Offshore
Wind Evidence
+ Change
Programme

Fisheries Sensitivity Mapping and Displacement Modelling (FiSMaDiM)

Final project report

THE CROWN ESTATE

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Document Control

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Executive summary

The UK government has high ambitions to expand offshore renewable energy production in the UK exclusive economic zone (EEZ) while at the same time aiming at profitable and sustainable fisheries. To achieve these goals, evidence is needed at a planning stage to avoid significant economic impact for the fisheries. Moreover, the process of developing offshore wind farms can be slowed by the agreements required between wind farm operators and fishing vessel operators, including generating and assessing evidence. The Crown Estate launched the Offshore Wind Enabling and Change programme to develop evidence to support the expansion of offshore wind in the UK EEZ. The project 'Fisheries Sensitivity Mapping and Displacement Modelling' (FiSMaDiM) was funded under this program to support the co-existence and co-location of offshore wind and fisheries and to develop data and methods which can support the planning as well as the consenting process. For this purpose, the project developed a methodology to augment data from Vessel Monitoring Systems (VMS) with data from Automated Identification Satellite (AIS) systems to generate high spatial resolution maps of fishing activity of UK- and non-UK-flagged vessels in the UK EEZ.

While a better understanding of the location of fishing activity is crucial, another element developed in this project are indicators to capture the economic importance of the fishing grounds and the wider economic consequences for the fishing industry if access to these grounds is restricted. It is highlighted that using fish landing value as a metric to assess the economic impact, is not capturing the actual consequences for the fishing industry. Indicators developed in this project, with input from representatives of fishing and offshore wind industry, as well as government, aim to overcome this issue and provide the evidence needed at the planning stage to avoid, as far as possible, locating offshore wind farm zones in important fishing grounds. To illustrate the indicators, Fisheries Sensitivity Indexes were generated and applied to the data produced in the project. Moreover, it is shown how these indices can be used to facilitate discussion on the economic impact of offshore wind on fishing activity, in particular, for the period of wind farm construction.

1. Introduction

The UK government has high ambitions to increase the offshore renewable energy capacity. For example, the British Energy Security Strategy of the previous government aimed to produce 50GW by 2030 with the help of offshore wind farms (OWF). The new government announced plans to push for 60GW of offshore wind by 2030[1]. In addition, the UK government committed to protect 30% of the sea in the UK for nature recovery by 2030 (30by30) while the UK Fisheries Act 2020 stated as one of his objectives to achieve a profitable and sustainable fishing industry which brings social and economic benefits to the UK. To meet the objectives of the UK government, marine planning is needed as well as reliable evidence to inform the marine planning process to achieve sustainable allocation of marine resources and sufficient space to the different sectors including fishing and offshore wind farm developments.

To successfully deploy offshore wind farms (OWFs) in UK waters, developers are legally required to consult with stakeholders and to collect evidence supporting the consent application process. This can present a challenge with respect to commercial fisheries because current approaches for assessing potential impacts from OWF are not sufficiently robust. The opposing positions of offshore wind industry and the fishing sector over the marine space can delay consenting of offshore wind developments. To avoid assigning economically important fishing grounds as offshore wind planning zones and ensure a faster consenting process, these important fishing grounds need to be identified. A better understanding of the economic sensitivity of fishing grounds is needed to identify areas that could potentially present a high and low risk of conflict between the two industries. High risk areas of conflict between commercial fishing and OWF can lead to objections and significant delays to the consultation process for OWFs as the economic stakes for the fishing sectors are high. In contrast, in areas characterised by lower levels of fishing activity, the tension between fishing and OWF development is expected to be lower.

In addition to the delay of the consultation process, there can be delays in compensation/ cooperation discussions with fishers for any displacement and other mitigation measures due to the lack of fisheries data often not available at the spatial scale needed to inform offshore wind farm developers, marine spatial planners and other stakeholders.

The project 'Fisheries Sensitivity Mapping and Displacement Modelling' (FiSMaDiM) seeks to fill the data and evidence gap by:

(1) identify the recent spatial distribution of fishing activities of UK vessels in the UK EEZ based on individual vessels' positional tracking data, fisheries activity database and relevant ancillary data collected by MMO & Marine Scotland [WP2]

(2) Developing a fisheries sensitivity index to identify areas of high and low conflict with the fishing industry due to economic importance of the area for the industry and assessing the opportunities and constraints for the fisheries sector with increasing offshore wind development [WP3]

(3) Provide publicly available evidence to inform policies related to energy security, marine conservation and meeting the objectives of the Fisheries Act [WP4]

This research project was conducted between 1st Sept 2022-30th Sept 2024 and was funded by the Crown Estate Offshore Wind Evidence and Change Programme (OWEC) under the project theme: Spatial co-ordination and co-location. The research project was led by Cefas,

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[1] New UK Government plans big push on wind | WindEurope [last access 08/10/2024]

supported by partners from Marine Scotland and University of St Andrews. A project advisory group (PAG) formed of representatives of fisheries and offshore wind farm developers as well as government agency accompanied the project and were frequently consulted.

Presented here, the work conducted including the outcomes of the project, summarized for each work package. Work package 1 was for project management, therefore the report starts with a summary of work package 2. In this work package, a review on existing data, tools and approaches with regards to fisheries data was carried out. Based on the review, a methodology was developed to augment data from Vessel Monitoring Systems (VMS) with data from Automated Identification Systems (AIS). This methodology led to creation of a dataset on fishing effort for UK and non-UK vessels operating in the UK Economic Exclusive Zone (EEZ) for the years 2012-2021. This dataset was used in work package 3 in the application of fisheries sensitivity index for UK vessels to identify areas of high economic importance for the fishing industry. Work package 3 also implemented displacement models for three case studies and developed a methodology to assess the economic impact of offshore wind on fisheries using the case studies as an example. The newly generated maps of fishing effort within the UK EEZ and the fisheries sensitivity index and other related maps have been made public with the help of a **webtool**. Work package 4 designed the webtool and its functionality. The report concludes with future steps and recommendations.

2. Work package 2: Who is fishing where?

2.1 Task 1: Review of data, methods and tools

The first task of work package 2 was to review the existing data, tools and approaches to identify fishing activity of vessels operating in the UK EEZ and provide an overview of the different kinds of data available to improve our understanding of the spatial distribution of fishing activity. Focus was on the English and Scottish fisheries dependent data, their frequency and coverage. The review was published as Mendo et al. (2023).

The review highlighted that a range of data sources are available, but while positional data are available for all vessels above 12 metres in length (VMS) and above 15 metres in length (AIS), high resolution data for the inshore fishing sector (below 12 metres in length) is lacking. In addition, the limitations associated with the spatio-temporal resolution of the data (for example, sightings, landings, or VMS data) can reduce confidence in decision making for offshore developments. For example, Stelzenmüller *et al*. (2022) showed that even resolutions of 0.05 degrees of gridded fishing effort tend to overestimate the actual overlap between fishing activities and offshore wind farms. They suggest that to appropriately represent fishing activities, fine scale depictions of effort (0.01 x 0.01 degrees, roughly 1 x 1 km) are needed, as some offshore wind sites can cover areas of only few squared kilometres (Stelzenmüller et al. 2022).

In discussion with the project advisory group, it was decided to augment VMS data with AIS data to generate maps on the spatial distribution of fishing effort at a higher resolution. It is acknowledged that this will not depict the effort of all vessels fishing in the UK EEZ (i.e. mostly those under 12m) but should give a more detailed picture than using only VMS data.

2.2 Task 2: Updated maps of fishing activity

VMS and AIS data were obtained, but while VMS devices are assigned to a vessel and a vessel identifier is part of the data set, the same is not the case for the AIS data. AIS devices are not vessel specific and as such the AIS data comes with a device identifier (MMSI number) but not a vessel identifier. To merge the two datasets, the Marine Management Organization (MMO), the Marine Coast Guard Agency (MCGA), the European Fleet registry and Global Fishing Watch provided us with list matching the vessels unique identifier and the MMSI number. This information was double-checked with information publicly available on Marine traffic. At the end of this process, VMS data could be complemented with AIS data for 569 vessels. Most vessels above 12 metres in length had information on the corresponding AIS device, while 24% of vessels below 12 metres in length provided AIS data only. 1,788 vessels with AIS data only, were added to the dataset for estimation of fishing effort, 1,245 of these registered to the UK.

The VMS data was linked to catch record data provided by MMO which also includes the gear used. The AIS data also provides the main gear of the vessel. If VMS and AIS or only VMS data was available for the fishing activity of the vessel, the gear as stated in their catch records was used, otherwise the main gear as registered in the AIS dataset. However, there were several uncertainties about which gear was used for the respective fishing activity, it was therefore decided to split the fishing activity data into the following gear groups:

- Demersal trawl: Fishing activity recorded in the MMO fisheries activity database to have used FAO gear codes: "OTB", "OTT", "PTB", "TBB", "PUL", "TB", "TBN", "TX", "OT" or in the database of Global Fishing Watch or the EU fleet register: "“OTM|TRAWLERS, "demersal_trawls"

- Gill nets and entangling nets: Fishing activity recorded in the MMO fisheries activity database to have used FAO gear codes: "GNC", "GND", "GNS", "GTN", "GTR", "GN", "GEN", "GNF" or in the database of Global Fishing Watch or the EU fleet register: "SET_GILLNETS"
- Pelagic/midwater trawl: Fishing activity recorded in the MMO fisheries activity database to have used FAO gear codes: "OTM", "PTM", "TMS", "TM" or in the database of Global Fishing Watch or the EU fleet register: “PTM|TRAWLERS”
- Scallop dredges: Fishing activity recorded in the MMO fisheries activity database to have used FAO gear codes: "DRB", "DRH", "HMD" or in the database of Global Fishing Watch or the EU fleet register: "DREDGE_FISHING"
- Hooks and lines: Fishing activity recorded in the MMO fisheries activity database to have used FAO gear codes: "LHP", "LHM", "LLD", "LLS", "LTL", "LL", "HF", "LX" or in the database of Global Fishing Watch or the EU fleet register: "SET_LONGLINES", "DRIFTING_LONGLINES", "POLE_AND_LINE"
- Seine nets: Fishing activity recorded in the MMO fisheries activity database to have used FAO gear codes: "SB", "SDN", "SPR", "SSC", "SV", "SX" or in the database of Global Fishing Watch or the EU fleet register: "OTHER_SEINES"
- Surrounding nets: Fishing activity recorded in the MMO fisheries activity database to have used FAO gear codes: "PS" or in the database of Global Fishing Watch or the EU fleet register: "PURSE_SEINES"
- Pots and traps: Fishing activity recorded in the MMO fisheries activity database to have used FAO gear codes: "FPO", "FAR", "FIX", "FPN", "FYK" or in the database of Global Fishing Watch or the EU fleet register: "POTS_AND_TRAPS"

An additional gear group was ‘lift nets’, however, due to the lack of data, this gear group was not further considered while producing the fishing effort maps.

The positional data of the vessels was processed according to the standard proposed by Mendo et al. (2024a) to identify fishing activity which was translated into fishing effort based on the methodology outlined in Mendo et al. (2024b).

The resulting fishing effort was summarized for the years 2012-2021 for each gear group in a grid (0.05x0.05 degree). Grid cells in which three or fewer vessels were active were redacted due to it being classified as commercial sensitive information. A more detailed description of the work being conducted will be published (Mendo, et al. 2024b).The latest version of the manuscript is provided as attachment to the report.

