing logbooks have been utilized by scientists to investigate LPUE of lobsters within an offshore wind farm (OWF). LPUE was found to vary spatially and temporally, with the presence of scour protection at turbines significantly increasing LPUE compared to turbines where no scour protection was present. In line with previous research on pot fisheries, fishing effort was also found to significantly increase LPUE (Lyle et al. 2005, Penn et al. 2015). These results not only suggest that the presence of scour protection at turbines within this particular OWF presents a suitable habitat for lobsters, but also highlight the opportunity to use fishery-dependent data collected as part of personal logbooks to investigate fisheries management issues.

Spatial variation in LPUE

The presence of scour protection at particular turbine locations was found to significantly increase LPUE within the OWF, with predictions suggesting LPUE was almost 1.5 times greater at turbines with scour compared to those without scour protection. We expect that these results are influenced by the habitat preferences and shelter requirements of lobsters. Lobsters have a strong association with shelter-providing habitat (Karnofsky et al. 1989, Wahle 1992, Wahle and Steneck 1992) and remain shelter-dwellers throughout their benthic life stages (Galparsoro et al. 2009). Therefore, the presence of suitable shelter providing habitat has potential to influence the abundance of lobsters found within different areas (Steneck 2006). Lobsters are known to occupy shelter in a variety of habitats, including crevices in both natural rock and artificial structures where they forage within the surrounding area and, in some cases, return to crevices occupied on previous occasions (Ennis 1984a, Jensen et al. 2000). Therefore, it is possible that the presence of scour protection at some turbines within the OWF presents habitat that is more suitable for shelter compared to turbines lacking scour protection, leading to greater abundances of lobsters present at these particular turbines and consequently higher LPUE. The potential of scour protection to support populations of decapod crustaceans is a topic that has already received some attention, with studies suggesting that the addition of rocky substrate into previously soft sediment habitats has the potential to provide suitable habitat for lobsters (Wilson and Elliot 2009, Langhamer 2012, Hooper et al. 2014; Glarou et al. 2020, Thatcher et al. 2023). Off the east coast of the United Kingdom, no significant differences in catch per unit effort (CPUE) of lobsters were reported between an OWF with scour protection present and a control site known to support populations of lobsters (Roach et al. 2018). In the German Bight, significantly greater numbers of *C. pagurus* were reported at turbines with monopile foundations with scour protection compared to turbines with jacket and tripod foundations and no scour protection (Krone

Table 2. Fixed and random effects for generalized linear mixed effects model estimating the effect of effort and the presence of scour protection on LPUE at single turbines.

Fixed effects	Estimate	Std. error	95% CL lower	95% CL upper	*P* value
Intercept	−0.55	0.09	−0.74	−0.36	<0.001
sqrt(Effort)	1.22	0.03	1.15	1.30	<0.001
Scour	0.31	0.06	0.19	0.44	<0.001
Random effects					
Year	0.02				
Turbine	0.00				
Observations	618				
Marginal R^2/Conditional R^2	0.639/0.667				

