JNCC Report 761

Gap analysis on the monitoring of marine bird bycatch by British vessels
Report to the Department for Environment, Food & Rural Affairs

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Summary

In 2022, the Department for Environment, Food and Rural Affairs (Defra) published their Marine Wildlife Bycatch Mitigation Initiative (BMI), which included an objective to improve the evidence base of bycatch of sensitive marine species. To support this objective, JNCC undertook a gap analysis to assess if there are significant monitoring gaps in existing at-sea data collection programmes which might impact the accuracy of marine bird bycatch estimates.

Monitoring data from three different data collection programmes (UK Bycatch Monitoring Programme, Commercial Catch Sampling Programme for Scottish vessels and the Commercial Catch Sampling Programme in England and Wales) were collated and merged in one database, covering all monitoring data from 2010–2019. The main purpose of the Bycatch Monitoring Programme is to collect data on sensitive species bycatch (wider than just seabirds), while the Commercial Catch Sampling Programmes have the main purpose to monitor fishery discards.

If bycatch monitoring data is to be collected to minimise potential biases from underlying environmental variables, one approach is to collect it proportionally to fishing effort. To understand if this assumption is met by the monitoring data an analysis of the Percentage of Correct Classification (PCC) was carried out, comparing on a broad scale if the spatial distribution of fishing effort and bycatch monitoring effort across ICES rectangles is approximately similar. The proportional agreement between distributions was best for gillnets and encircling nets, ranging between 42% (summer) and 38% (winter) of rectangles showing fishing and monitoring effort being carried out proportionally. The lowest agreement was found for hooks and lines, with 11% agreement in summer and 3% agreement in winter, however this was largely due to the incorporation of handlines into this gear group, which are not routinely monitored (see further details of this in the discussion). For traps (including pots and creels), the gear type with the largest fishing effort of all gear types, bycatch monitoring was so low that the PCC analysis could not be carried out. For all gear types, distribution maps were produced to indicate where potential monitoring gaps occur within UK waters.

The locations of potential monitoring gaps were then compared with marine bird distributions of species potentially susceptible to bycatch by the respective gear types. We determined the proportion of these bird populations present in potential monitoring gaps to assess how much of the populations are found in areas outside recent monitoring coverage. For most gear types, some locations where identified were high densities of potentially sensitive species overlapped with monitoring gaps. Other gear types, like gillnets and encircling nets and beam trawls, have most of their fishing effort in English waters while highest densities of potentially sensitive seabirds occur mainly in Scottish waters. As a result, there was little overlap between the monitoring gaps for these gears and high bird densities of potentially susceptible species.

For traps, some areas were identified where monitoring could be improved (mainly for cormorants and shags). However, with the current lack of knowledge about the scale of marine bird bycatch in traps it seems more appropriate to investigate first how many birds are found to be entrapped in the different types of traps, and depths of water, to assess if traps could pose a significant bycatch risk and inform if direct monitoring of trap fisheries should be considered.

For demersal trawls and seines, there are few bycatch records (despite being the gear with the largest amount of monitoring) and improving the monitoring effort is less of a priority. But if monitoring were to be improved for this gear type, particularly around the Scottish east coast and to the west and north of the Outer Hebrides, this could benefit the bycatch estimates for a range of species.

The distribution of monitoring effort of gillnets and encircling nets follows fishing effort distributions better than other gears. But since gillnets pose a larger known bycatch risk, an overall increased monitoring effort could be beneficial to improve bycatch estimates from this gear type.

For hooks and lines, an increased monitoring of the longline fishing along the continental shelf edge is likely to improve bycatch estimates, especially of fulmars. For handlines/rod and line fisheries, a basic study to establish if these gears pose any significant risk could be useful.

There are no records of bird bycatch from beam trawling we know of, and beam trawling does generally not occur in areas with high bird densities. Currently, therefore, there is no indication that improvement of monitoring is necessary for this gear type.

Increased monitoring efforts of pelagic trawls and seines to the north of Scotland would potentially be beneficial to improve bycatch estimates for several marine bird species.

Contents

Glossary and abbreviations

BMI	Bycatch Mitigation Initiative
BMP	Bycatch Monitoring Programme
Cefas	Centre for Environment, Fisheries and Aquaculture Science
CSP	Commercial Catch Sampling Programme.
DEFRA	Department for Environment, Food and Rural Affairs
EEZ	Exclusive Economic Zone
ICES	International Council for the Exploration of the Sea
JNCC	Joint Nature Conservation Committee
MERP	Marine Ecosystems Research Programme
MD	Marine Directorate
MMO	Marine Management Organisation
OSPAR	Oslo/Paris Convention.
PCC	Percentage of Correct Classification, spatial comparison method (Webb *et al.* 1987)
PoA	Plan of Action.
SFF	Scottish Fishermen's Federation
SMRU	Sea Mammal Research Unit, University of St Andrews

1 Introduction

In 2022, the Department for Environment, Food and Rural Affairs (Defra) published the Marine Wildlife Bycatch Mitigation Initiative (BMI; formerly Seabird Bycatch Plan of Action (PoA)), to set out how to "…minimise, and where possible eliminate bycatch and entanglement of sensitive marine species in UK waters". The first objective addresses the need to improve the evidence basis of bycatch of sensitive marine species. To underpin the BMI, reliable estimates of the number of marine birds being accidentally killed in fishing gear in UK waters are required. Some work has already been undertaken by JNCC, funded by Defra, on estimating seabird bycatch from existing data. These will help to assess the magnitude of overall bycatch in UK waters, identify any desirable management and mitigation (some work has already been undertaken by JNCC, funded by Defra, to investigate possible suitable mitigation measures for use in UK fisheries), track changes in bycatch rates, and will help to assess and report against targets and indicators on bycatch (e.g. OSPAR, UK Marine Strategy). JNCC and the devolved administrations were asked to support the work with the aim to "Deliver a coherent approach to understand and where necessary to reduce seabird bycatch in UK fisheries, though engagement and dialogue with all interested parties and the implementation of subsequent recommendation.".

As part of this work a first assessment of levels of seabird bycatch mortalities and their effects on seabird populations were published in 2020 (Miles *et al.* 2020; Northridge *et al.* 2020). Evidence was gathered on current best practice on seabird bycatch mitigation from fisheries, applicable in UK waters and a hotspot analysis was performed to identify those areas where highest bycatch rates were observed and which would therefore be best suited to perform trials of different bycatch mitigation measures (Anderson *et al.* 2022; Northridge *et al.* 2023). To add to this recent work on evidence around seabird bycatch, JNCC was asked to assess the data on marine bird bycatch currently being collected by different at-sea monitoring initiatives and undertake a gap analysis with the aim to understand whether there are monitoring gaps in the existing programmes which could impact the production of robust and comprehensive marine bird bycatch estimates.