3. Work package 3: Constraints & Opportunities

3.1 Task 1: Sensitivity assessment of fishing activities

3.1.1 Task 1.1: Identifying the level of conflict between offshore renewable energy and fisheries sectors

Besides generating fishing activity maps for the UK EEZ, this project also focused on generating indicators capturing the economic importance of fishing activity at the respective sites. Together with the PAG, indicators were discussed and developed to capture the wider economic impact beyond landing values. Landing values generated at the site were rated as not appropriately reflecting the actual impact of the offshore wind expansion on the fishing industry. Instead, indicators were used which would reflect the impact of restricted access to fishing grounds due to offshore wind farm developments on the fishing business but also on the fishing sector in a wider sense. The final list of indicators used:

- *Indicator 1*, the number of vessels with a substantial amount of their landing values generated at the site – reflecting the economic dependency of individual vessel on the site. For the fraction of revenue generated at the site to be considered as "substantial", the 75th percentile of the total distribution for each year and gear group was used as threshold. Two versions of indicator 1 were used, a) the number of vessels as absolute number and b) the proportion of vessels which are economically dependent on fishing at the site out of all vessels operating at the site with the same gear.
- *Indicator 2,* the concentration of fishing vessels at the site, based on the theory that if only a small number of vessels share the landing value generated at the site, it could lead to a higher conflict potential than if many vessels are sharing the landing value at a site. This theory was originally tested and proven within the context of civil conflict between ethnic and linguistic population segments in developing countries (Alesina et al. 2003) and is here applied to the context of fisheries. The assumption is that a low number of vessels will likely have also a low level of coordination and collaboration costs while at the same time high stakes in the area to defend, hence the motivation to oppose a development which restricts their access to the fishing ground. This indicator was also provided in two versions: a) the business concentration measured as Hirschman-Herfindahl Index (HHI) with 1 denoting high concentration and 0 high fractionalization of landing values generated at the site over multiple vessels; and b) the HHI weighted by landing values to account for the levels at stake for the potential conflict.
- *Indicator 3,* how difficult would it be to replace the value generated at a fishing site if access to it was restricted. In particular, species managed with quota were of interest for this indicator. Version a) of the indicator measured the value of species under quota management which can only be harvested in a limited number of areas. A species was considered as being harvested in a limited number of areas if it was harvested in number of areas less than the 25th percentile by year and gear group. Version b) of the indicator is the fraction of the landing values generated by quota species of the total landing value generated at the site.
- *Indicator 4*, a) the concentration of species under quota management for each vessel at the site measured as well as Hirschman-Herfindahl index. The higher the number, the more focused are the vessels on harvesting quota species at the site. Quota species are often high valuable species and therefore this indicator reflects the dependency of the

fishing vessels on quota species at the site in contrast to indicator 3b which captures just the general availability of quota species at the site. b) in contrast measures the concentration of gear groups used in the site reflecting that the higher the number the more likely the site is used by a specialized target fishery which might not be able to find alternative fishing sites without encroaching on sites used by other fishing gears.

- *Indicator 5* captured the inter-annual variability of fishing activity by providing a) number of years between 2012-2021 the site was harvested, and b) the standard deviation of annual landing values at the site between 2012-2021.
- *Indicator 6,* measuring the intra-annual variability by a) the number of months between 2012-2021 the site was harvested, and b) the standard deviation of monthly landing values at the site between 2012-2021.

Applying these six indicators for nine gear groups over 10 years generated a vast amount of information which needs to be operationalized to be able to inform adequately the policy process. For this purpose, several options on how to bundle the indicators were tested. Statistical methods did not lead to any substantial reduction of dimensions of the information provided, therefore a rather standard but robust method was used to generate the Fishing Sensitivity Index. In a first step, the indicators were split into fisheries sensitivity indicators (indicator 1 (a, b), 2 (a, b), 3(a, b) and 4a) and context-providing indicators (indicator 4b, 5 (a, b), and 6 (a, b). While the context-providing indicators are provided as an outcome of the project as individual indicators the fisheries sensitivity indicators are combined in a Fisheries Sensitivity Index. In a second step, each indicator was transformed using a ranking approach based on the quantiles in the distribution of z-standardized individual indicators into ranks from 1-5. This transformation assures comparability between indicators.

Two versions of the Fisheries Sensitivity Index were generated:

Fisheries Sensitivity Index 1 is the sum of the transformed individual indicators ranging from 1-35,whereby each indicator is given the same weight within the combined index.

Fisheries Sensitivity Index 2 is a weighted version of Index 1. The number of years the individual ranked indicator at the site was 1 or higher was used as the weighting. Using this temporal weight deflates Fisheries Sensitivity Index 1 by acknowledging that the site might have not been of high importance in each year. A more detailed description on how the indexes were generated was previously published in Muench et al. (2024).

The final output of the project applies the indicators on the data generated in work package 2, i.e. the dataset of VMS and AIS data for UK fishing vessels for the years 2012-2021 in the UK EEZ, combined with catch reports provided by MMO fisheries data using VMStools (Hintzen et al. 2012) and aggregated into a C-square grid (0.05x0.05degree). An average of the index for all years (2012-2021), the most recent 5 years (2017-2021) and the most recent 3 years (2019-2021) are provided in the webtool (work package 4).

3.1.2 Task 1.2: Uncertainty analysis

In this task, the indicators and combined indices were assessed on their robustness and stability.

Concern 1: One of the first concerns raised with applying the indicators to the data generated in work package 2, was the representativeness of the data compared to the overall fishing activity recorded for UK flagged vessels in the UK EEZ. Considering that VMS data (mandatory only for vessels larger than 12 metres) was augmented by AIS data (mandatory only for vessels larger than 15 metres), this concern of representativeness is a crucial one. Although we incorporate any VMS and AIS data irrespective of vessel size, data for vessels below the length threshold is voluntarily submitted and therefore is likely to underrepresent smaller fishing vessels. To assess the representativeness of the data used to generate the final maps of Fisheries Sensitivity Indexes, the number of UK vessels, the number of fishing trips and their corresponding landing values, was used as baseline to evaluate the representativeness of the data used in work package 3.

Table 1: Percentage of fishing activity represented in the VMS and VMS&AIS combined dataset provided by WP2 for UK vessels harvesting the UK EEZ compared to fishing activity records provided by MMO.

Year	Number of vessels	Number of fishing trips	Landing value
2012	13%	11%	55%
2013	14%	11%	56%
2014	16%	14%	62%
2015	16%	18%	68%
2016	18%	20%	70%
2017	17%	19%	68%
2018	19%	23%	71%
2019	18%	21%	71%
2020	19%	22%	73%
2021	17%	20%	54%
Average	**17%**	**18%**	**65%**

While it was estimated that on average only 17% of fishing vessels were included in the newly generated dataset and on average only 18% of fishing trips, the dataset represents on average 65% of landing value (Table 1). The vessels in the newly generated dataset therefore are those producing relatively high landing values per trip do not reflect the effort or sensitivity for low activity or smaller vessels.

Concern 2: Another concern raised was whether each indicator captures different aspects or whether indicators could substitute each other. To assess this, the correlation between the indicators which were combined into the Fisheries Sensitivity Indexes was estimated (Table 2). While indicator 4a, which measure the concentration of landings of species under quota management tends to be correlated higher than average with several of the other indicators, this is not consistently the case and varies between gear groups. The two versions of indicator 1 are often also highly correlated with the two versions of indicator 2, with indicator 1a negatively correlated with indicator 2a. Therefore, although there is some correlation between indicators, these correlations are not persistent in all gear groups and not considered to be at a level of concern (>0.8), and therefore should not result in a biased Fisheries Sensitivity Index.

Table 2: Correlation of indicators used to generate the fisheries sensitivity index by gear group

Gillnet & entangled nets	Ind_1B	Ind_1A	Ind_2A	Ind_2B	Ind_3A	Ind_3B	Ind_4A
Ind_1B	1						
Ind_1A	-0.05	1					
Ind_2A	**0.73**	**-0.55**	1				
Ind_2B	0.34	-0.13	0.36	1			
Ind_3A	-0.18	0.33	-0.28	0.03	1		
Ind_3B	-0.07	0.03	-0.06	0.13	0.14	1	
Ind_4A	**-0.59**	0.41	**-0.63**	-0.13	0.20	**0.54**	1

Demersal trawl	Ind_1B	Ind_1A	Ind_2A	Ind_2B	Ind_3A	Ind_3B	Ind_4A
Ind_1B	1						
Ind_1A	0.23	1					
Ind_2A	**0.57**	-0.39	1				
Ind_2B	0.18	-0.08	0.25	1			
Ind_3A	0.07	**0.64**	-0.28	0.27	1		
Ind_3B	-0.17	0.00	-0.14	0.00	0.17	1	
Ind_4A	-0.01	**0.81**	-0.44	-0.10	**0.62**	0.24	1

Pelagic/midwater trawl	Ind_1B	Ind_1A	Ind_2A	Ind_2B	Ind_3A	Ind_3B	Ind_4A
Ind_1B	1						
Ind_1A	0.00	1					
Ind_2A	**0.54**	**-0.66**	1				
Ind_2B	0.21	-0.11	0.25	1			
Ind_3A	-0.17	0.19	-0.21	0.01	1		
Ind_3B	0.04	0.05	0.03	0.16	0.08	1	
Ind_4A	-0.48	**0.75**	**-0.77**	-0.10	0.32	0.25	1

Seine nets	Ind_1B	Ind_1A	Ind_2A	Ind_2B	Ind_3A	Ind_3B	Ind_4A
Ind_1B	1						
Ind_1A	0.00	1					
Ind_2A	**0.66**	**-0.58**	1				
Ind_2B	0.42	-0.15	0.46	1			
Ind_3A	-0.05	0.43	-0.21	0.37	1		
Ind_3B	0.18	-0.13	0.24	0.24	0.41	1	
Ind_4A	-0.28	0.29	-0.34	-0.09	**0.58**	**0.56**	1

Hooks & lines	Ind_1B	Ind_1A	Ind_2A	Ind_2B	Ind_3A	Ind_3B	Ind_4A
Ind_1B	1						
Ind_1A	0.23	1					
Ind_2A	**0.55**	**-0.55**	1				
Ind_2B	0.44	0.00	0.40	1			
Ind_3A	0.09	**0.78**	-0.46	0.14	1		
Ind_3B	-0.16	0.13	-0.23	-0.01	0.10	1	
Ind_4A	-0.37	**0.70**	**-0.82**	-0.26	**0.57**	0.24	1

Pots & traps	Ind_1B	Ind_1A	Ind_2A	Ind_2B	Ind_3A	Ind_3B	Ind_4A
Ind_1B	1						
Ind_1A	0.01	1					
Ind_2A	**0.50**	**-0.65**	1				
Ind_2B	0.13	-0.01	0.12	1			
Ind_3A	-0.05	0.13	-0.10	0.45	1		
Ind_3B	0.05	-0.11	0.10	-0.18	0.38	1	
Ind_4A	-0.22	0.18	-0.22	-0.12	0.46	**0.82**	1

Scallop dredges	Ind_1B	Ind_1A	Ind_2A	Ind_2B	Ind_3A	Ind_3B	Ind_4A
Ind_1B	1						
Ind_1A	0.17	1					
Ind_2A	0.48	-0.34	1				
Ind_2B	0.28	-0.10	0.38	1			
Ind_3A	0.06	0.10	-0.11	0.06	1		
Ind_3B	0.40	-0.12	0.30	-0.11	0.29	1	
Ind_4A	0.24	-0.02	0.14	-0.12	0.37	**0.76**	1

Surrounding nets	Ind_1B	Ind_1A	Ind_2A	Ind_2B	Ind_3A	Ind_3B	Ind_4A
Ind_1B	1						
Ind_1A	-0.14	1					
Ind_2A	**0.58**	**-0.79**	1				
Ind_2B	0.32	-0.25	0.37	1			
Ind_3A	0.16	-0.15	0.22	**0.90**	1		
Ind_3B	0.29	-0.24	0.38	**0.53**	**0.56**	1	
Ind_4A	0.07	-0.20	0.23	0.42	**0.60**	**0.82**	1

* For ease of presentation, values >|0.5| were displayed in bold to indicate high correlation.

Concern 3: A further concern raised was whether the final index is driven by only one or two indicators. Like concern 1, the correlation matrix was calculated between the indicators and Fisheries Sensitivity Index 1 (Table 3) as well Fisheries Sensitivity Index 2 (Table 4). While some higher correlations can be detected, for Fisheries Sensitivity Index 1, the highest correlation is 0.74 with indicator 1b and consistently high only for the gear group pots & traps. For the Fisheries Sensitivity Index 2, the highest correlation was 0.65 with indicator 4a for hooks & line fisheries. While indicator 3a seems to contribute to the Fisheries Sensitivity Indexes higher than average, it was viewed to be not at a level that this indicator was driving the index and was often not the only indicator in the gear group which is highly correlated with the corresponding index. As the correlation varied between gear groups and no persistent pattern which might bias the Fisheries Sensitivity Indexes could be detected, it was assessed that this concern was not founded. However, applying the indicators to another dataset could generate a different outcome.