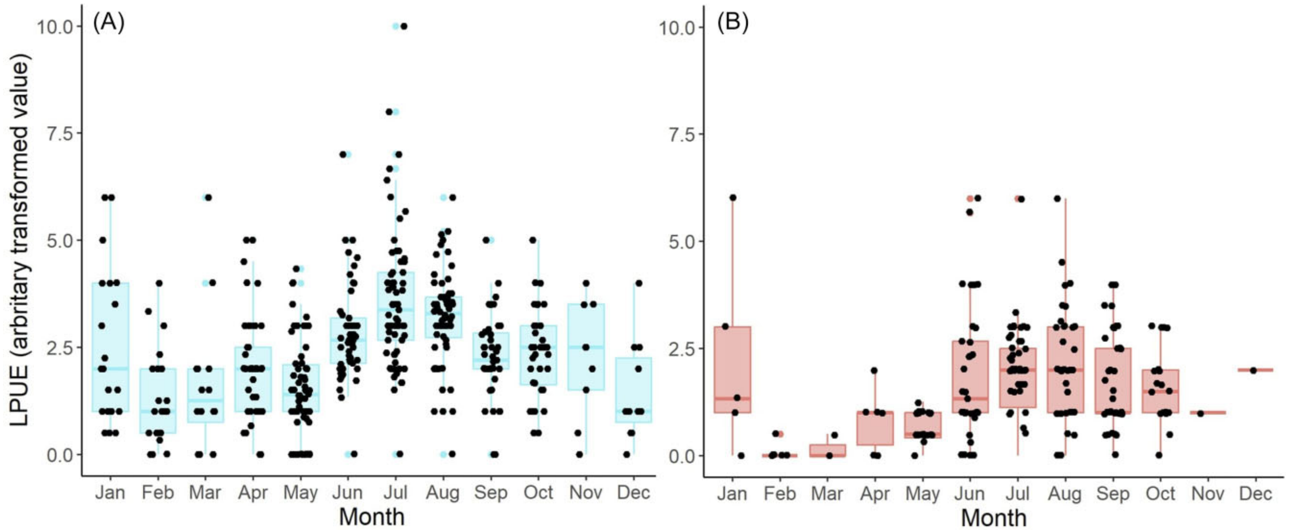

Figure 4 (A) Median, quartiles, and 95% confidence limits of monthly LPUE at turbines with scour protection and (B) monthly LPUE at turbines without scour protection. Points represent observations in each month.

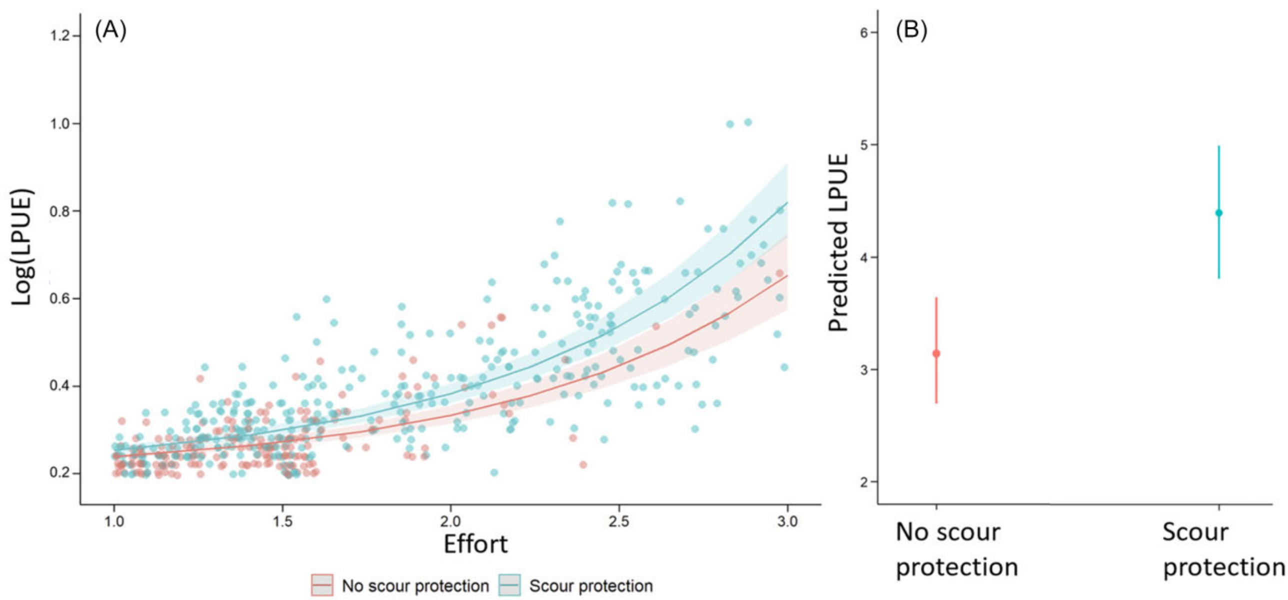

Figure 5 (A) Marginal effects plot from NB GLMM, indicating the effect of effort and the presence of scour on log (LPUE). Points represent raw data. (B) Back-transformed predicted effect of the presence of scour protection on LPUE at a single turbine using a single pot generated by NB GLMM. Vertical lines represent 95% confidence limits associated with predicted values.

et al. 2013). Scour protection has also been shown to influence the abundance of commercially important fish species with significantly greater numbers of plaice (*Pleuronectes platessa*) found within scour protection compared to surrounding sand habitat within the C-power and Belwind OWFs off the Belgian coast (Buyse et al. 2022). These results highlight artificial reef effects taking place following the addition of OWF-associated artificial hard substrates into soft sediment habitats (Degraer et al. 2020).