In UK waters, a few different at-sea monitoring initiatives collect data on bycatch of susceptible species; for example, specific monitoring of bycatch of sensitive species is carried out under the UK Bycatch Monitoring Programme (BMP) and monitoring of commercial species discard rates is carried out under the Commercial Catch Sampling Programmes (CSPs). The CSPs have more recently also included recording of sensitive species bycatch in their data collection protocols but sampling designs were not developed specifically to consider sensitive species bycatch and are not optimised for this purpose (Northridge *et al.* 2020).

As part of the work to establish estimates of marine bird bycatch, JNCC undertook a gap analysis to assess the potential of the current monitoring efforts to provide an improved understanding of marine bird bycatch in UK fisheries, and whether there are clear monitoring gaps in the existing programmes which could impact the production of robust and comprehensive marine bird bycatch estimates.

Northridge *et al.* (2020) have stressed the importance of minimising any bias through non-representative sampling when collecting data on seabird bycatch. This gap analysis aims to assess if the current monitoring efforts might be biased by spatio-temporal gaps in the monitoring coverage of fishery activity in general, and to assess whether – if gaps occur - there are high or low numbers of marine birds vulnerable to bycatch present in those areas. The study does not investigate whether or how much bycatch occurs, but only if the distribution of current monitoring can be improved to provide more reliable data on marine bird bycatch rates. To achieve this, we compare the spatial distribution of fishing effort with the distribution of monitoring effort over the same period, and with the distribution of marine birds during different times of year. The results of the analysis should improve our understanding of where additional monitoring of marine bird bycatch could be targeted to improve future bycatch estimates.

The comparison between bycatch monitoring effort, fishing effort and marine bird distributions aims to assess whether:

1. Monitoring data are collected proportionately to fishing effort. This is based on the general principle that monitoring should be approximately proportional to the overall fishing effort, to ensure representativity of the sample data and thereby reduce bias as much as reasonably possible.
2. Potential gaps in monitoring coincide with relatively high or low marine bird species densities which are susceptible to bycatch in particular gears, which may impact the accuracy of estimated bycatch rates and subsequent mortality estimates and which should be considered in future sampling designs.

2 Method

2.1 Data sources

To address the first objective of the gap analysis, fishing effort data and monitoring effort data are required to assess if these are collected approximately proportionally to each other. For the second objective, there is also a need for marine bird distribution data for species which are potentially susceptible to a bycatch.

2.1.1 Fishing effort data

The fishing effort data is calculated from logbooks and landings declarations provided by vessels to each devolved administration for all UK registered vessels. This information includes departure and landing date, and the landed weight of species by gear, mesh-size, and rectangle. Gear codes are provided using the international standard statistical classification of fishing gear 2016.

Days absent for each fishing trip was calculated using departure and landing date. Quarter was defined by landing date for consistency with other measures. Gears were grouped by ISSCFG gear category. Days absent for each fishing trip were shared equally among the gear group, rectangle, and quarter combinations for that trip.

Quarters were allocated to seasons, with Quarter four of one year and Quarter one of the following year being in the same winter season, and the effort data were summed over the full time series by rectangle, gear category and season. Effort in cells in which fewer than six unique vessels are recorded fishing across the full time series were redacted.

The data includes fishing effort from vessels registered to Northern Ireland, although monitoring effort by Northern Ireland has not been included in the analysis.

2.1.2 Monitoring effort data

Bycatch monitoring data were made available by three at-sea monitoring programmes as follows:

- Data from the UK Bycatch Monitoring Programme (UK BMP) is provided by the Sea Mammal Research Unit (SMRU) of the University of St Andrews. The BMPs main objective is to collect data on sensitive species bycatch. It primarily targets those fishing gears and locations where sensitive species bycatch can be expected and are not monitored by other data collection programmes.
- Data from the Commercial Catch Sampling Programme (CSP) for Scottish vessels is provided by Scottish governments Marine Directorate (MD). This initiative has the main purpose to monitor fishery discards from Scottish fishing vessels and sampling designs are focussed on gear types with relatively high discard rates.
- Data from the CSP in England and Wales is provided by the Centre for Environment, Fisheries and Aquaculture Science (Cefas). The overall objective of the offshore catch sampling programme has been to collect size and age data from all categories of commercial catch of all fish and shellfish species, with particular focus on the discard component, from English and Welsh vessels.

Note that monitoring data from vessels from Northern Ireland were not available. The analysis focussed only on British vessels.

The data collected by the three monitoring programmes were not standardised but were collected following programme-specific protocols. The three monitoring initiatives prioritised different gear types to gather data in accordance with their main monitoring objectives: SMRU collected data mainly on vessels using midwater otter trawls and set gill or trammel nets and to a lesser extent on longline fisheries. Cefas had a broader spectrum covering vessels using beam trawl, bottom otter trawl, dredges (not considered in this analysis), set gillnets and trammel nets, while MD focused their efforts primarily on bottom otter trawls (Figure 1, data after redaction, see 2.2.4).

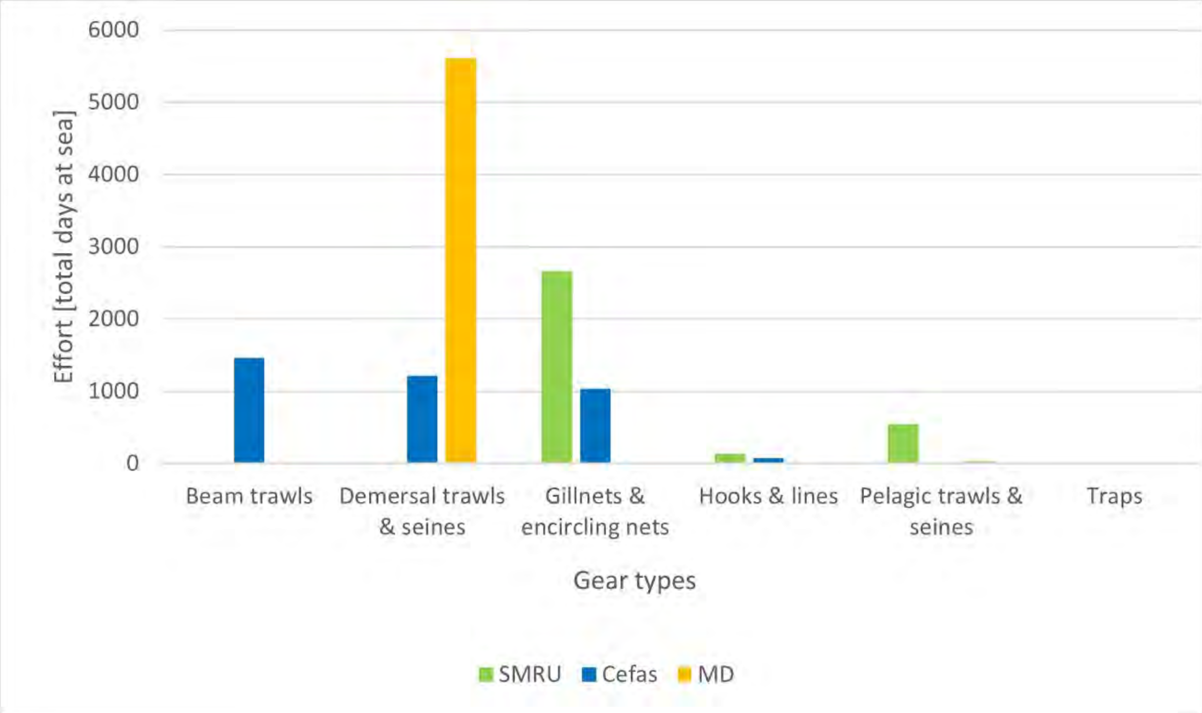

Figure 1. Bar chart, showing total monitoring effort between 2010 and 2019 of the three monitoring programmes (data after redaction, see 2.2.4).