Table 3: Correlation matrix of Fisheries Sensitivity Index 1 and the individual indicators used to generate the index by gear group

Gear Group	Ind_1A	Ind_1B	Ind_2A	Ind_2B	Ind_3A	Ind_3B	Ind_4A
Demersal trawls	0.37	0.40	-0.27	0.15	**0.52**	0.19	0.43
Dredges	-0.05	0.25	-0.05	0.29	**0.50**	0.43	0.35
Gillnet & entangled nets	0.07	**0.52**	-0.04	**0.59**	0.32	0.35	0.35
Hooks & lines	**0.64**	0.41	-0.39	0.47	**0.60**	0.24	**0.55**
Pelagic/midwater trawl	0.15	0.36	-0.07	0.44	0.30	**0.56**	0.48
Seine nets	0.06	**0.53**	0.00	**0.59**	**0.57**	**0.54**	0.48
Surrounding nets	-0.12	0.32	0.09	**0.63**	**0.59**	**0.50**	0.43
Pots & traps	-0.09	**0.74**	0.18	0.48	**0.51**	0.49	0.49

* For ease of presentation, values >|0.5| were displayed in bold to indicate high correlation.

Table 4: Correlation matrix of Fisheries Sensitivity Index 2 and the individual indicators used to generate the index by gear group

Gear group	Ind_1A	Ind_1B	Ind_2A	Ind_2B	Ind_3A	Ind_3B	Ind_4A
Demersal trawls	**0.50**	-0.09	**-0.55**	0.02	**0.54**	0.17	**0.52**
Dredges	0.19	-0.16	-0.32	0.18	**0.54**	0.05	0.08
Gillnet & entangled nets	0.18	-0.17	-0.29	0.40	0.30	0.22	0.34
Hooks & lines	**0.63**	-0.10	**-0.59**	0.24	**0.63**	0.13	**0.65**
Pelagic/midwater trawl	0.27	-0.08	-0.24	0.21	0.24	0.24	0.39
Seine nets	0.35	-0.16	-0.37	0.39	**0.58**	0.25	0.45
Surrounding nets	0.19	0.22	-0.16	0.16	0.13	-0.39	-0.32
Pots & traps	0.19	0.19	-0.02	0.49	**0.58**	0.33	0.44

* For ease of presentation, values >|0.5| were displayed in bold to indicate high correlation.

Concern 4: Apart from the relationship between the indicators and whether this would lead to bias in the index formation, another concern was whether the assumptions to generate the indicator may bias the results. Indicator 1 and indicator 3 thresholds were used based on the percentiles in the distribution for each gear group and year. To assess whether these thresholds in the indicators may lead to a bias in the index, the thresholds were adjusted for each indicator. For example, indicator 1 uses as threshold to assess the economic dependency of a vessel on the site at the 75th percentile. In the sensitivity assessment, this threshold was changed to the 74th, 76th as well as 90th percentile. The Fisheries Sensitivity Index 1 was estimated for each of the new thresholds. Comparing the resulting Fisheries Sensitivity Index 1 outputs, no changes were detected for the small change in threshold and only a slight change when using the 90th percentile (Figure 1).

Similarly, indicator 3 uses the 25th percentile as threshold for each gear group to identify species harvested in only a limited number of sites. Changing the threshold to the 24th or 26th percentile or even 10th percentile made no notable change to the resulting Fisheries Sensitivity Index 1 (Figure 2).

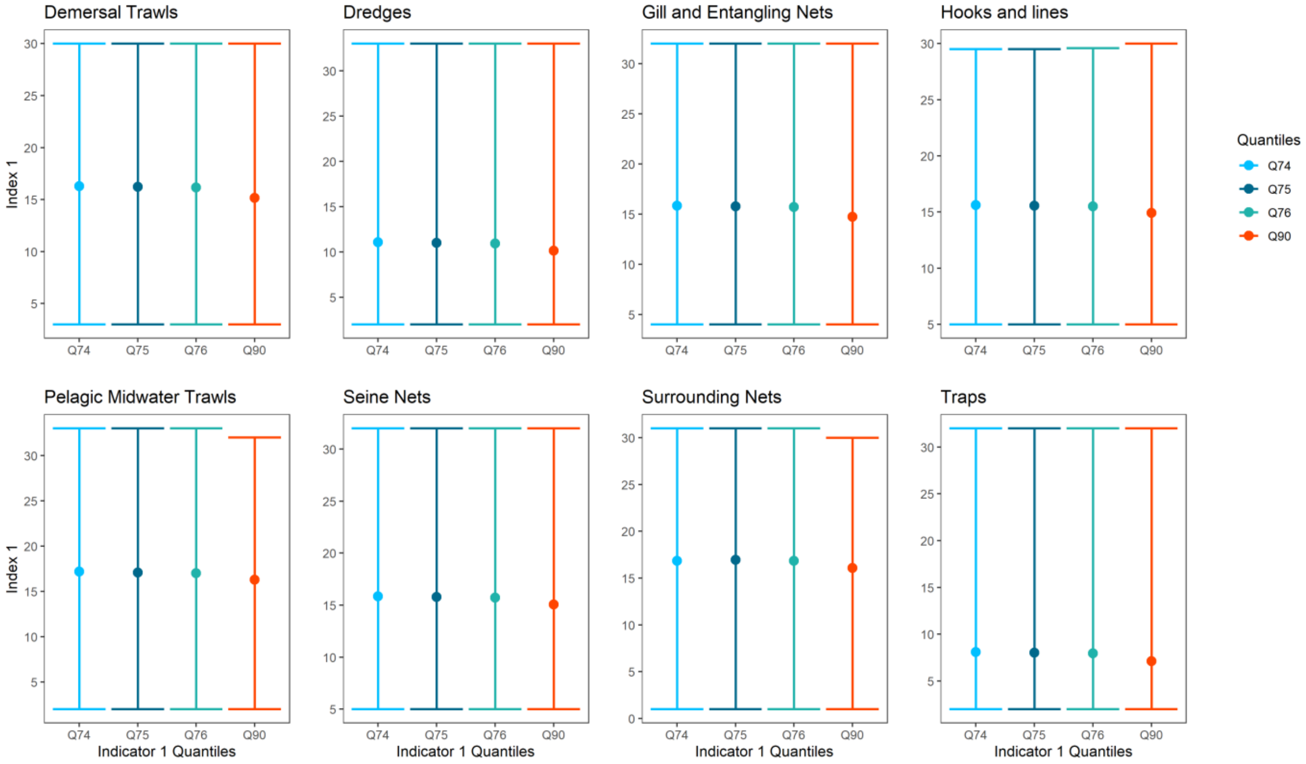

Figure 1: Average value of the Fisheries Sensitivity Index 1 as well as the minimum and maximum range estimated under different assumption on the threshold used to generate indicator 1 for each gear group.

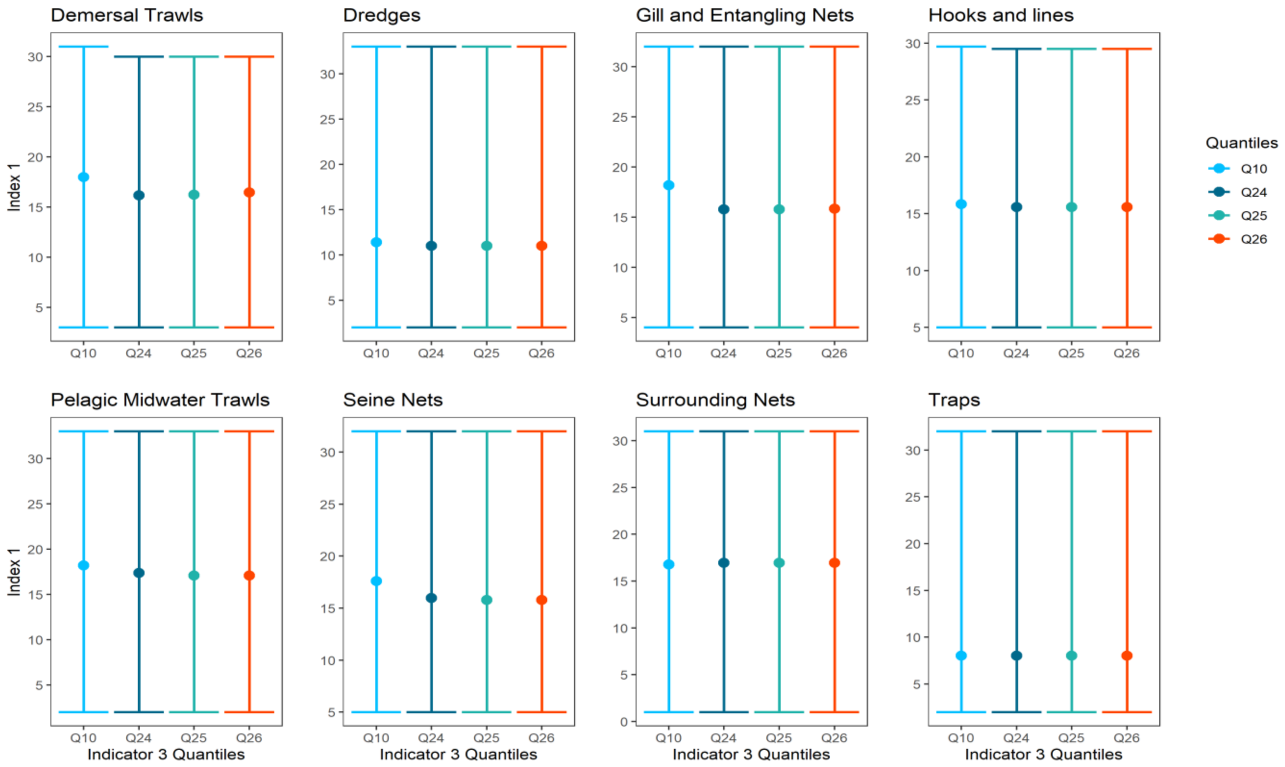

Figure 2: Average value of the Fisheries Sensitivity Index 1 as well as the minimum and maximum range estimated under different assumption on the threshold used to generate indicator 3 for each gear group.

Concern 5: Another issue raised was how the indicator captures changes over time. The indicator used 10 years of data, but spatio-temporal analysis separately for each gear group was out of scope for this work. Instead, a visual inspection of the annual plots of Fisheries Sensitivity Index 1 for each gear group (Figure 6 –Figure 13, Appendix) was conducted. It can be observed that, although there are slight changes in the extent, the areas of highest sensitivity remain high over the period. While this provides a sufficiently robust index over the medium-term economic importance of an area for the fishing industry, it should not be used for assessments under climate change scenarios.

3.2 Task 2: Displacement

3.2.1 Location choice modelling

There are several ways to assess displacement, ranging from using assumptions and scenarios, surveys (i.e., stated preference approach) or modelling based on existing data of past fishers' behaviour (i.e., revealed preference approach). One of the most common methods to modelling fishers' choices is the site choice model using a random utility framework (Girardin et al. 2017; Andrews, Pittman, and Armitage 2020). These model individual fisher's decision to harvest a specific site as trade-off between the expected revenue at the site, the travel distance to the site and other variables (e.g. risk aversion of the fisher, uncertainty of the outcome, adaptive capacity of the fisher, resources available to the fisher). To use a site choice model as displacement model, the assumption is that if the fisher cannot harvest his preferred location anymore, he will move to the second-best option if it is considered a profitable alternative. Hence, understanding fishers' location choice and his individual ranking of fishing location (i.e. preference structure) allows to identify the second-best option (given gear and resource constraints) and to assess the changes in profitability and economic impact for the individual fishers from spatial access restrictions. However, at the core of fisher's site choices are expected revenue, which need to be estimated. Often, it is assumed that fishers form their expectation based on previous experience at the site (Abbott and Haynie 2012; Smith 2005; Tidd et al. 2012), but also integrating information shared with them by other fishers (Dépalle, Thébaud, and Sanchirico 2020; Curtis and McConnell 2004) or inferring from experience of others or their own in adjacent areas (Hutniczak and Muench 2018). The advantage of using these types of modelling approach is that only sites harvested by the same gear group are considered as realistic alternatives as well as changes in expected profitability caused by the displacement of the fishing activity. The disadvantage is that these models are very resource intense and need information on individual vessel level to provide realistic results.