The results of our study are in accord with previous literature and further suggest the potential for scour protection to support populations of lobsters within OWFs, which we suggest is the result of lobsters using the scour protection as a shelter. As such, the continued expansion of fixed-turbine OWFs utilizing scour protection may present potential fishing opportunities. The presence of lobsters in association with OWF-related hard substates could be the result of either attraction, or increased production (Hooper et al. 2014). If lobsters are attracted to OWF sites then our results suggest that modifying the characteristics or the amount of the scour protection present within future OWF has the potential to support increased lobster populations and as such could form an important compensatory measure for fishermen negatively impacted by OWF construction (Stelzenmüller et al. 2021, 2022). This could help to increase the prospects for the co-location of OWFs and fisheries, mitigating the effects of “spatial squeeze.” It is likely that static gear fisheries would be best suited to benefit from these co-location opportunities due to the logistics of operating fishing equipment within a highly developed marine area; however, further research is required to better understand how commercial fishermen could operate within an OWF to meet their own needs and the needs of the site operators. Nevertheless, increased abundances of lobsters within OWFs are likely to lead to a range of ecological impacts, which require further investigation to gain a greater understanding of the full range of ecological impacts arising from OWF-associated artificial reef effects. Moreover, it is important to recognize that the presence of lobsters within OWFs is inherently site-specific, likely influenced by a range of ecological factors, such as habitat characteristics, substrate type, and local environmental conditions (Langhammer 2012, Bailey et al. 2014). The nuanced interactions observed in this study, conducted within a specific OWF, cannot be universally applied to all OWFs. It is crucial to recognize that the findings of this study may not be directly transferable to all OWFs, emphasizing the importance of conducting site-specific investigations to understand the intricate relationships between a range of economically important species and OWF infrastructure.

Temporal variation in LPUE

At turbines where scour protection was present significant variations in mean LPUE were detected between different years. Specifically, LPUE in 2016 was found to be significantly greater than LPUE in 2018–2019. The decrease in LPUE throughout the first 3 years of the logbook may reflect the effect of introducing fishing pressure into an area that had not been previously exposed to fishing. Similarly, off the east coast of the United Kingdom at the Westermost Rough OWF, Roach et al. (2018) reported significantly greater CPUE of lobsters when the OWF was closed to commercial fishing compared to a control site outside the OWF, which was open to fishing. After fishing resumed inside the OWF, CPUE was observed to decrease to numbers below that recorded during the no-fishing period. While there was an initial decrease recorded in LPUE in the present study, following the third year of fishing, this value is seen to increase throughout the rest of the data series to levels that resonate with that observed in the first year of fishing. This finding suggests the relative abundance of lobsters after 6 years of fishing activity is similar to that after 1 year of fishing activity. An alternative explanation for LPUE initially decreasing, then returning to levels similar at the start of the dataset is the natural recruitment of lobsters to the OWF. The scour protection was put in place in 2012; therefore, early benthic phase lobsters that may have recruited to this new habitat during the first 1–2 years of it being in place would be 7–8 years old by the 2020 fishing season could have been of minimum landing size (Uglem et al. 2005). Nevertheless, our current understanding of lobster recruitment to OWFs remains limited, and the results presented in this study do not offer adequate information to address this aspect comprehensively. Therefore, additional research efforts are necessary to validate and build upon this preliminary theory.

Although not statistically significant, LPUE at turbines where no scour is present also showed a trend towards increases throughout the dataset. While we believe it likely that shelter availability was the main factor driving the abundance of lobsters in different areas of the OWF, the availability of food sources may have influenced the abundance of lobsters across the whole site and therefore at turbines without scour protection. For example, lobsters have been found to be attracted to offshore mussel farms where they exploit mussel fall as a food resource. In some cases, mussels (*Mytilus edulis*) made up nearly 50% of the lobster's diet found within these sites (Sardenne et al. 2019). As part of a 10-year study, Kerckhof et al. (2019) reported that it can take up to 6 years for the fouling species found on OWF hard substrates to reach the climax community. Increased LPUE at turbines lacking scour may represent succession of fouling organisms taking place on wind farm-associated hard substrates and therefore the availability of certain prey items increasing over time, which means the whole site has the potential to support greater lobster populations. However, further research on the feeding habits of lobsters within OWFs is required to gain a greater understanding of this effect. At turbines with and without scour protection, LPUE was found to vary significantly among months. Generally, LPUE during summer months was greater than in winter months. This result is likely to reflect the relationship between lobster activity and water temperatures. Both activity and feeding by lobsters have been shown to be strongly correlated with seasonal changes in water temperatures (Cooper and Uzmann 1980, Ennis 1984a, Smith et al. 1999). Branford (1979) showed daily food consumption by lobsters can increase by up to 11 times with an increase in temperature from 6° to 16°C. The temporal trends in LPUE generated as part of this study reflect the effects of fishing pressure and changing environmental conditions that have been reported in the peer-reviewed literature; hence, we are confident in the suitability of the data extracted from the logbook. At turbines with and those without scour protection present, LPUE were found to be significantly lower during May compared to the following summer and autumn months. This result is likely to reflect the effect the seasonal changes in the proportion of berried hens caught in each pot. The fishermen who supplied this data returns all berried hens; therefore, during May, when the local peak in berried hens are caught LPUE would be reduced.