2.1.3 Marine bird distribution data

In 2017, Bradbury *et al.* published a report under contract to Defra where they developed a GIS Tool to show the relative risk of UK marine bird species to bycatch from fisheries operating in UK waters. For this report, they produced separate winter and summer marine bird distribution maps for the UK Exclusive Economic Zone with a 3 km by 3 km grid resolution, aligned to the Ordnance Survey Great Britain grid. 'Seabirds' were defined by Bradbury *et al.* (2017) as petrels and shearwaters, storm-petrels, gannets, cormorants, and shags, skuas, gulls, terns, and auks. Some marine waterbird species (seaducks, divers, grebes, and phalaropes) were added and considered, too. For English waters, they used readily available marine bird distribution maps produced for the Seabird Mapping Sensitivity Tool (SeaMaST, Bradbury *et al.* 2014). For the remaining UK waters, they combined various data sets, mainly the European Seabirds at Sea (ESAS) database and WWT Consulting's visual aerial survey database, but also a number of smaller datasets, and used a GEE-CRESS modelling approach to produce marine bird distribution maps (Generalised Estimating Equation framework with an implemented Complex Region Spatial Smoother method. For details see Bradbury *et al.* 2017). A list of marine bird species considered is provided in the Annex, Table 22.

Because the marine bird distribution maps were generated by Bradbury *et al.* (2017) for a comprehensive group of seabirds and waterbirds, based on a modelling approach using a wide range of available data sets, these were deemed to be the best available data for use in this analysis. There are other modelled marine bird distribution maps available, such as those produced by the Marine Ecosystems Research Programme (MERP) (Waggitt *et al.* 2020), which use largely the same datasets in combination with some more recent data. However, those are only available for a smaller set of marine bird species and were therefore deemed to be too restricted for this project.

To ensure that only robust modelled estimates of marine bird densities with a reasonable confidence were part of the analysis, only marine bird densities with a Coefficient of Variation less than 0.5 were included.

2.2 Data preparation

All fishing effort and monitoring effort data, collected in the 10-year period from 2010 to 2019, were considered for the analysis, including data from both within and outside the UK Exclusive Economic Zone (EEZ). Fishing and monitoring effort were collected as days at sea by trip. During one trip more than one ICES rectangle could be visited and more than one gear type could be used, hence effort was allocated evenly to relevant ICES rectangles and gear categories within a trip. Fishing gears were categorised using ISSCFG gear categories (International Standard Statistical Classification of Fishing Gear, ISSCFG, 2016).

2.2.1 Aggregation across monitoring programmes

All three monitoring programmes made marine bird bycatch monitoring effort data available as 'days at sea per ICES rectangle'. Since the individual monitoring programmes focus on vessels from only one nation or on specific gear types (see 2.1.2), data from individual monitoring initiatives were deemed to be too disparate from the wider fishing effort data to allow for comparisons between the fishing effort with data from individual monitoring programmes (e.g. a comparison of an isolated MD monitoring effort with the overall fishing effort would mainly indicate that there is a major gap outside of Scottish waters). Instead, data from all programmes were combined to provide a single 'total monitoring days' value for each ICES rectangle, year, season, and gear type to enable a more comprehensive comparison with fishing effort. However, given the different purposes, priorities and sampling procedures of the monitoring initiatives, the aggregated monitoring data are likely to contain biases (e.g. where data collection followed different data collection protocols in different areas).

2.2.2 Aggregation by ICES statistical rectangles

The data were aggregated spatially by ICES statistical rectangles, depending on where they were collected. The spatial resolution of the analysis corresponds therefore with the ICES rectangle grid where latitudinal rows and longitudinal columns are in 30' and 1° intervals, respectively.

2.2.3 Aggregation by season

Where the spatial distribution of monitoring effort is being compared with marine bird distribution data, it is important to differentiate the analysis by season as both can exhibit strong seasonal patterns. The fishing and monitoring effort data were therefore aggregated into a summer season (April to September) and a winter season (October to March), to correspond roughly to the seasonality of marine bird distributions (winter vs summer/ breeding). A finer temporal resolution (e.g. monthly) was not appropriate as this would have reduced the available data per period so much that it would have led to a significant proportion of data needing to be redacted due to data protection requirements (see 2.2.4).

2.2.4 Data protection requirements and redaction of data

Due to data protection requirements, the MMO, SMRU, MD and Cefas were unable to disclose all available fishing effort and monitoring effort data to JNCC, as data points (i.e. ICES rectangles) containing data from less than six vessels would potentially allow the identification of individual vessels and their fishing locations and would breach data protection requirements. The steering group therefore agreed that the MD would collate all monitoring data from the different monitoring programmes, aggregate them into a single dataset and redact any data as required, prior to providing it to JNCC for analysis.

For the data redaction, fishing effort data for 2010–2019 were aggregated by ICES statistical rectangle, gear category and season over the 10-year period, and the number of vessels in each rectangle-gear category-season combination (cell) was calculated. Cells with less than 6 unique vessels fishing were redacted to ensure confidentiality of data. Information on the loss of data on fishing effort and on monitoring effort due to the redactions is provided in the Annex (Table 16 - Table 19 and Table 20, respectively).

A total of 55% of ICES rectangles with fishing effort data had to be redacted, however, as redacted cells are typically those with the lowest overall level of fishing effort, the redaction accounted for only 1.42% of the total fishing effort. The analysis was therefore conducted on the ICES rectangles accounting for 98.6% of the fishing effort (Annex, Table 16).

The proportion of fishing effort data redacted differed between the considered gear types, ranging from 14.08% for pelagic trawls and seines and only 0.75% for demersal trawls and seines (Annex, Table 17).

Across all fishing data there were minimal seasonal differences in data redacted during summer (1.32%) compared to data redacted during winter (1.55%) (Annex, Table 18).

Spatially, the level of fishing data redaction varied strongly between locations, with some areas requiring 100% of data redaction (notably 27.1, with close to 2,000 days at sea being redacted), while other locations, typically those with the largest amounts of data (greater than 100,000 days at sea), had less than 2% of data redacted (Annex, Table 19).The redaction of data affected mainly locations with comparatively little fishing effort, which may be less important contributors to marine bird bycatch levels, unless they coincide with relatively high densities of marine birds that might lead to higher than average bycatch rates.

For the monitoring data, data redaction was most prominent in pelagic trawls and seines (12.54% of data) and hooks and lines (6.88% of data, Annex, Table 20).