For this project, it was proposed to apply existing location choice models on case studies to test their predictive power. Cefas are currently using three location choice models (Tidd et al. 2012; Hutniczak and Muench 2018; Dépalle, Thébaud, and Sanchirico 2020), using ICES rectangle as spatial resolution. In the past, these models showed robust estimate with respect to their explanatory power (Muench and Spence 2020), however, they have not been tested to predict future fishing locations. In this project, we started to use the most basic configuration of a location choice model and to implement it on the data provided by work package 2 on the high-resolution grid of 0.05x0.05 degrees.

The working hypotheses was that we should see at the time of construction a lack, or at least a reduced level, of fishing activity within the offshore wind farm due to access restrictions based on health & safety concerns.

After construction, a shift within fishing activity could be assumed, due to the spatial constraints of the wind turbines, whereby instead of mobile gears, more static gear is used within the offshore wind sites or a permanent shift of fishing to other locations if the wind farm design is not considered to allow safe and profitable fishing.

3.2.2 Case studies

Together with the PAG, case studies were identified according to the following criteria: (1) the construction of the wind farm was within the timeframe of the data (i.e. between 2012-2021); (2) a variety of fisheries using different gears at the site were covered by the different case studies (i.e. focus should not be given to only one gear group in all case studies), (3) the case studies should be of different spatial extent to allow testing on how good the models can handle different spatial scales.

The following case studies were decided to be used for this project. Based on the data produced in WP2, vessels were identified with fishing activity within the case study area to generate a fishing activity profile over the years 2012-2021.

Case study 1: Moray East

Moray East is a wind farm located in the Moray Firth (east coast of Scotland, northeast of Inverness). This wind farm is next to the Beatrix offshore wind farm, which was constructed before our study period. The construction of Moray East took place from 2018-2022, hence only slightly outside our study period. The main fishing gear used with respect to effort at the site were demersal trawl and scallop dredges. The site overlayed with 46 grid cells of the c-square grid used for the project. However, our data showed no significant reduction of fishing activity at the site during the time of construction with regards to the numbers of fishing vessels operating (Figure 3a) or the number of fishing trips undertaken with fishing activity (Figure 3b).

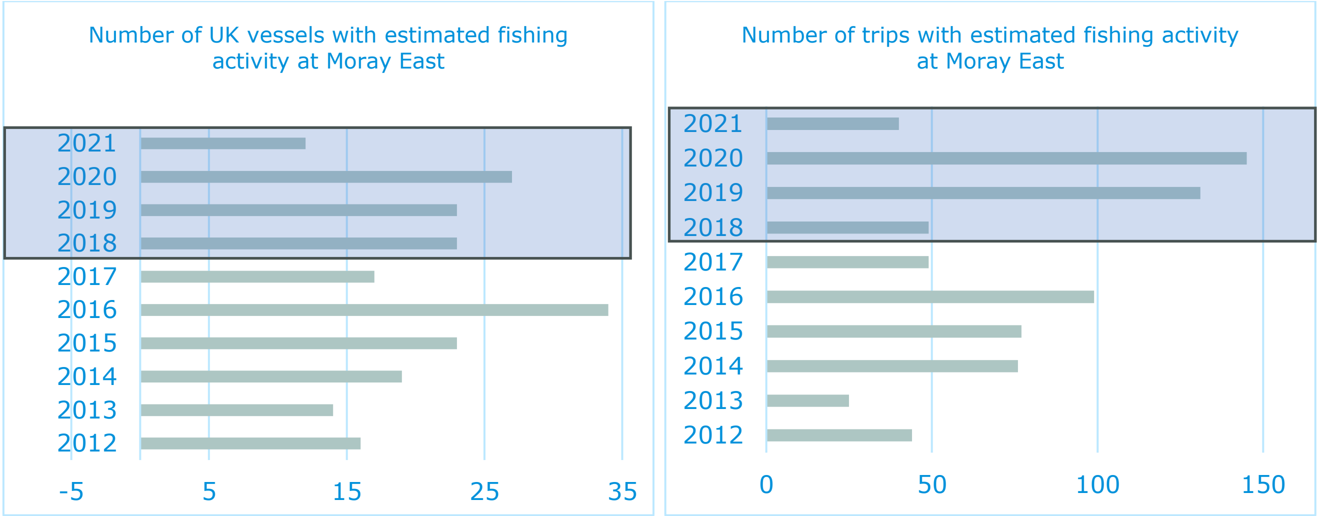

Figure 3: a) Annual sum of fishing vessels and b) annual sum of fishing trips predicted fishing activity within the offshore wind farm site of Moray East before and at times of construction. Years of constructions are highlighted with blue box.

Although a shift in fishing gear used or reduction in fishing effort in the area could not be detected, it was estimated that fishing trips from UK vessels for which at least some part of the fishing activity took place within Moray East area before construction (2012-2017) generated on average about £0.4m per year using scallop dredges and £0.3m per year using demersal trawls. During the period of construction in the years 2018-2021, the landing values stemming from trips at least partly harvesting the site were estimated to have changed to an annual average of £2.4m per year using demersal trawl and £1.0m per year using scallop dredges. Although, it is estimated that average landing value increased between the two periods, this estimated change can be a result of external factors (e.g. changes in biomass, seasonality of the fishing activity) or simply results of changes in the data collection, or any other changes not necessarily related to the construction of the wind farm. Therefore, using annual data, no impact of the offshore wind farm could be established in this case study, although a finer temporal resolution (e.g. monthly data) could reveal impacts at that scale.

Hornsea 1 & 2

The wind farms Hornsea 1 & 2 are located in the North Sea, off the east coast of the UK (east of Hull) and south of the Dogger Bank. Hornsea 1 was constructed between January 2018 and December 2019, while construction for Hornsea 2 started August 2020 and finished August 2022). Based on the data generated in work package 2, it was estimated that the main gear used by fishers with respect to fishing effort in the two sides were pots & traps. As most fishing trips were estimated to have fishing activities in both offshore wind sites and to avoid double-counting, the two sites were considered as one case study which overlayed with 117 grid cells of the c-square grid. Similar to the Moray East case study, no significant reduction in fishing activity, neither number of vessels (Figure 4a) nor number of trips operating at the site could be detected (Figure 4b) using annual aggregated data.

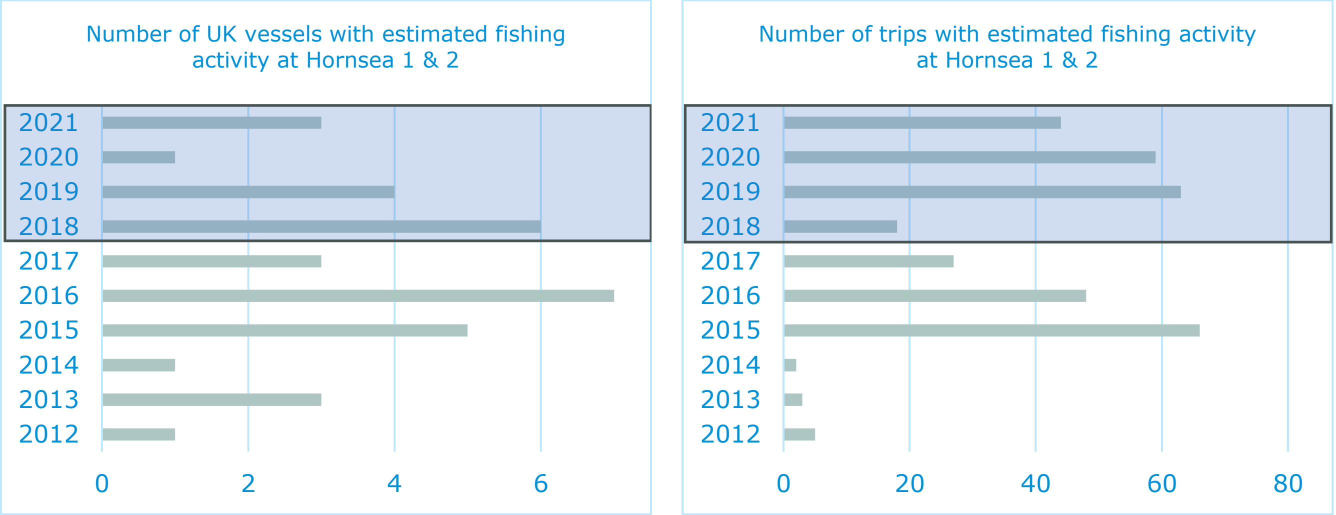

Figure 4: a) Annual sum of fishing vessels and b) annual sum of fishing trips predicted fishing activity within the offshore wind farm site of Hornsea 1 & 2 before and at times of construction. Years of constructions are highlighted with blue box.

Although a shift in fishing gear used or changes to fishing effort in the area could not be detected, it was estimated that fishing trips from UK vessels for which at least some part of the fishing activity took place within Hornsea 1 or Hornsea 2 area before construction (2012-2017) generated in average about £0.3m per year using pots and traps. During the period of construction in the years 2018-2021, the landing values steeming from trips at least partly harvesting the site were estimated to have changed to an annual average of £3.9m per year using pots and traps. Although, it is estimated that average landing value increased between the two periods, this estimated change can be a result of external factors (e.g. changes in biomass, seasonality of the fishing activity) or simply results of changes in the data collection, or any other changes not necessarily related to the construction of the wind farm. Therefore, using annual data, no impact of the offshore wind farm could be established in this case study, although a finer temporal resolution (e.g. monthly data) could reveal impacts at that scale.

Walney extensions (1&2)

The third case study was the extension 1 & 2 of the Walney offshore wind farm site which was constructed between 2017 and 2018. Walney offshore wind farm is located in Liverpool Bay, off the coast of Barrow-in-Furness on the west coast of the UK. The main fishing gear with regards to fishing effort used in the area is demersal trawl. The site overlayed with 26 grid cells of the c-square grid and was the smallest case study area. In contrast to the other case studies, a reduction in fishing activity at the time of construction was detected, based on the number of vessels operating in the area (Figure 5a) and the number of fishing trips within the site (Figure 5b).

In the years before constructions (2012-2016), it was estimated that fishing activity that took place at least partly at the site of the Walney extensions 1 & 2 generated on average £46.4k per year using demersal trawls. No fishing activity took place in the years of construction that could be detected in our dataset. After construction (2019-2021), it was estimated that on average £374k.8 per year was generated by demersal trawls and in average £165.3k per year using pots and traps. Hence, although this case study supported our working hypothesis, that fishing is reduced during the construction phase and the use of static gear will likely increase after construction within the wind farm site, no causality can be established at this stage as other factors may cause these estimated changes which are not related to the wind farm.

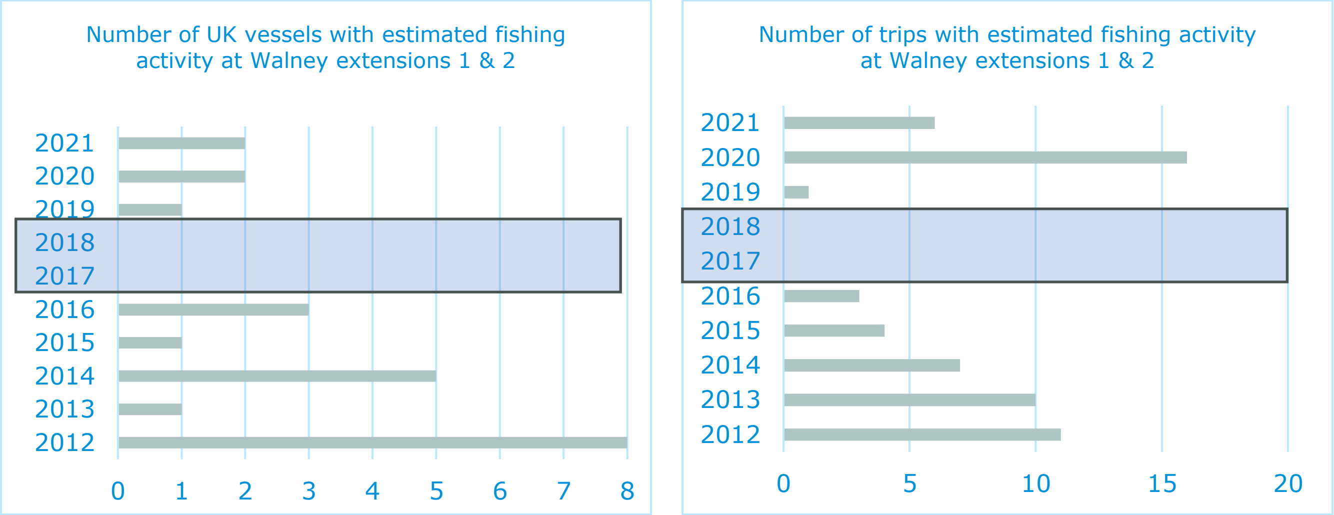

Figure 5: a) Annual sum of fishing vessels and b) annual sum of fishing trips predicted fishing activity within the offshore wind farm site of Walney Extension 1 & 2 before, after and at times of construction. Years of constructions are highlighted with blue box.