Data suitability

Data from the fishing logbook was diligently recorded. However, it presented a number of analytical challenges that would have been considered and addressed in the early stages of study design if using data collected as part of a scientific study. Firstly, uneven fishing effort at certain turbine locations leads to a lack of replication. This meant we had to remove a number of records from the logbook to balance the data. Furthermore, as we had no influence on data collection, there are certain factors missing from the logbook that would be useful to our understanding of lobster fisheries within OWFs. For example, including soak time (the time between a pot being deployed and retrieved) as a predictor variable within our GLMM is one of a few additional factors that would have likely increased our confidence in the model, as it has been shown to significantly influence CPUE/LPUE of lobsters (Bennett 1974, Clark et al. 2015). This was not possible as pots were not given a unique identifier, and in some cases, two pots were deployed at a single turbine location at the same time meaning we were unable to confidently extract the period of time between the deployment and retrieval of each pot. The absence of specific data on soak time introduces a level of uncertainty into the temporal analysis. The variability in soak time, influenced by factors such as weather conditions, is a crucial aspect that could impact the reliability of our results. Consequently, the limited information on soak time contributes to a reduced level of confidence in the outcomes of our temporal analysis. Moreover, there are a number of limitations associated with interpreting fisheries-dependent data collected from a single vessel that need to be considered when interpreting the results generated from the logbook used in this study. However, in spite of these shortcomings, following data cleaning and preparation, the logbook presented a unique and invaluable data set covering a large area, which had been collected over an extended time period that would have cost a lot to generate as part of scientific study. The results generated from this data are in line with results reported as part of previous peer-reviewed studies, and we therefore content that personal commercial fishing logbooks do present a valuable resource to fisheries management. These data could play an important role in assessing long-term trends in LPUE/CPUE of commercially valuable species, which may be necessary for working towards goals of the Joint Fisheries Statement (UK Government 2022) and future Fisheries Management plans. In a UK context, Inshore Fisheries Conservation Authorities (IFCA's) could play an important role in communicating the research needs of local fishing communities to fisheries scientists and help to provide contacts for suitable candidates to be involved in future collaborations.

Conclusion

The present study provides the first assessment of LPUE of lobsters within an OWF from a commercial fishing personal logbook, providing an insight into how the presence of scour protection affects LPUE and the relative abundance of lobsters within these sites. LPUE was recorded to be significantly greater at turbines that had scour protection compared to those that did not. Differences in mean yearly LPUE presented in this study are likely to reflect the effect of introducing fishing pressure into to previously unfished areas, while changes in monthly LPUE show how seasonal changes in lobster activity can influence LPUE. The consistency of the results generated from the logbook with that of the peer-reviewed literature suggest that logbook data was appropriate to investigate LPUE of lobster within the OWF, and therefore that fishing logbooks collected to a similar standard may present a valuable resource for fisheries management. However, certain factors missing from the logbook may have provided a better understanding of the drivers in the patterns observed, and we therefore suggest that fishers', fisheries managers, and scientists work together to design standardized commercial fishing logbooks to fully utilize the potential for fishers' to collect data that will improve our understanding and ability to sustainably manage fisheries resources. Finally, we would like to highlight that for future projects of this nature to be successful, the interests of the fishers' supplying the data must be paramount throughout data analysis and output delivery. It is also particularly important that researchers share their findings with the fishers' involved in the research and the wider fishing industry.

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Supplementary data

Supplementary material is available at the *ICESJMS* online version of the manuscript.

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Author contributions

H.T. developed the main idea in correspondence with D.W. H.T. performed the analysis, and the writing. T.S., P.M., and D.W. provided expertise on the analysis and helped with writing.