2.3 Bycatch risk associated with gear types

Fishing gears differ in levels of bycatch risk they pose to marine birds, depending, among other things, on the depth at which the gear is worked. Similarly, marine bird species differ in their risk of being bycaught, depending on their foraging behaviour (e.g. due to how deep they dive into the water in pursuit of prey). To avoid an indiscriminate comparison of fishing and monitoring effort with marine bird distributions, we focussed on those fishing gear-marine bird species combinations where a significant bycatch risk can be expected. However, while this can highlight where there is potential for marine bird bycatch, it does not indicate actual bycatch or whether the potential risk poses a conservation concern for those species.

2.3.1 Water depths at which individual gear types can pose a bycatch risk

The bycatch risk to marine birds by different fishing gear types can occur at water depths where these gears are set/worked and/or when gears are shot and hauled. After setting, some of the gear types might therefore be out of the diving depth range of most marine birds. As no data were available on gear handling times, considerations of the bycatch risk at different times of the fishing operations were beyond the scope of this report.

To determine which metiers are potentially posing an entrapment risk at which depth, Bradbury *et al.* (2017) reviewed the information provided by an ICES Workshop to Review and Advise on Seabird Bycatch (ICES 2013), which summarised the available evidence for marine bird bycatch from different fishing gears. Suggested water depths of bycatch relevance for individual gear types, differentiated into surface, pelagic (or midwater) and benthic (or at the seabed, is outlined in Bradbury *et al.* (2017). To simplify the analysis for the purpose of the gap analysis, gear types with similar impacts were grouped into five main groups: 'traps', 'gillnets and encircling nets, 'hooks and lines, 'demersal trawls and seines' and 'pelagic trawls and seines' and 'beam trawls'. Apart from dredges, all of these gears are considered to pose a potential bycatch risk to marine birds on the sea surface and in the pelagic depth (in midwater) and/or at the benthic depth (at the seabed).

Based on the information on potential bycatch risks, 'dredges' were excluded from the analysis as they are unlikely to pose a significant bycatch risk for marine birds at any water depth (Bradbury *et al.* 2017).

Table 1. Fishing gear types from the fishing and monitoring data submitted to JNCC and the depths where these might pose a bycatch risk for marine birds, according to Bradbury *et al.* (2017).

Group	Gear types (Metier 4)	Code	Surface risk	Pelagic risk	Benthic risk
Traps	Pots and traps	FPO	x	-	x
Gillnets and encircling nets	Set gillnets	GNS	x	x	x
	Driftnets	GND			
	Trammel nets	GTR			
Hooks and lines	Hand and pole lines (hand-operated)	LHP	x	x	x
	Drifting longlines	LLD			
	Set longlines	LLS			
Demersal trawls and seines	Bottom otter trawls	OTB	x	-	x
	Anchored seines	SDN			
Pelagic trawls and seines	Midwater otter trawls	OTM	x	x	-
	Pelagic pair trawls	PTM			
Beam trawls	Beam trawls	TBB	x	-	x

2.3.2 Water depths at which individual marine bird species are susceptible to bycatch

In UK waters, for most gear types there is insufficient bycatch data available to directly assess where in the water column individual marine bird species are susceptible to bycatch.

As an alternative, Bradbury *et al.* (2017) assigned seabird entrapment risk scores for each species and water depth (surface, pelagic and benthic) as part of their assessment of marine bird bycatch sensitivities. The work is based on the assumption that the risk of a marine bird species to being bycaught is largely dependent on the behaviour of the species (e.g. whether it is diving into the water in pursuit of prey or feeding at the surface). The five-point scoring system was based on expert assessments of either published evidence of bycatch or on species behaviours. Scores ranged between 1 (no relevant evidence of bycatch of a species at the given water depth) to 5 (species is known to be affected by bycatch at this water depth). For the full scale of scores and their descriptions see the Annex, 6.2. After initial scores were assigned by Bradbury *et al.* they were independently assessed by external experts to reach a consensus on the final risk score for every species and water depth. A table with the final risk scores is provided in the Annex, Table 22.

2.4 Comparison of monitoring effort with fishing effort

To analyse if the current monitoring effort (where monitoring takes place) is broadly similarly distributed to fishing effort, a coarse-scale comparison with focus on broad differences was deemed to be the most appropriate approach, as the aggregated monitoring data are likely to contain biases. Data collection methods under the different monitoring programmes were not standardised and prioritised different metiers (fishing gears and areas of sea). Data with very low fishing effort and/or monitoring effort had to be redacted due to data protection issues (see 2.2.4) and although this affected only small amounts of fishing and monitoring effort (and is therefore possibly of limited relevance), spatially a large number of ICES rectangles had to be excluded from the analysis. The level of necessary redaction varies between gear types, and, in addition, the aggregated monitoring effort data are highly zero inflated (i.e. when compared to fishing effort data, there are many rectangles with withing effort but zero monitoring effort).

Planning monitoring activities to target specific areas is not always possible in many fisheries. Comparisons at fine scales would therefore also be unlikely to be particularly informative or useful for planning future monitoring effort.

To assess if the available monitoring effort has been distributed approximately proportionally to the fishing effort distribution, the Percentage of Correct Classification (PCC) method, developed by Webb *et al.* (1987) in climatology to quantify the level of association between observed and simulated fossil-pollen maps, was used. To compare two datasets, each dataset is split into intensity categories, and it is calculated in how many locations the categories of the two datasets agree with each other. The higher the agreement between categories across the mapped locations, the more similar the two datasets are in their distribution.

To categorise the fishing and monitoring data for each gear type, in both datasets non-zero data were split into quartiles with help of Excel's function 'Quartile.INC'. The bottom quartile was defined 'low effort', the top quartile was defined as 'high effort' and the two quartiles in the middle were jointly defined as 'medium effort'. The exclusion of rectangles with zero data was necessary to avoid swamping of the lower categories with zero effort values. For example, if we would have included zero monitoring rectangles into the categorisation into high/med/low monitoring effort, and 80% of rectangles contain zero monitoring, the low, medium, and part of the high monitoring category would all contain rectangles with zero monitoring. It is not possible to determine into which category a specific zero-monitoring rectangle should be placed, and a spatial comparison becomes impossible. To keep rectangles with zero monitoring effort (but high, medium, or low fishing effort) in the analysis, these rectangles received a fourth monitoring category 'None'.

To determine the PCC, the percentage of ICES rectangles with equal fishing and monitoring effort categories were calculated. Because monitoring effort had one more category than fishing effort (the 'None' category), it was impossible to reach 100% agreement in any gear type. The degree of agreement between the fishing effort and the monitoring effort categories nevertheless indicates how similar their spatial distributions are.

Note that the number of data defined as 'medium effort' data is double the number of data defined as either 'high effort' or 'low effort'. Also, the number of records within each category differs between datasets due to the differences in size of the datasets.