3.2.3 Application of the location choice models

A simple location choice model was implemented as a first step to minimise the complexity of the model. In this model, individual fishers seek to maximize only their expected operational profit by trading off the expected revenue at the site against the travel cost. To reduce the computational burden of the modelling caused by using the grid size of 0.05x0.05 degrees (instead of ICES rectangles (1x0.5 degrees), the temporal resolution of monthly and quarterly was applied. Distance to a grid cell (i.e. fishing site) was measured from the main landing port (i.e. highest landing value) of the vessel. Expected revenues were derived as average revenues generated in the previous period or same period in the previous year. Although the location choice model converged, the explanatory power of the model was less than 5% (i.e. only a small fraction of location choice could be explained this way). Several reasons for the failure of the model were identified and are discussed below. The list here is just an initial assessment on why the model did not perform as expected but should not be seen as exhaustive.

Issue 1 - Equal split of landing values: Fishers report their catch at a spatial resolution of an ICES rectangle every 24 hours. The corresponding catch values are assigned with help of the VMStool (Hintzen et al. 2012) to the identified fishing locations, and are equally distributed across all fishing operations for the time period. However, employing such a high-resolution grid often reduces the fishing effort to one haul per grid cell, and so an equal spread of landing values over the high-resolution grid cell. Therefore, in the choice model, the fisher choses between locations (i.e. grid cells) which have the same expected revenue and are at a similar distance, and so have comparable expected operating profits. While this might sometimes be the case in the real world and lead fishers to being indifferent between these fishing locations, the model does not account for indifference but rather picks one location randomly instead. In our case, using the high-resolution grid size, choices in which the fishers were indifferent out-weighted choices with clear ranking and therefore led to poor model performance.

Potential solutions: Increasing the grid sizes (e.g. ICES rectangles) reduces the number of indifferent choices. An obvious solution would be to increase the grid size while continuing using the method to assign catch to the fishing location. However, this would lead to a loss of the spatial resolution deemed necessary for marine spatial planning and the assessment of the economic impact of offshore wind farm sites on fisheries. The way landings are assigned to fishing locations needs to be improved, e.g. by fishing haul, but this would require landings data to be generated at the haul level.

Issue 2 - Too many choices but not enough choices: Using a high resolution grid means that for each fishing activity the fisher does not choose between a handful of locations as they would do if ICES rectangles were used, but instead chooses from about 900 alternative sites on average each time they decide on their fishing activity. While this added computational burden to the model, it also increased the need that fishers needed to have fishing activity in the previous season or same season previous year in the same location (grid cell) to derive the expected revenues at the site. Hence, if previous fishing activity was only evident for adjacent sites but not exactly the same site, this information could not be used in the model in the current setup to derive expected revenues and was lost.

Potential solutions: Similar to the previous issue, increasing the grid size may solve some of it, however, would come at the cost of losing the spatial resolution deemed necessary for marine planning and robust economic impact assessment. Another solution would be to include information of adjacent areas into the formation of the expected revenue (e.g. moving window approach), however this would not reduce the computational burden the simplified site choice model is facing. This could be overcome by using an irregular grid and focusing on core fishing grounds instead of all fishing sites in the previous season or same season previous year.

Issue 3 – Computational burden: The location choice model is using a maximum likelihood approach, hence a statistical approach. Using a statistical approach allows to include errors and uncertainties in the outcomes, however, also increases the computational burden. Here, the temporal resolution was reduced to a minimum accepting that pivotal information explaining the site choice might be lost to decrease the computational burden. However, this allowed us to maintain the spatial resolution at a level deemed necessary for spatial planning. Even in this setup, the choice set reached 100GB in size for the 10 years of data and therefore led to challenges in applying the statistical model.

Potential solution: Instead of using a statistical model, a deterministic or heuristic model could be applied (Madsen et al. 2024; Carrella et al. 2020; Bailey et al. 2019). While these types of models would allow the use of large datasets, they are based on assumptions drawn by the researcher, hence can lead to assumption driven outcomes and are parameter intensive to set up. So far, no application of this type of modelling to location choice models has demonstrated that it performs significantly better than the statistical approach commonly used.

3.3 Task 3: Economic impact assessment

In the project outline, it was proposed to integrate the outcomes of task 1 - sensitivity mapping and task 2 - displacement modelling to assess the economic impact of offshore wind on fisheries. However, due to the displacement modelling work not providing robust results, it was agreed with the PAG to approach this task by using assumptions.

To assess the economic impact, firstly the Fisheries Sensitivity Indexes needs to be translated into an economic impact measure, similar to economic impact multiplier. Although the indicators were developed to assess the potential for conflict between fishers and wind farm sites, they are capturing the wider economic impact of spatial access restrictions on fisheries. Hence, instead of using only landing values to assess the economic importance of the area, other aspects are captured in the indicators which form the Fisheries Sensitivity Index, and therefore it can also be used to capture the economic impact. So, for example, indicator 1 is seeking to understand how many vessels generate a high proportion of their annual fishing value at the site. It is assumed that there is a higher level of conflict if a high number of fishers loose significant proportions of their annual revenues in contrast to a high number of fishers loose only a small proportion of their annual landing values. Similarly, if a high proportion of a fisher's annual income is affected by spatial access restrictions, it will be harder to replace the loss of income than if only a small fraction of its annual income is impacted. As such, the index captures the potential economic burden on the fisher's business and presents an economic impact measure.

Indicator 2 measured how many fishers shared the value generated in the area. From conflict theory (Alesina et al. 2003), conflict potential is shown to be higher if you have a low number of actors with a high stake in an area. A low number of actors (in our case fishers) means a low level of coordination and collaboration to oppose a development but also high stakes if a high landing value is generated at the site (i.e. motivation to oppose). Similar, if a fisher's landing value are highly concentrated in one area, it will be more difficult for the fisher to find adequate substitution. As such, the index captures the potential economic impact on the fisher's business in a different way than indicator 1. While these indicators are correlated, this was not for each gear group.

Indicator 3 measured the risk of loss of income and whether the species captured in these indicators are the most profitable ones. Specifically, Indicator 3a includes only species harvested in a limited number of areas. from this it can be determined whether restricting spatial access leads not just to conflict but also to severe economic loss for the fishing vessels as replacement is likely to be costly if not impossible.

Indicator 4a measured the concentration of quota managed species at the site. Like the above indicators, spatial access restriction may lead to high conflict potential as it would be difficult for fishers to find adequate replacement, and so can also be seen as an indicator for the potential economic loss or impact for fishers.

To use the Fisheries Sensitivity Indexes as impact multiplier the indicator would need to be transformed. The multiplier *M* for each site *i* was generated by the following equation:

$$M_i = 1 + \widehat{FSI}_i \big/ \max(FSI) \tag{1}$$

with $\widehat{FSI}_i$ denoting the average cell score for the site *i* of the Fisheries Sensitivity Index for the years 2012-2021, which is divided by the maximum possible score of the Fisheries Sensitivity Index (in our case 35). Using this transformation, an impact multiplier ranging from 1.03-1.94 (mean 1.52) is estimated based on Fisheries Sensitivity Index 1 and an impact multiplier ranging from 1.003-1.84 (mean 1.47) based on Fisheries Sensitivity Index 2.

So, for example, to assess the potential economic impact during the time of construction, the average annual landing value before the time of the construction generated at the site can be adjusted using the impact multiplier to approximate the potential wider economic impact on the fisheries for the time of construction. Using the two versions of the impact multiplier provides further a range of the potential loss of income.

Using Walney extension 1 & 2 as an example, based on the dataset provided by work package 2, it was estimated that, before construction, the demersal gear fishery generated on average

£46.4k annually on trips with at least some fishing activity within the site. Fishing activity occurring only within the site before construction was estimated to have generated an average annual income of £5.1k. Two scenarios were developed: in scenario 1, it was implied that the full fishing trip did not take place if some parts of the fishing activity was prohibited by spatial access restriction to the offshore wind farm site and all fishing trips at the time of constructions were impacted. Hence, it was assumed that no access was granted to the site at times of construction for fishing, meaning that exemptions allowing fishers to enter the sites while construction takes place were not accounted for. The average economic impact multiplier was estimated for this scenario for all grid cells the fishing activity was estimated to have taken place. Based on these assumptions, it was estimated that the economic impact from the closure of Walney extensions 1 & 2 for construction for the demersal fisheries ranged from £68.1k-£75.1k per year of closure (Table 5).

In scenario 2, only the fishing activity estimated to have taken place at the site in the previous years was considered in the impact estimation. The average economic impact multipliers of the site were used to understand the potential economic impact. Using these assumptions, the resulting economic impact for the fisheries of restricting access to the site in scenario 2 was estimated to range between £6.1k-£7.5k for each year of construction (Table 5).

Table 5: Example calculations for the economic impact of constructing offshore wind farms and restricting access for fisheries completely using the economic impact multiplier derived from the Fisheries Sensitivity Indexes and the case study Walney Extension 1 & 2.

	Estimated average annual landing value before construction	**Average economic impact multiplier at the site**	**Potential annual economic impact for fishing at the time of construction (full closure of the site)**
Walney Extension 1 & 2 (Demersal trawl) **Scenario 1: All fishing activity at least partly taking place at site are impacted**			
Version 1	£46.4k	1.618	£75.1k
Version 2	£46.4k	1.468	£68.1k
Walney Extension 1 & 2 (Demersal trawl) **Scenario 2: Only fishing activity taking place at site are impacted**			
Version 1	£5.1k	1.473	£7.5k
Version 2	£5.1k	1.201	£6.1k

These two scenarios provided for the estimation of the economic impact of the closure of the site for fisheries could be considered two extreme alternatives of what is the likely the actual impact. However, this estimated economic impact only captures the value fishers would need to find alternative fishing grounds for, however, it does not include the additional cost to find these alternative fishing grounds.

Although, it is unlikely that full access restrictions will be in place for most of the newly established offshore wind farm sites, and these scenarios would need to be adjusted accordingly, however, using these kinds of impact assessment may help to facilitate co-existence and collaboration conversation between fisheries and offshore wind operator, and illustrate that the economic impact for the fishing businesses are wider than simply the loss of landing values generated at the site.

4. Work package 4: Webtool

One of the main aims of the project is to provide evidence which can inform the planning process but also can support consents and compensation discussions. Therefore, the outputs should be made publicly available to allow stakeholders to use the data and outputs of the project. For this purpose, a webtool was designed which incorporates the fishing effort maps generated in work package 2 for fishing activity of UK and non-UK flagged vessels within the UK EEZ for which fishing activity could be reliable estimated based on VMS and/or AIS information. The data was further used to generate maps of the Fisheries Sensitivity Index 1, Fisheries Sensitivity Index 2 and the context-providing layers using only data for the UK-flagged vessels. The webtool was designed originally in a QGIS environment but was transferred into ArcGIS at the end of the project to provide a public version of the maps as well as a restricted access version. This was necessary as a significant proportion of the area assessed had only 3 or less vessels harvesting in them and therefore the data was classified as commercial sensitive and so cannot be made publicly available. The limited access version provides a set number of people from MMO, Marine Scotland, The Crown Estate and Defra (and their ALBs) access to the full dataset if needed for planning purpose and to inform policy.

The public version of the webtool can be found **here**. A restricted access version allowing users to access data for grid cells of fishing activity of less than 3 vessels will be made available to specifically named people from The Crown Estate, Defra, MMO and Scottish Government after all data sharing agreements are signed and security checks are passed.

To assure that the maps generated in WP2 and WP3 can be easily updated, script are produced in the computing software **R** and stored in Cefas private repository on **github**. Therefore, anyone with access can update the content of the webtool when new data becomes available as well as the scripts can be easily shared with other interested in applying, for example, the Fisheries Sensitivity Index on a different data source.