Data availability

The data underlying this article cannot be shared publicly to protect the interests of the fishermen who supplied the data. In adherence to the data protection agreement established at the project's outset, the data will not be shared upon request.

References

ABPmer. Spatial squeeze in fisheries, final report. 2022. https://www.nffo.org.uk/wp-content/uploads/2022/06/R3900_SpatialSqueeze_Final_23Jun2022-part-1.pdf(16th May 2023, date last accessed).

Bailey H, Brookes KL, Thompson PM. Assessing environmental impacts of offshore wind farms: lessons learned and recommendations for the future. *Aqua Biosys* 2014;**10**:1–13. https://doi.org/10.1186/2046-9063-10-8

Bastardie F, Nielsen JR, Ulrich C *et al.* Detailed mapping of fishing effort and landings by coupling fishing logbooks with satellite-recorded vessel geo-location. *Fish Res* 2010;**106**:41–53. https://doi.org/10.1016/j.fishres.2010.06.016

Bennett DB. The effects of pot immersion time on catches of crabs, *Cancer pagurus* L. and lobsters, *Homarus gammarus* (L.). *ICES J Mar Sci* 1974;**35**:332–6. https://doi.org/10.1093/icesjms/35.3.332

Branford JR. Locomotor activity and food consumption by the lobster *Homarus gammarus*. *Mar Freshwater Behav Phy* 1979;**6**:13–24.

British Energy Security Strategy. Department for Business, Energy & Industrial Strategy, British Energy Security Strategy. 2022, 16pp. https://www.gov.uk/government/publications/british-energy-security-strategy(25th October 2021, date last accessed).

Brooks ME, Kristensen K, Van Benthem KJ *et al.* glmmTMB balances speed and flexibility among packages for zero-inflated generalized linear mixed modeling. *R J* 2017;**9**:378–400. https://doi.org/10.32614/RJ-2017-066

Buyse J, Hostens K, Degraer S *et al.* Offshore wind farms affect the spatial distribution pattern of plaice *Pleuronectes platessa* at both the turbine and wind farm scale. *ICES J Mar Sci* 2022;**79**:1777–86. https://doi.org/10.1093/icesjms/fsac107

Clark AS, Jury SH, Goldstein JS *et al.* A comparison of American lobster size structure and abundance using standard and ventless traps. *Fish Res* 2015;**167**:243–51. https://doi.org/10.1016/j.fishres.2015.02.016

Conway FD, Pomeroy C. Evaluating the human—as well as the biological—objectives of cooperative fisheries research. *Fisheries* 2006;**31**:447–54. https://doi.org/10.1577/1548-8446(2006)31%5b447:ETHWAT%5d2.0.CO;2

Cooper RA, Uzmann JR. Ecology of juvenile and adult *Homarus*. *Biol Manag Lobsters* 1980;**2**:97–142. https://doi.org/10.1016/B978-0-08-091734-4.50010-X

Davies BF, Holmes L, Bicknell A *et al.* A decade implementing ecosystem approach to fisheries management improves diversity of taxa and traits within a marine protected area in the UK. *Diversity Distribut* 2022;**28**:173–88. https://doi.org/10.1111/ddi.13451

Davies CE, Johnson AF, Wootton EC *et al.* Effects of population density and body size on disease ecology of the European lobster in a temperate marine conservation zone. *ICES J Mar Sci* 2015;**72**:i128–38. https://doi.org/10.1093/icesjms/fsu237

Degraer S, Carey DA, Coolen JW *et al.*, Offshore wind farm artificial reefs affect ecosystem structure and functioning. *Oceanography* 2020; **33** (4): 48–57.

Department for Environment Food & Rural Affairs. *Proposed Management Plan for Crab and Lobster in English Waters, Annex 2: Evidence and Research Plan*. 2023. https://consult.defra.gov.uk/fisheries-management-plans-1/crab-lobster-fmp-consultation/First(27 July 2023, date last accessed).