To visualise the varying degrees of divergence between fishing effort and monitoring effort categories spatially, for each rectangle the degree that the monitoring effort category differed from the fishing effort category was calculated. In the PCC tables and in the maps, all differences which indicated either an equal or higher monitoring effort category to the fishing effort category were colour coded in grey, while slightly under-monitored areas (by only one category) were light green, medium under-monitored areas (by two categories) were medium green and highly under-monitored areas (i.e. no monitoring but high fishing effort categories) were dark green (Table 2).

Table 2. Degrees of differences in PCC categories. (A colour contrast indicates the number of categories by which the monitoring effort differs from the fishing effort.)

		Monitoring effort			
		None	Low	Medium	High
Fishing effort	Low	1	equal	-1	-2
	Medium	2	1	equal	-1
	High	3	2	1	equal

2.5 Comparison of potential monitoring gaps with marine bird distributions

To assess if areas with potentially too little monitoring of a given gear type coincide with areas where marine birds occur which are sensitive to bycatch from that gear type we undertook a mapping exercise.

Areas with potentially too little bycatch monitoring were defined as those areas where the PCC analysis identified that the monitoring effort category was lower than the corresponding fishing effort category, or where there was no monitoring at all.

To identify those marine birds with a bycatch risk from a given gear type, we matched the water depth category at which the gear type poses a potential bycatch risk (Table 1) with those species known to be affected by bycatch at this water depth category (Bradbury *et al.* 2017). Only species with a risk score of 5 were taken into consideration, as these are known to be affected by bycatch at the given water depth (Annex, Table 22). The density distributions of these species were superimposed and added up to form the 'bird community with a bycatch risk of this particular gear type'.

Maps highlighting the areas with potentially too little monitoring were then superimposed onto the maps of the bird communities with a bycatch risk to this particular gear type to indicate if those gaps coincide with higher aggregations of birds, and to calculate the proportion of the population shown on the map which occurs in those areas. Since the marine bird density maps were modelled, they were not used to identify absolute numbers encountering a given bycatch risk. However, the maps indicate the relative distribution of birds across UK waters and based on this we can get an idea of what proportion of the population might be exposed to a bycatch risk which is not well monitored.

Note: the marine bird distribution maps cover only UK waters, hence any bird distribution coinciding with potential monitoring gaps outside of UK waters will not impact the calculations of the marine bird community.

3 Results

Of all the gear types considered, traps were responsible for the biggest proportion of fishing effort with nearly 50% of the total fishing effort by British vessels, followed by demersal trawls & seines (23%), dredges (8%), gillnets & encircling nets (7%) and hooks & lines (5%). The remaining gear types are below 5%. Apart from dredges, all of these more frequently used gear types are known to present a risk of marine bird bycatch (Figure 2, Table 3).

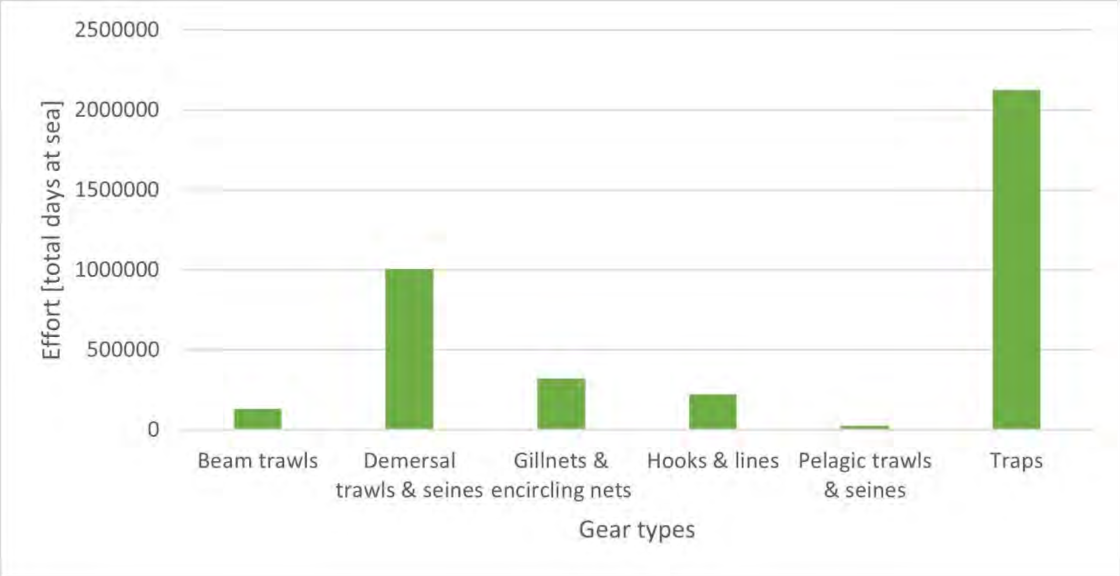

Figure 2. Bar chart showing total fishing effort in days at sea by different gear types between 2010 and 2019 (data after redaction, see 2.2.4).

3.1 Comparison of monitoring effort with fishing effort

3.1.1 Total amounts of effort

In terms of overall effort (i.e. days at sea), pelagic trawls and seines were monitored most, with 2.39% of their fishing effort being monitored. Of all other gear type groups, around or below 1% of the fishing effort was monitored. Note that this is after redaction of data due to data protection requirements, so actual monitoring effort will be marginally higher, as from pelagic trawls & seines 12.54% of monitoring data were redacted, from hooks & lines 6.88% and from Gillnets & encircling nets 3.18% (Table 20). Table 3 lists the different gear types, monitoring proportion and examples of species which were found to be bycaught by these gear types.

Table 3. Total monitoring effort and fishing effort by gear type between 2010 and 2019.

Gear type	Fishing effort (days at sea)	% of combined fishing effort of all metiers	Monitoring effort (days at sea)	% of this gear's fishing effort monitored	Examples of species listed as bycatch
Traps	2,126,746.19	48.56	7.87	<0.01	shags[1], cormorants[2]
Demersal trawls & seines	1,005,261.83	22.96	6,821.74	0.68	gannets[1], cormorants[1,2], shags[1], shearwaters[1] and gulls[1, 10]
Dredges	334,798.87	7.65	151.00	0.05	-
Gillnets & encircling nets	319,178.05	7.29	3,700.99	1.16	auks[1,11,13], shearwaters[1], gannets[1,11,13], cormorants[1, 13], shags[1,13], common scoters[1,3,4] eider[5,6,7], lesser black-backed gull[10,13], other diving ducks[1], fulmar[13] shearwaters[12] and divers[1,12,13]
Hooks & lines	220,671.99	5.04	210.45	0.10	fulmars[1,13], Balearic shearwaters[1], gannets[1,13], gulls[1,10,13], Cory's shearwaters[1], cormorants[1,2], auks[1], terns[1,8], shags[1] and great skuas[1]
Miscellaneous	218,065.63	4.98	6.00	<0.01	-
Beam trawls	129,593.40	2.96	1,458.20	1.13	-
Pelagic trawls & seines	24,889.08	0.57	594.22	2.39	Gannets[1,14], cormorants[13], guillemots[13], razorbills[13]

References: [1] ICES (2013), [2] Pott & Wiedenfeld (2017), [3] Mendel *et al.*(2008), [4] Schirmeister (2003), [5] Merkel (2004), [6] Glemarec *et al.* (2020), [7] Kirchhoff (1982), [9] Li *et al.*(2016), [10] Oliveira *et al.*(2015), [11] Žydelis *et al.* (2013), [12] Benjamins *et al.* (2008), [13] Northridge *et al.* (2020), [14] Pierce *et al.* (2002).