The webtool was designed to visualize high-resolution data in an accessible and user-friendly way. Maps, currently included in the webtool were provided by TCE (offshore wind planning zones) or produced with data either purchased from a private provider (AIS) or obtained via Cefas from MMO. **Latest updates** to the MMO data have not been included in the project as they were still in progress at the time the project was concluded. Any future updates of the data to be visualized in the webtool would depend on the access, quality and availability of the data to be included and the data sharing agreements in place. Although the maps can be easily generated with the help of the scripts available on the github, quality assurance before publication of the data is highly recommended. The webtool uses the ESRI infrastructure, any future changes in functionality of the webtool due to changes in the ESRI infrastructure or license agreement may support or restrict future functionality.

5. Limitations and caveats

The aim of the project was to provide a better understanding of the spatial distribution of fishing activities in the UK EEZ. After reviewing the available data, a methodology was developed to augment existing VMS data for UK vessels with AIS data for UK and non-UK vessels. This allowed the inclusion of information on fishing activity for some of the non-UK vessels and to estimate the fishing effort on a high-resolution grid (0.05x0.05 degrees). Although, it was shown that a grid of 0.01x0.01 degrees would be better suitable for planning offshore wind farm sites (Stelzenmüller et al. 2022), fisheries data, specifically landings reported by area, are collected at a lower resolution and the assumptions required to use these data at the higher resolution to inform marine spatial planning leads to higher uncertainty. The current dataset also only includes a proportion (on average 17%) of the UK flagged fishing vessels operating in the UK EEZ, mainly the larger fishing vessels (vessels above 12-metres in length) that generate relatively high value of landings per unit of fishing effort. For more robust estimates, representative of the wider fleet, new data (e.g. iVMS) or existing data from non-UK vessels should be included when it becomes available. Although not all fishing activity was included, this dataset is more comprehensive than the ones currently used to inform marine spatial planning and therefore can be seen as additional evidence informing policy.

The Fisheries Sensitivity Indexes were based on indicators developed in discussion with representatives of the fishing industry, government and the offshore wind farm industry. However, while they may capture aspects these individuals deem important, there may be others that were not considered. Before applying these indices in other contexts, checking with relevant representatives would be important to assure crucial aspects of the potential economic impact for the respective fishery are included.

In addition, the Fisheries Sensitivity Indexes were applied to the data generated within the project for the years 2012-2021 and provided as 3-, 5- and 10 years averages to interested parties with help of the webtool. Changes with regards to spatial access restrictions to an area or reporting standards were not explicitly considered. Hence, an area may score low in the indicators simply because fishing activity was restricted over the years in the area. Although, without restrictions, the area may score higher, for this project the existing restrictions were treated as given and not hypothetical scenario generated which would acknowledge the importance of an area for fishing if restrictions would not be in place.

Moreover, the indices only capture the short-term impact and do not include any potential cost and gains if fishers are able to replace the restricted fishing activity by harvesting alternative sites. Neither are the biological and ecological consequences considered in this rather simplified and static assessment of the potential economic impact of offshore wind on fisheries, nor secondary economic impacts of displacement of fishing activity. Hence, the long-term consequences of shifting fishing pressures are not captured, these indices should be viewed as tools to facility discussion on compensation and collaboration between fishers and offshore wind farm operators.

While the project sought to base an economic impact assessment on modelled outputs, the data limitation and methodology to assign catch to fishing locations limited the useability of models and highlighted the need to improve identifying fishing locations and assigning catches to those locations, either through improved monitoring or enhanced methodology.

6. Conclusion and recommendation

The project was able to generate fishing effort maps at a high spatial resolution for fishing activity of UK and non-UK fishing vessels which can inform marine spatial planning and be considered an additional source of information. Based on the dataset developed in the project, two versions of a Fisheries Sensitivity Index were provided which capture the potential for conflict between fishing industry and offshore wind farm operators based on the economic importance of the site for the fishing industry. It was shown how these indices can be used to determine the potential economic impact of limiting fishing access to the site. All the evidence has been made publicly available. However, the project also showed the limitations of fisheries data as it is currently collected, and while modelling tools are available, assumptions needed to use the data at the high spatial resolution to inform marine spatial planning generates a high level of uncertainty.

The outputs of this project provide a further step to understanding more comprehensively the economic impact of offshore wind developments on fisheries. While the work could be seen as an additional layer to be implemented within the 'whole seabed' approach aimed at by The Crown Estate, it is recommended to verify the outputs of the project with stakeholders.

While the project was developed in discussion with the PAG representing various stakeholders, a wider outreach to ensure impact is recommended. In more detail, we would suggest the following actions:

- **Fishing industry validation**: the data and indices should be introduced to a wider range of stakeholders as well as the outputs tested to learn whether it reflects the views of fishers on fishing activity and economic importance of fishing locations.
- **Scientific method validation**: the methodology developed by this project should be shared with the scientific community to seek further feedback. To our knowledge, no other indicators exist in the scientific-peer reviewed literature, however, as this theme is quickly evolving, methods are likely developing elsewhere. We would aim to apply methods that are accepted in the wider scientific community to inform decision making.
- **Policy integration**: data and methodology developed by this project needs to be discussed within the policy arena in terms of whether it meets the requirements and can confidently be integrated into the evidence base for the relevant programmes.
- **Data update and maintenance**: One of the main outcomes of the project is whether the right data is collected to facilitate marine spatial planning, who is responsible of collecting the data, and how to make this data available for government and research institute (including academia). One of the main barriers for a project like this is the data access and required data sharing agreements. To ensure that the data and methods generated can be accessed and updated at low cost, and so be efficiently applied, a process to ensure data sharing and data quality needs to be in place and responsibilities assigned.