Eddy TD, Gardner JP, Pérez-Matus A. Applying fishers' ecological knowledge to construct past and future lobster stocks in the Juan Fernández Archipelago, Chile. *PLoS One* 2010;**5**:e13670. https://doi.org/10.1371/journal.pone.0013670

Ennis GP. Territorial behaviour of the American lobster *Homarus americanus*. *Trans Am Fisheries Soc*, 1984a;**113**:330–5. https://doi.org/10.1577/1548-8659(1984)113%3c330:TBOTAL%3e2.0.CO;2

Feeney RG, La Valley KJ, Hall-Arber M. Assessing stakeholder perspectives on the impacts of a decade of collaborative fisheries research in the Gulf of Maine and Georges Bank. *Mar Coastal Fisheries* 2010;**2**:205–16. https://doi.org/10.1577/C09-038.1

Galparsoro I, Borja Á, Bald J *et al.* Predicting suitable habitat for the European lobster (*Homarus gammarus*), on the Basque continental shelf (Bay of Biscay), using ecological-niche factor analysis. *Ecol Modell* 2009;**220**:556–67. https://doi.org/10.1016/j.ecolmodel.2008.11.003

Giglio VJ, Luiz OJ, Gerhardinger LC. Depletion of marine megafauna and shifting baselines among artisanal fishers' in eastern Brazil. *Anim Conserv* 2015;**18**:348–58. https://doi.org/10.1111/acv.12178

Glarou M, Zrust M, Svendsen JC. Using artificial-reef knowledge to enhance the ecological function of offshore wind turbine foundations: implications for fish abundance and diversity. *J Mar Sci Eng* 2020;**8**:332. https://doi.org/10.3390/jmse8050332

Grilli G, Curtis J, Hynes S. Using angling logbook data to inform fishery management decisions. *J Nat Conserv* 2021;**61**:125987. https://doi.org/10.1016/j.jnc.2021.125987

Hart AM, Fabris FP, Brown J *et al.* Digital video surveys of abalone (*Haliotis* sp.) stocks by commercial fishers' in western Australia. *Fish Res* 2008;**93**:305–14. https://doi.org/10.1016/j.fishres.2008.06.002

Heery EC, Bishop MJ, Critchley LP *et al.* Identifying the consequences of ocean sprawl for sedimentary habitats. *J Exp Mar Biol Ecol* 2017;**492**:31–48. https://doi.org/10.1016/j.jembe.2017.01.020

Hooper T, Ashley M, Austen M. Perceptions of fishers and developers on the co-location of offshore wind farms and decapod fisheries in the UK. *Marine Policy*, 2015; **61**: pp.16–22.

Hooper T, Austen M. The co-location of offshore windfarms and decapod fisheries in the UK: constraints and opportunities. *Mar Policy* 2014;**43**:295–300. https://doi.org/10.1016/j.marpol.2013.06.011

Hubert WA, Fabrizio MC. Relative abundance and catch per unit effort. In: *Analysis and Interpretation of Freshwater Fisheries Data*. Bethesda, MD: American Fisheries Society, 2007, pp.279–325.

Jansen T, Arlinghaus R, Als TD *et al.* Voluntary angler logbooks reveal long-term changes in a lentic pike, *Esox lucius*, population. *Fisheries Manag Ecol* 2013;**20**:125–36. https://doi.org/10.1111/j.1365-2400.2012.00866.x

Jansen T, Kristensen K, Van der Kooij J *et al.*, Nursery areas and recruitment variation of Northeast Atlantic mackerel (Scomber scombrus). *ICES Journal of Marine Science* 2015; **72**(6): 1779–1789.

Jensen A, Wickins J, Bannister C. The potential use of artificial reefs to enhance lobster habitat. In: *Artificial Reefs in European Seas*. Springer, 2000, pp. 379–401.

Johannes RE, Freeman MM, Hamilton RJ. Ignore fishers' knowledge and miss the boat. *Fish Fisheries* 2000;**1**:257–71.

Johannes RE, Neis B. The value of anecdote. *Fishers' Know Fisheries Sci Manag* 2007;**4**:41–58.

Karnofsky EB, Atema J, Elgin RH. Field observations of social behavior, shelter use, and foraging in the lobster, *Homarus americanus*. *Biol Bull* 1989;**176**:239–46. https://doi.org/10.2307/1541982

Kerckhof F, Rumes B, Degraer S. About "mytilisation" and "slimeification": a decade of succession of the fouling assemblages on wind turbines off the Belgian coast. In: S. Degraer, R. Brabant, B. Rumes, L. Vigin (Eds) *Environmental Impacts of Offshore Wind Farms in the Belgian Part of the North Sea: Marking a Decade of Monitoring, Research and Innovation*. Brussels: Royal Belgian Institute of Natural Sciences, OD Natural Environment, Marine Ecology and Management, 2019, 73–84.

Krone R, Gutow L, Brey T *et al.*, Mobile demersal megafauna at artificial structures in the German Bight–likely effects of offshore wind farm development. *Estuarine, Coastal and Shelf Science*, 2013; **125**: pp.1–9.