3.1.2 Comparison of effort distributions: scatter plots

Direct plotting of monitoring effort against fishing effort, including only ICES rectangles where monitoring is above zero, indicates that monitoring effort increases with elevated fishing effort for beam trawls and possibly also for demersal trawls and seines. For gillnets and encircling nets, pelagic trawls, and seines and for hooks and lines the relationship is less clear (Figure 3). For traps no figure could be produced as there are only three ICES rectangles with monitoring effort available.

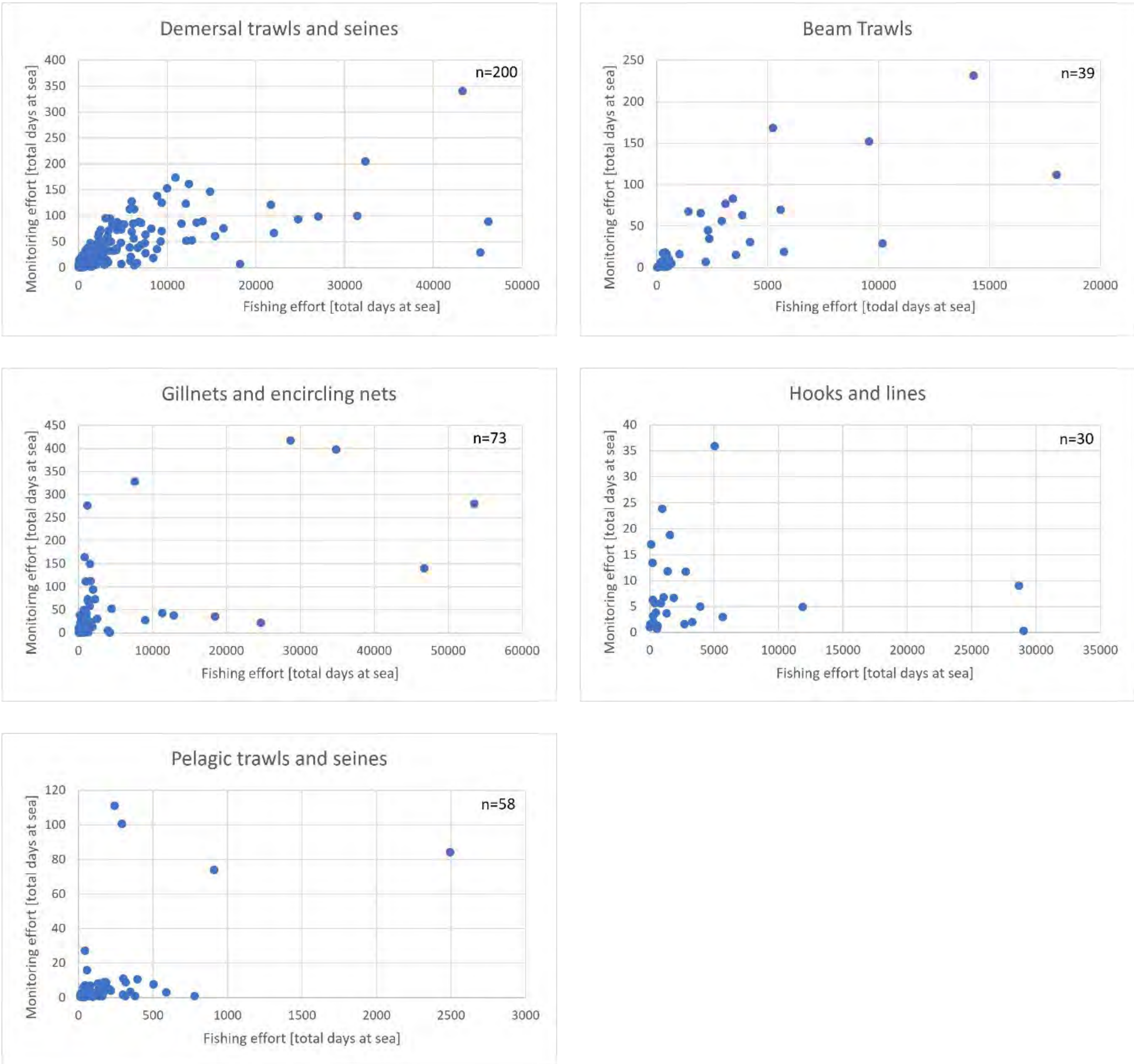

Figure 3. Total monitoring effort plotted against the total fishing effort per ICES rectangle between 2010-2019. Due to limited monitoring data on traps at the time of the analysis, no plot could be produced for trap monitoring effort.

3.1.3 Comparison of effort distributions: PCC

The PCC was calculated to compare how similar the spatial distributions of these two actions are during summer and during winter. The method investigated in how many ICES rectangles the intensity categories of fishing and monitoring agreed with each other. Across all gear types, the agreement between fishing effort and monitoring effort distributions ranged between as high as 42% for gillnets and encircling nets in summer and as low as 3% for hooks and lines in winter (Table 4).

Note that traps, the gear type with the largest amount of ‘days at sea’ fishing effort, were monitored with too little effort for a meaningful PCC calculation.

Within a gear type, the PCC was generally lower during winter than during summer, except for pelagic trawls and seines where the agreement reached in winter was 15% and in summer only 11%.

Table 4. Spatial monitoring coverage and PCC for different gear types and seasons. The percentages indicate the proportion of ICES rectangles with monitoring, and the proportion of rectangles where the monitoring effort falls into the same category (high/medium/low) as the fishing effort.

Gear type	Summer		Winter	
	Monitoring coverage [%]	Agreement [%]	Monitoring coverage [%]	Agreement [%]
Traps	2	N/A*	1	N/A*
Demersal trawls & seines	58	36	59	34
Gillnets & encircling nets	68	42	64	38
Hooks & lines	25	11	15	3
Beam trawls	44	24	39	14
Pelagic trawls & seines	36	11	37	15

* Due to the small number of rectangles available, the calculation of a PCC is not appropriate.

3.1.4 Traps

Traps are the gear group which accounts for the biggest proportion (49%) of the total fishing effort of British vessels (Table 3). In summer and winter, traps are found throughout all British coastal waters. The highest trap effort is found around the Northern Isles and nearly all the Scottish coastline, along the English east coast, in the northern Irish Sea and at the Channel coast (Figure 4).