7. References

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Appendix

Fisheries Sensitivity Index 1 over time

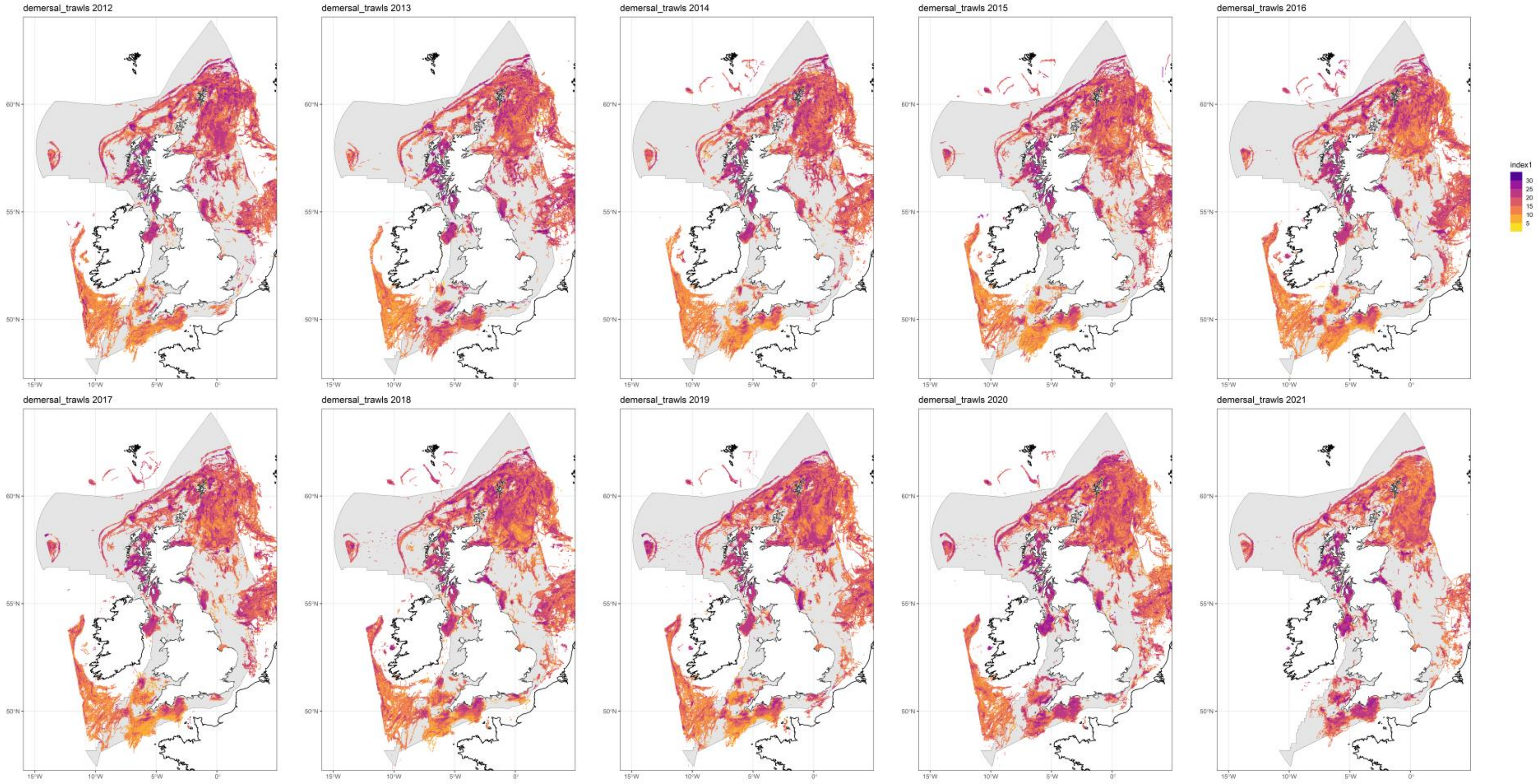

Figure 6: Fisheries Sensitivity Index 1 over time for demersal trawls

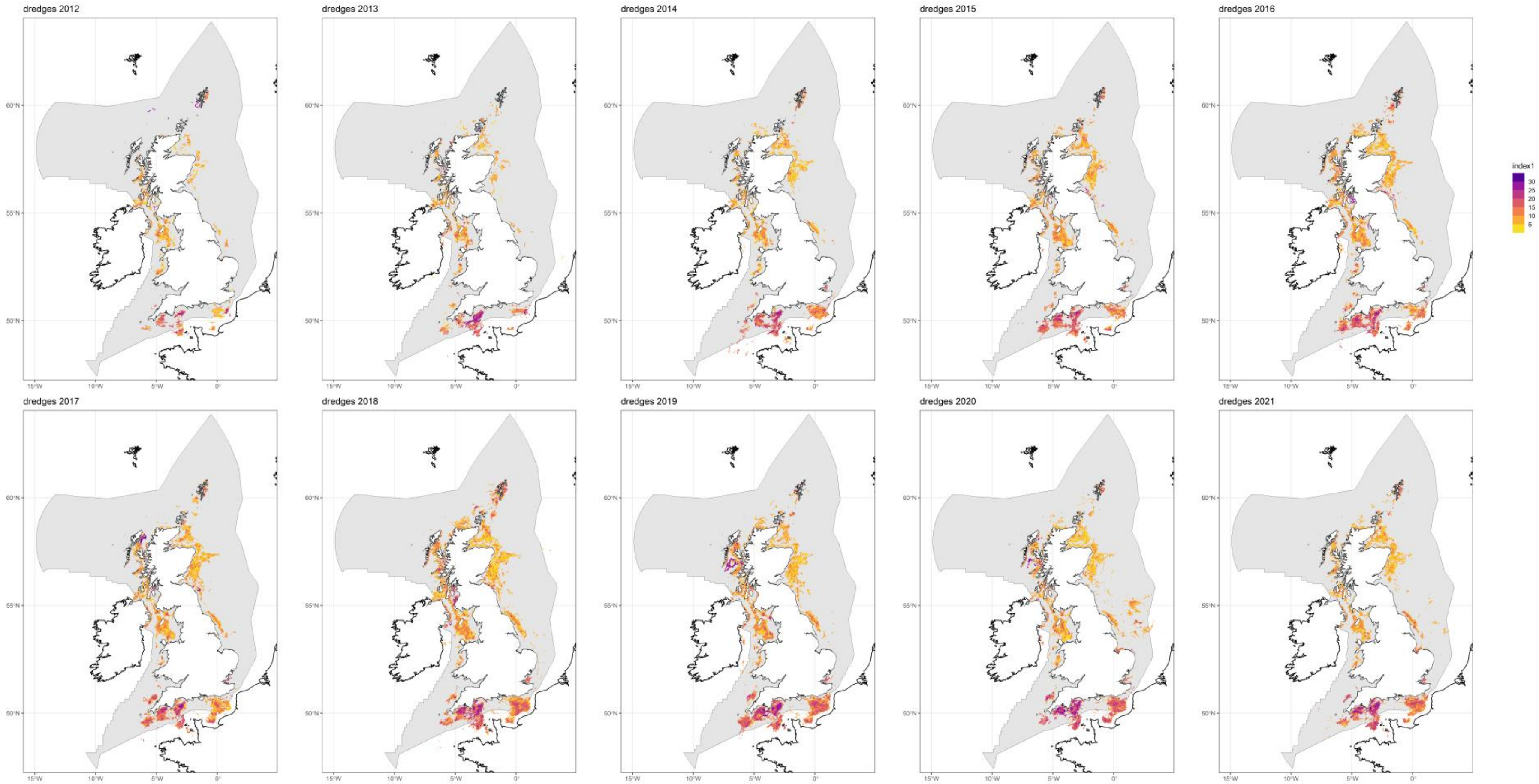

Figure 7: Fisheries Sensitivity Index 1 over time for scallop dredges

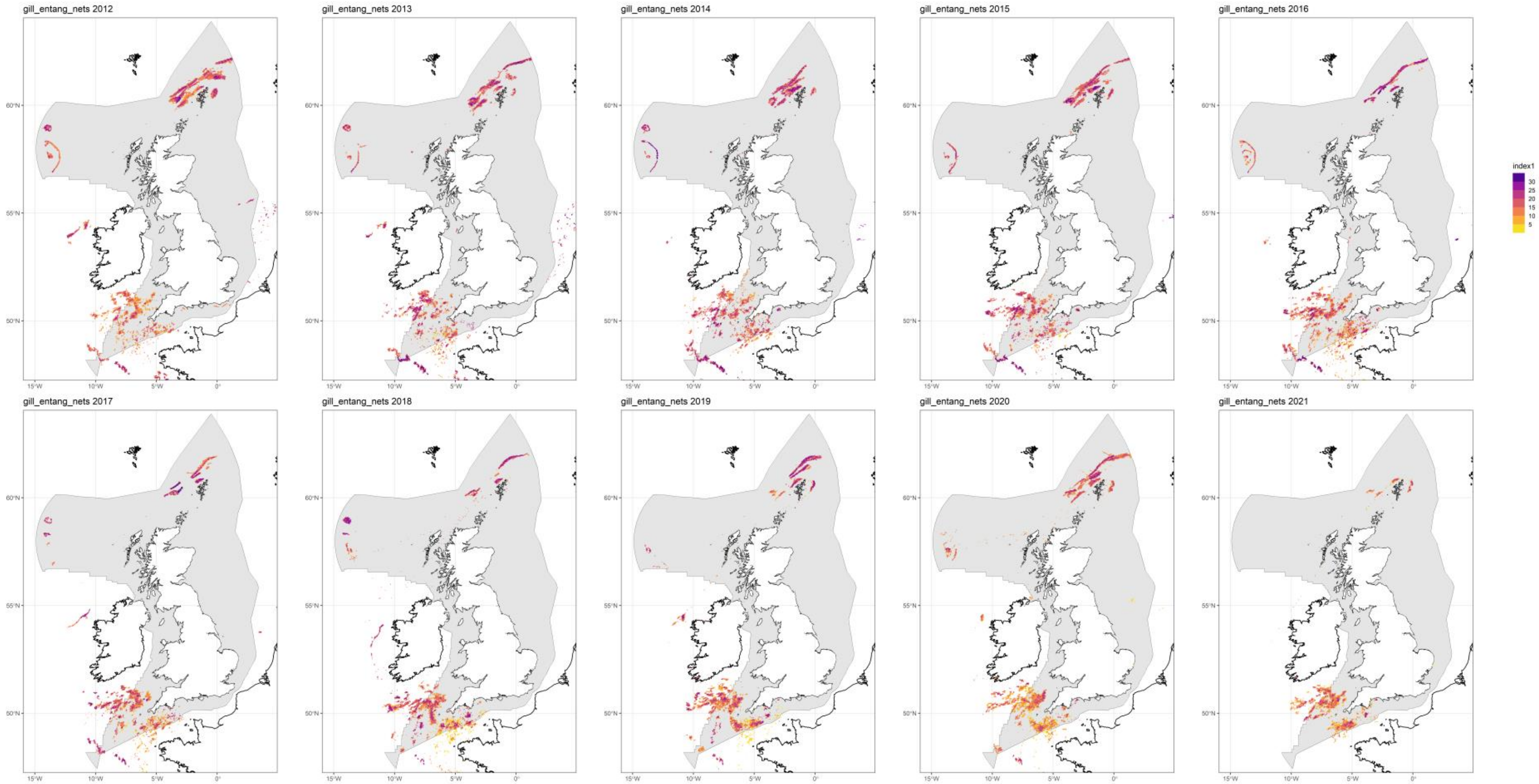

Figure 8: Fisheries Sensitivity Index 1 over time for gillnet and entangled nets

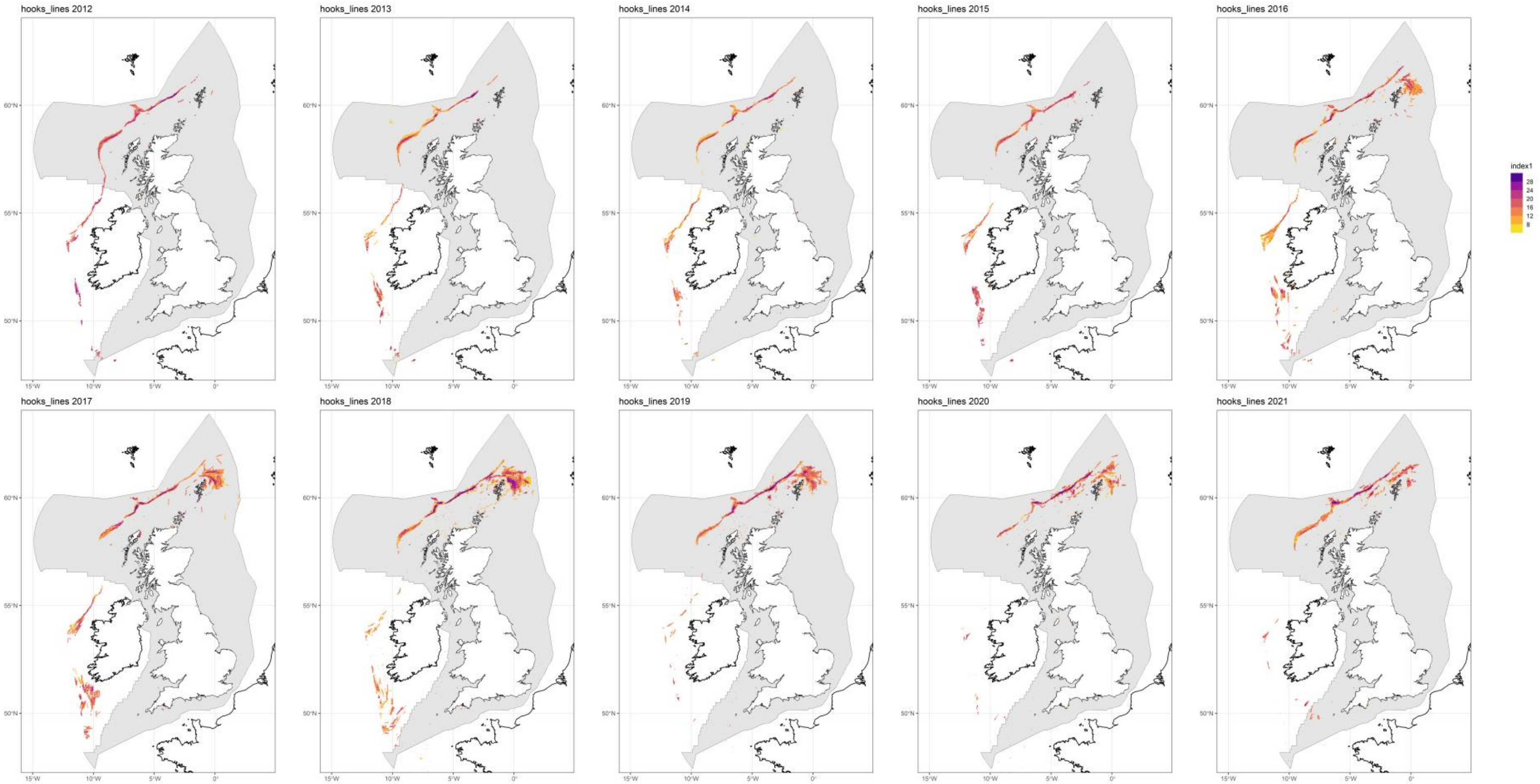