Langhamer O. Artificial reef effect in relation to offshore renewable energy conversion: state of the art. *Scientific World J* 2012;**2012**:386713.

Lüdecke D, Makowski D, Waggoner P *et al.* Performance: assessment of regression models performance. *R Package Version 0.4* 2020;**5**:599.

Lüdecke D. ggeffects: tidy data frames of marginal effects from regression models. *J Open Source Software* 2018;**3**:772. https://doi.org/10.21105/joss.00772

Lunneryd SG, Hemmingsson M, Tärnlund S *et al.* A voluntary logbook scheme as a method of monitoring the by-catch of seals in Swedish coastal fisheries. *ICES CM* 2005;**10**(4).

Lyle JM, Morton AJ, Forward J. Characterisation of the recreational fishery for southern rock lobster, *Jasus edwardsii*, in Tasmania, Australia: implications for management. *NZ J Mar Freshwater Res* 2005;**39**:703–13. https://doi.org/10.1080/00288330.2005.9517346.

Macdonald P, Angus CH, Cleasby IR *et al.* Fishers' knowledge as an indicator of spatial and temporal trends in abundance of commercial fish species: megrim (*Lepidorhombus whiffiagonis*) in the northern North Sea. *Mar Policy* 2014;**45**:228–39. https://doi.org/10.1016/j.marpol.2013.11.001.

Maunder MN, Sibert JR, Fonteneau A *et al.* Interpreting catch per unit effort data to assess the status of individual stocks and communities. *ICES J Mar Sci* 2006;**63**:1373–85. https://doi.org/10.1016/j.icesjms.2006.05.008.

Mooney TA, Andersson MH, Stanley J. Acoustic impacts of offshore wind energy on fishery resources. *Oceanography* 2020;**33**:82–95. https://doi.org/10.5670/oceanog.2020.408.

Murray LG, Hinz H, Hold N *et al.* The effectiveness of using CPUE data derived from Vessel Monitoring Systems and fisheries logbooks to estimate scallop biomass. *ICES J Mar Sci* 2013;**70**:1330–40. https://doi.org/10.1093/icesjms/fst099.

Nunes JDACDC, Medeiros DV, Reis-Filho JA *et al.* Reef fishes captured by recreational spearfishing on reefs of Bahia State, northeast Brazil. *Biota Neotropica* 2012;**12**:179–85. https://doi.org/10.1590/S1676-06032012000100014.

O'Donnell KP, Molloy PP, Vincent AC. Comparing fisher interviews, logbooks, and catch landings estimates of extraction rates in a small-scale fishery. *Coast Manag* 2012;**40**:594–611. https://doi.org/10.1080/08920753.2012.727734.

Öhman MC, Sigray P, Westerberg H. Offshore windmills and the effects of electromagnetic fields on fish. *AMBIO J Human Environ* 2007;**36**:630–3. https://doi.org/10.1579/0044-7447(2007)36%5b630:OWATEO%5d2.0.CO;2.

Pearson E, Hunter E, Steer A *et al.* Fishermen and scientists in the same boat. A story of collaboration in the UK South Devon crab fishery.