Despite the importance of traps in terms of overall fishing effort, only a tiny proportion of this effort (less than 0.01%) is monitored under the three programmes considered here. This monitoring takes place at the northwest coast of Scotland and in summer also in Cornwall (Figure 4). Because of the limited monitoring effort, no PCC analysis could be undertaken for traps.

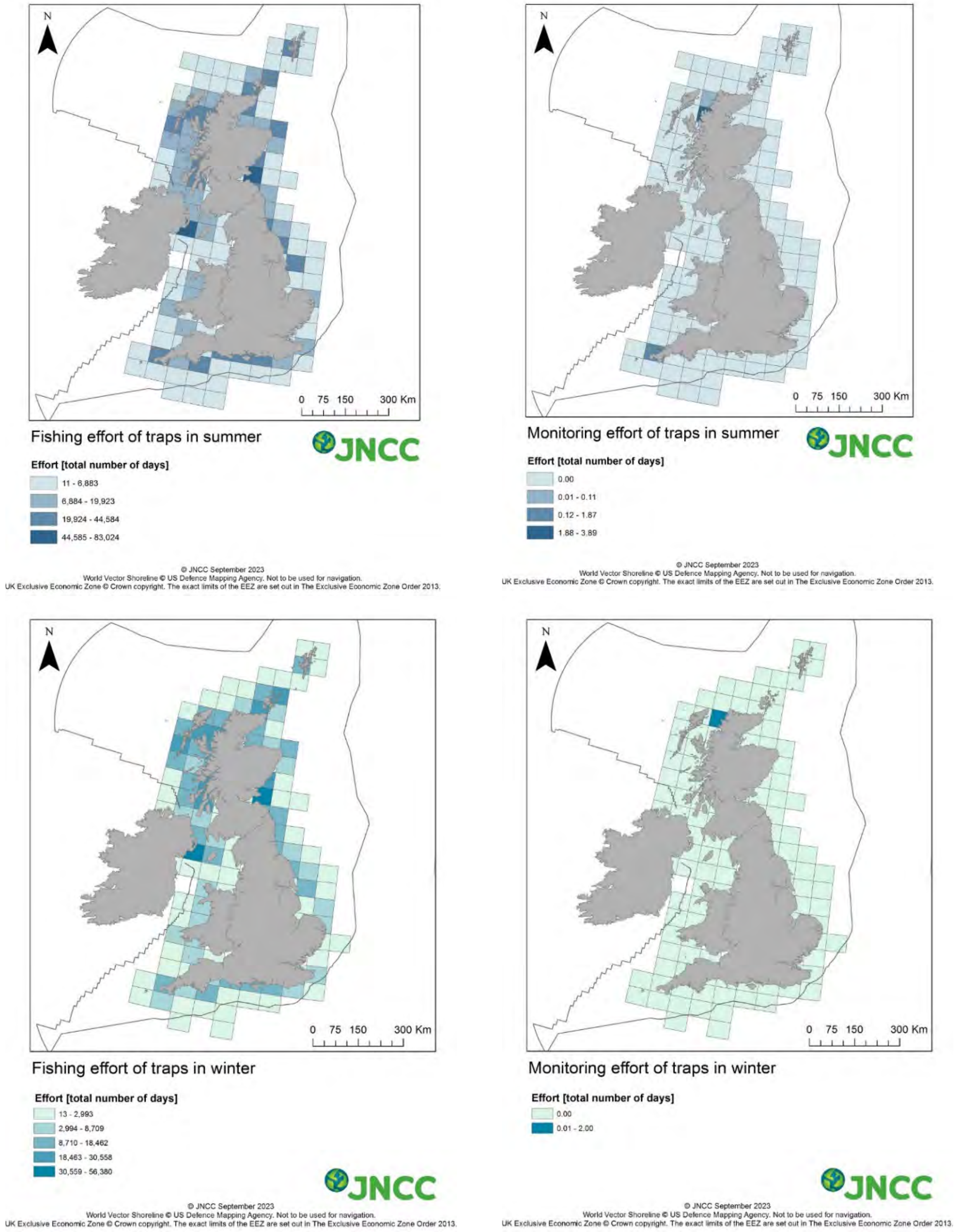

Figure 4. Maps showing total fishing (left) and monitoring effort (right) of traps between 2010 and 2019 in summer (top) and in winter (bottom).

3.1.5 Demersal trawls and seines

Demersal trawls and seines are responsible for a large proportion (23%, Table 3) of all fishing effort of British vessels. Spatially, demersal trawls and seines fishing takes place mostly in north-east UK waters, around Shetland and Orkney, at the Little Halibut Bank and

Fladen Ground, around the Scottish coastline, but also in Irish waters and to some degree along the south coast of England (Figure 5).

Of all rectangles with demersal trawls and seines fishing effort in summer, 58% had monitoring coverage. The distributions of fishing and monitoring effort showed a 36% agreement in summer. In 3% of monitored rectangles the monitoring effort category was higher than the fishing effort category. In 61% of monitored rectangles the monitoring effort category was lower than the fishing effort category.

In winter, demersal trawls and seines fishing effort had monitoring coverage in 59% of the fished area. The distributions of fishing and monitoring effort agreed in 34% of rectangles. The monitoring category was lower in 66% of rectangles.

Table 5. Percentage of ICES rectangles falling into PCC categories for demersal trawls and seines in summer (top) and winter (bottom).

Summer		**Monitoring effort**			
		None	**Low**	**Medium**	**High**
Fishing effort	**Low**	18.10%	4.76%	2.22%	0%
	Medium	22.54%	9.21%	17.14%	0.95%
	High	0.95%	0.63%	9.84%	13.65%

Winter		**Monitoring effort**			
		None	**Low**	**Medium**	**High**
Fishing effort	**Low**	25.26%	0%	0%	0%
	Medium	15.57%	15.22%	19.03%	0%
	High	0%	0%	10.03%	14.88%

When the PCC comparison is mapped, it indicates where monitoring effort categories are too low or too high compared to the fishing effort categories; for example, where monitoring ideally would be increased or decreased to reach a better similarity between the distributions and more balanced monitoring.