Figure 9: Fisheries Sensitivity Index 1 over time for hooks and lines

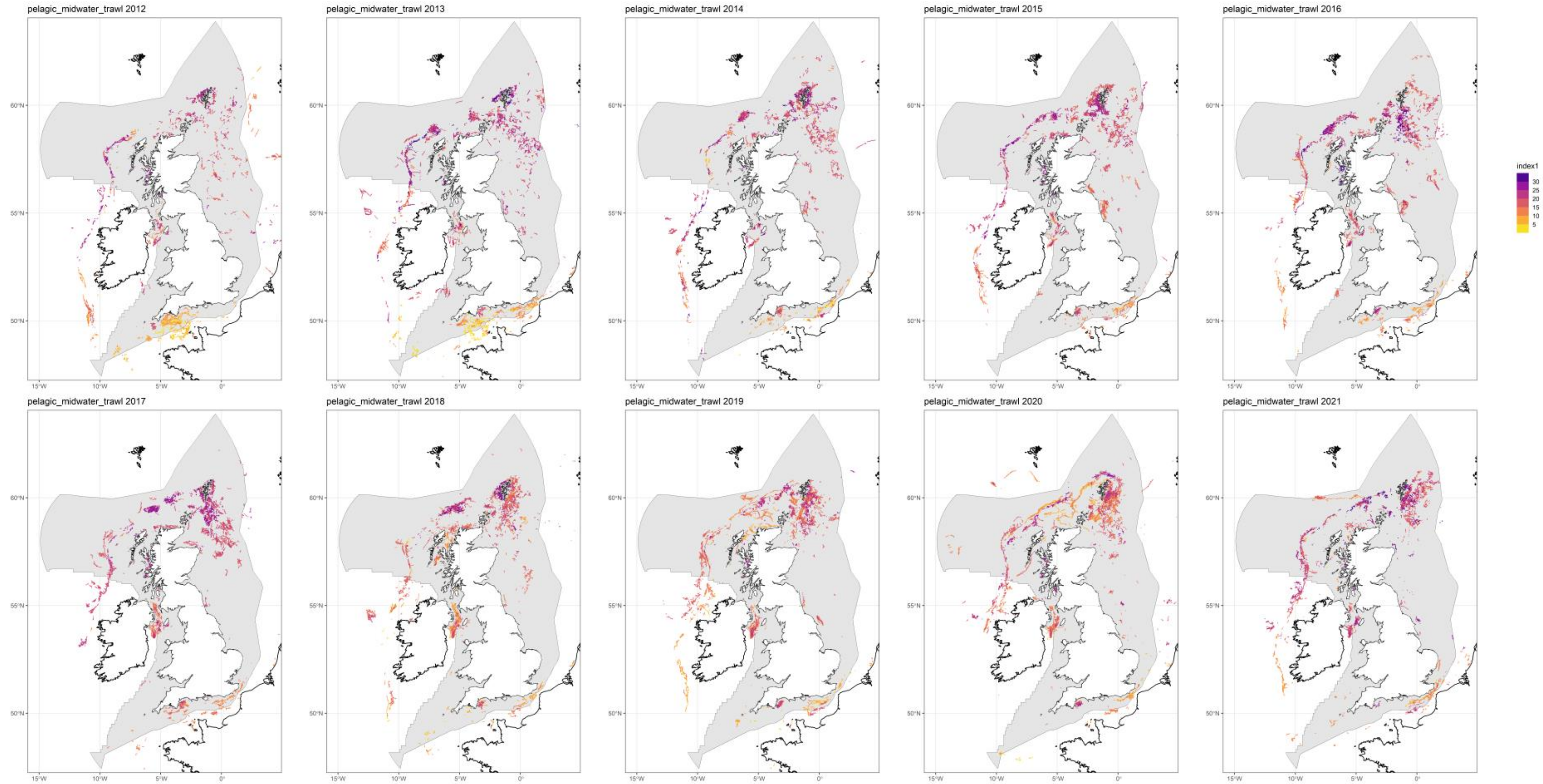

Figure 10: Fisheries Sensitivity Index 1 over time for pelagic/midwater trawl

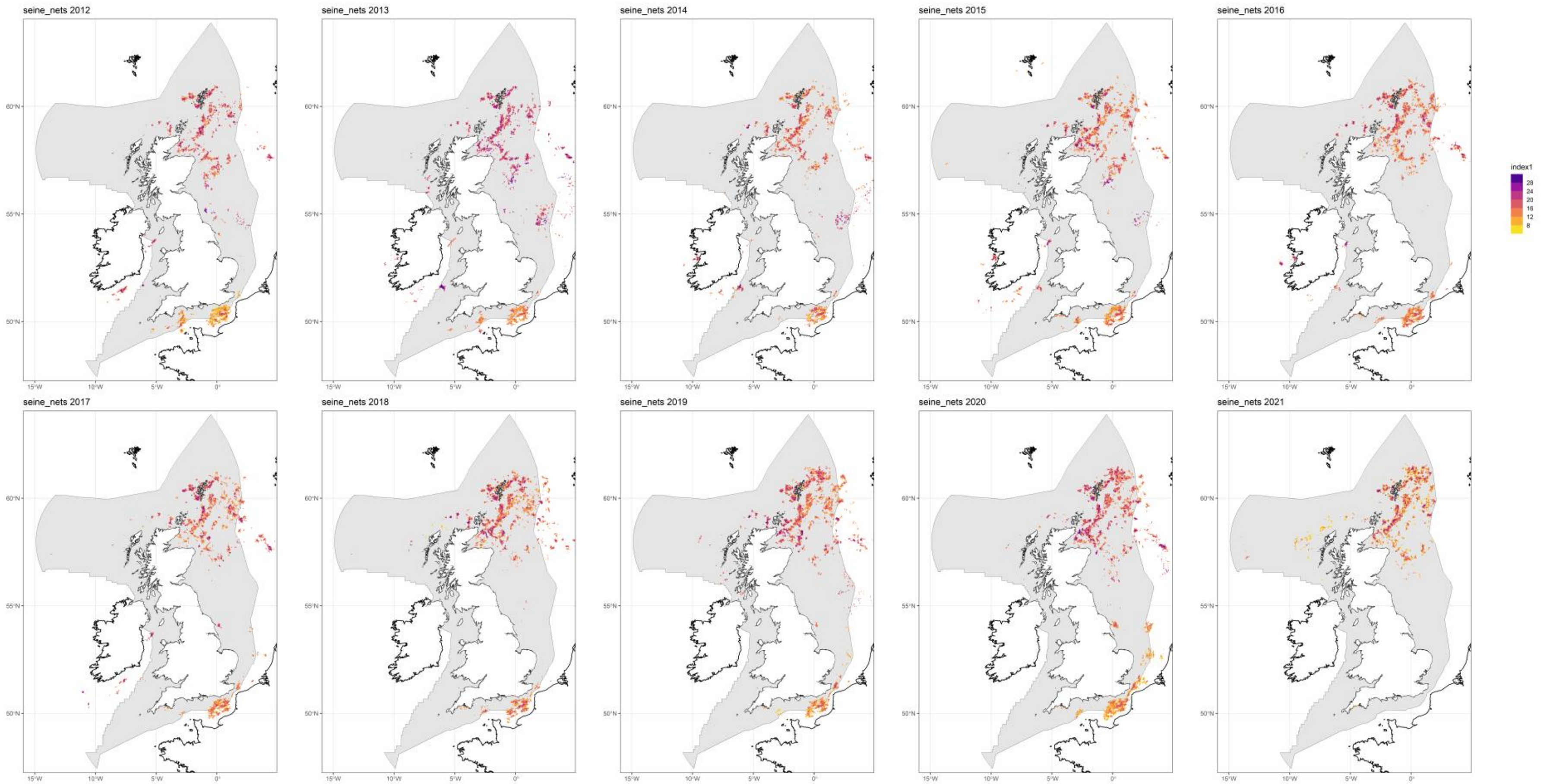

Figure 11: Fisheries Sensitivity Index 1 over time for seine nets

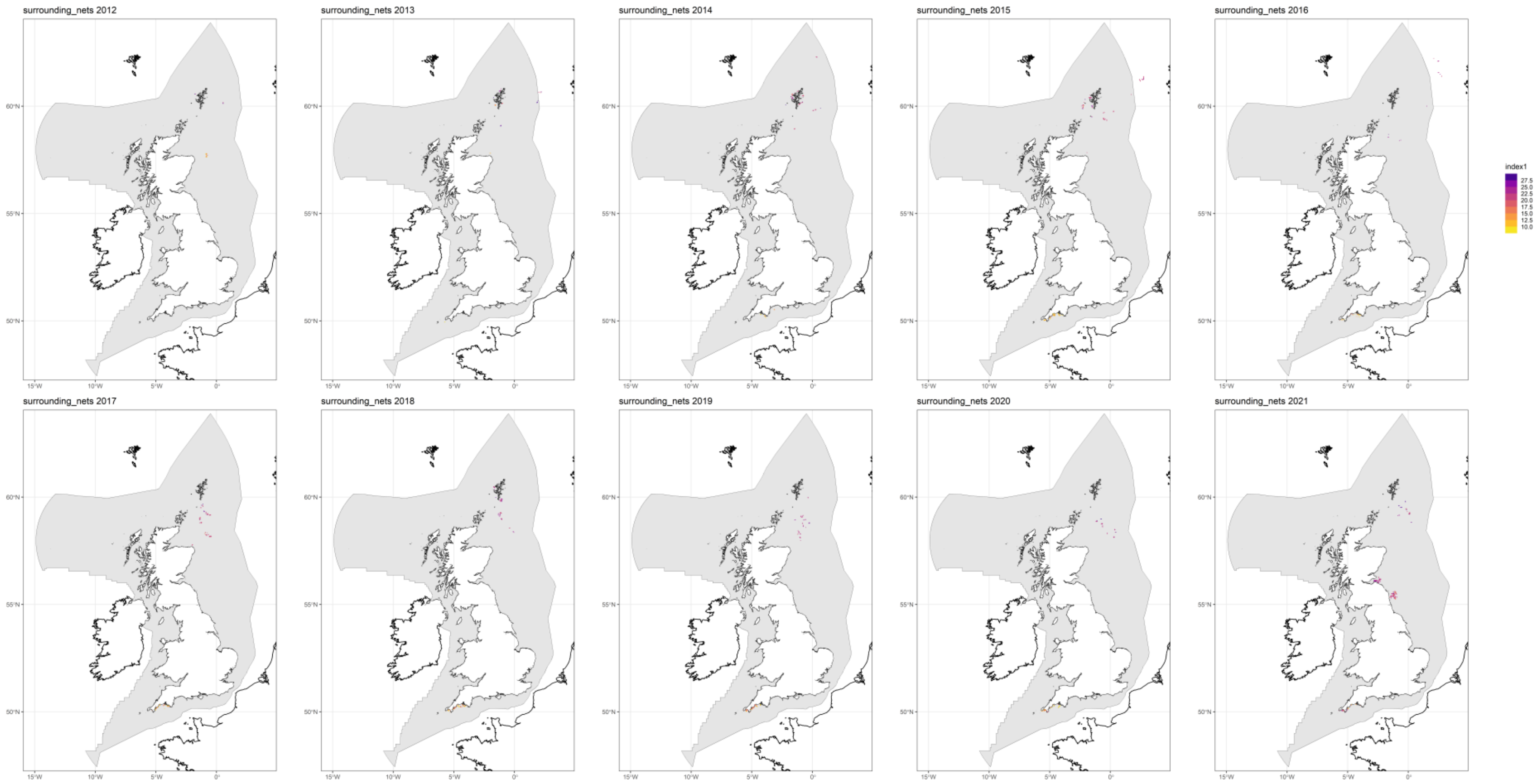

Figure 12: Fisheries Sensitivity Index 1 over time for surrounding nets

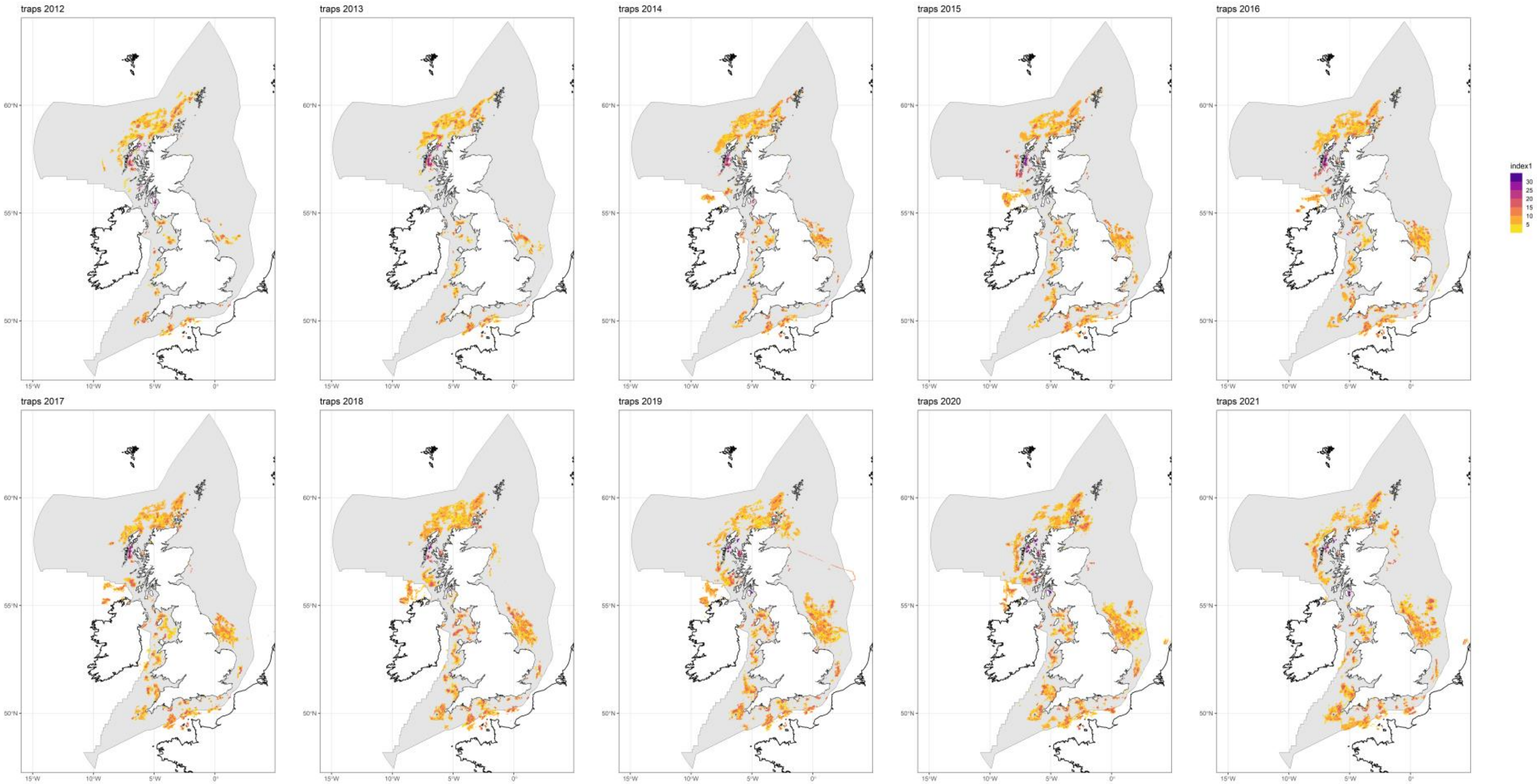

Figure 13: Fisheries Sensitivity Index 1 over time for pots and traps