In: *Collaborative Research in Fisheries: Co-creating Knowledge for Fisheries Governance in Europe*. Springer, 2020, 27–41.
Penn JW, Caputi N, de Lestang S. A review of lobster fishery management: the Western Australian fishery for *Panulirus cygnus*, a case study in the development and implementation of input and output-based management systems. *ICES J Mar Sci* 2015;**72**:i22–34. https://doi.org/10.1093/icesjms/fsv057
R Core Team. R: A language and environment for statistical computing. 2023, Vienna, Austria: R Foundation for Statistical Computing, https://www.R-project.org/.
Reed M., Courtney P., Lewis N. *et al*., Assessing participation of commercial fishers and recreational anglers in fisheries science and management in England.2020.
Rees A, Sheehan EV, Attrill MJ. Optimal fishing effort benefits fisheries and conservation. *Scientific Rep* 2021;**11**:3784.
Reis-Filho JA, Miranda RJ, Sampaio CL *et al*. Web-based and logbook catch data of permits and pompanos by small-scale and recreational fishers': predictable spawning aggregation and exploitation pressure. *Fish Res* 2021;**243**:106064. https://doi.org/10.1016/j.fishres.2021.106064
Roach M, Cohen M, Forster R *et al*. The effects of temporary exclusion of activity due to wind farm construction on a lobster (*Homarus gammarus*) fishery suggests a potential management approach. *ICES J Mar Sci* 2018;**75**:1416–26. https://doi.org/10.1093/icesjms/fsy006
Roach M, Revill A, Johnson MJ. Co-existence in practice: a collaborative study of the effects of the Westermost Rough offshore wind development on the size distribution and catch rates of a commercially important lobster (*Homarus gammarus*) population. *ICES J Mar Sci* 2022;**79**:1175–86. https://doi.org/10.1093/icesjms/fsac040
Saldaña A, Salas S, Arce-Ibarra AM *et al*. Fishing operations and adaptive strategies of small-scale fishers': insights for fisheries management in data-poor situations. *Fisheries Manag Ecol* 2017;**24**:19–32. https://doi.org/10.1111/fme.12199
Sardenne F, Forget N, McKindsey CW. Contribution of mussel fall-off from aquaculture to wild lobster *Homarus americanus* diets. *Mar Environ Res* 2019;**149**:126–36. https://doi.org/10.1016/j.marenvres.2019.06.003
Sari I, Ichsan M, White A *et al*. Monitoring small-scale fisheries catches in Indonesia through a fishing logbook system: challenges and strategies. *Mar Policy* 2021;**134**:104770. https://doi.org/10.1016/j.marpol.2021.104770
Smith IP, Collins KJ, Jensen AC. Seasonal changes in the level and diel pattern of activity in the European lobster *Homarus gammarus*. *Mar Ecol Progress Ser* 1999;**186**:255–64. https://doi.org/10.3354/meps186255
Stange K. Building a knowledge base for management of a new fishery: boarfish (*Capros aper*) in the northeast Atlantic. *Fish Res* 2016;**174**:94–102. https://doi.org/10.1016/j.fishres.2015.08.023
Stelzenmüller V, Gimpel A, Haslob H *et al*. Sustainable co-location solutions for offshore wind farms and fisheries need to account for socio-ecological trade-offs. *Sci Total Environ* 2021;**776**:145918. https://doi.org/10.1016/j.scitotenv.2021.145918
Stelzenmüller V, Letschert J, Gimpel A *et al*. From plate to plug: the impact of offshore renewables on European fisheries and the role of marine spatial planning. *Renew Sustain Energy Rev* 2022;**158**:112108. https://doi.org/10.1016/j.rser.2022.112108
Steneck RS. Possible demographic consequences of intraspecific shelter competition among American lobsters. *J Crustacean Biol* 2006;**26**:628–38. https://doi.org/10.1651/S-2753.1
Stephenson RL, Paul S, Pastoors MA *et al*. Integrating fishers' knowledge research in science and management. *ICES J Mar Sci* 2016;**73**:1459–65. https://doi.org/10.1093/icesjms/fsw025
Thatcher H, Stamp T, Wilcockson D *et al*. Residency and habitat use of European lobster (*Homarus gammarus*) within an offshore wind farm. *ICES J Mar Sci* 2023;**80**:fsad067.
Uglem I, Belchier M, Svåsand T. Age determination of European lobsters (*Homarus gammarus* L.) by histological quantification of lipofuscin. *J Crustacean Biol* 2005;**25**:95–9. https://doi.org/10.1651/C-2448
UK Government Joint Fisheries Statement (JFS). This statement sets the direction of UK fisheries management from the Department for Environment, Food and Rural Affairs. 2022. https://www.gov.uk/government/publications/joint-fisheries-statement-jfs(5 May 2023, date last accessed).
Van Hoey G, Bastardie F, Birchenough S *et al*. *Overview of the Effects of Offshore Wind Farms on Fisheries and Aquaculture*. Washington, DC: European Union, 2021.
Wahle R, Dellinger L, Olszewski S. A fisherman-scientist collaboration to re-assess lobster nurseries in Narragansett Bay after two decades of environmental change. 2013.
Wahle RA, Steneck RS. Habitat restrictions in early benthic life: experiments on habitat selection and *in situ* predation with the American lobster. *J Exp Mar Biol Ecol* 1992;**157**:91–114. https://doi.org/10.1016/0022-0981(92)90077-N
Wahle RA. Body-size dependent anti-predator mechanisms of the American lobster. *Oikos* 1992;**65**:52–60. https://doi.org/10.2307/3544887
Wilson JC, Elliott M. The habitat-creation potential of offshore wind farms. *Wind Energy* 2009;**12**:203–12. https://doi.org/10.1002/we.324

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