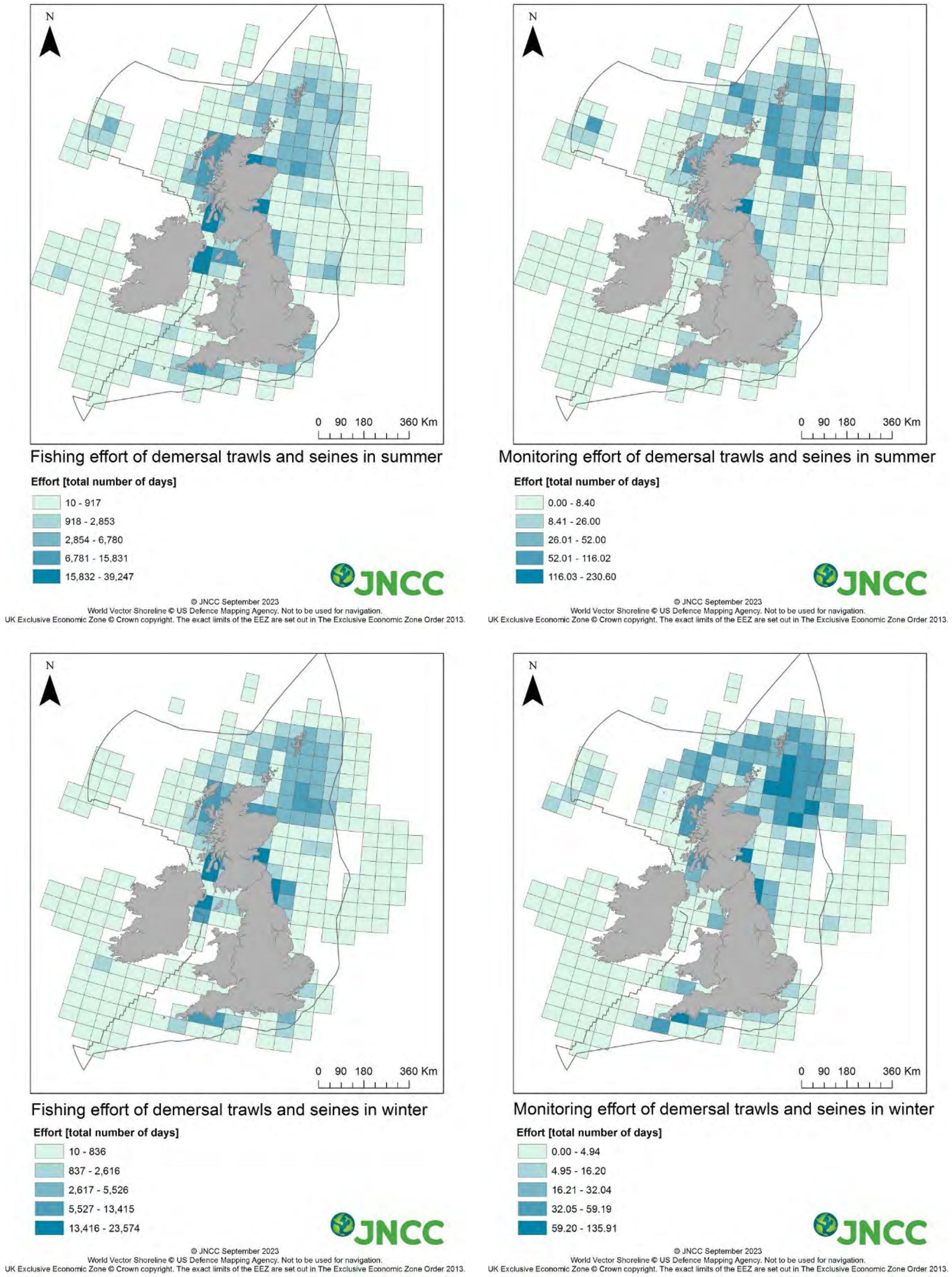

Figure 5. Total fishing and monitoring effort of demersal trawls and seines 2010–2019 in summer (top) and in winter(bottom).

For demersal trawls and seines, large parts of the northern UK waters are dominated by similar distributions of fishing and monitoring effort, and in summer in some places monitoring effort was higher than fishing effort. Areas where monitoring is, in comparison, too low are found in the North Sea outside of the UK EEZ, and in the Irish Sea and all around Ireland, more pronounced during summer than in winter (Figure 6). There are three apparently severely under-monitored ICES rectangles in the northern Irish Sea (i.e. no monitoring taking place where there is a high fishing effort, indicated in dark green). However, this could be an artefact since Northern Irish monitoring effort was not used in this analysis.

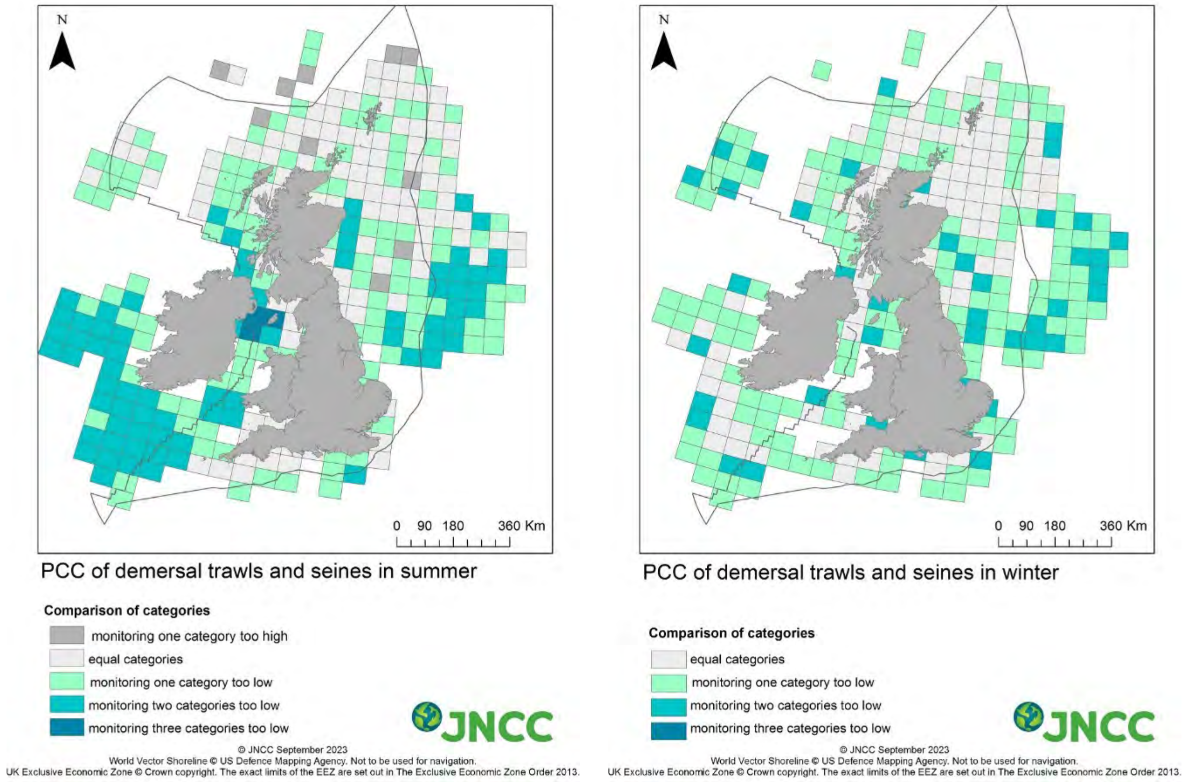

Figure 6. PCC score differences of demersal trawls and seines in summer (left) and winter (right).

3.1.6 Gillnets and encircling nets

Gillnets and encircling nets are responsible for 7% of the total fishing effort of British vessels (Table 3). This gear type is found around Shetland and in much of English coastal waters, with higher effort in the Thames area and along the Channel coastline. Further offshore, this fishery occurs in the Atlantic waters west of the Channel and west of Ireland (Figure 7).

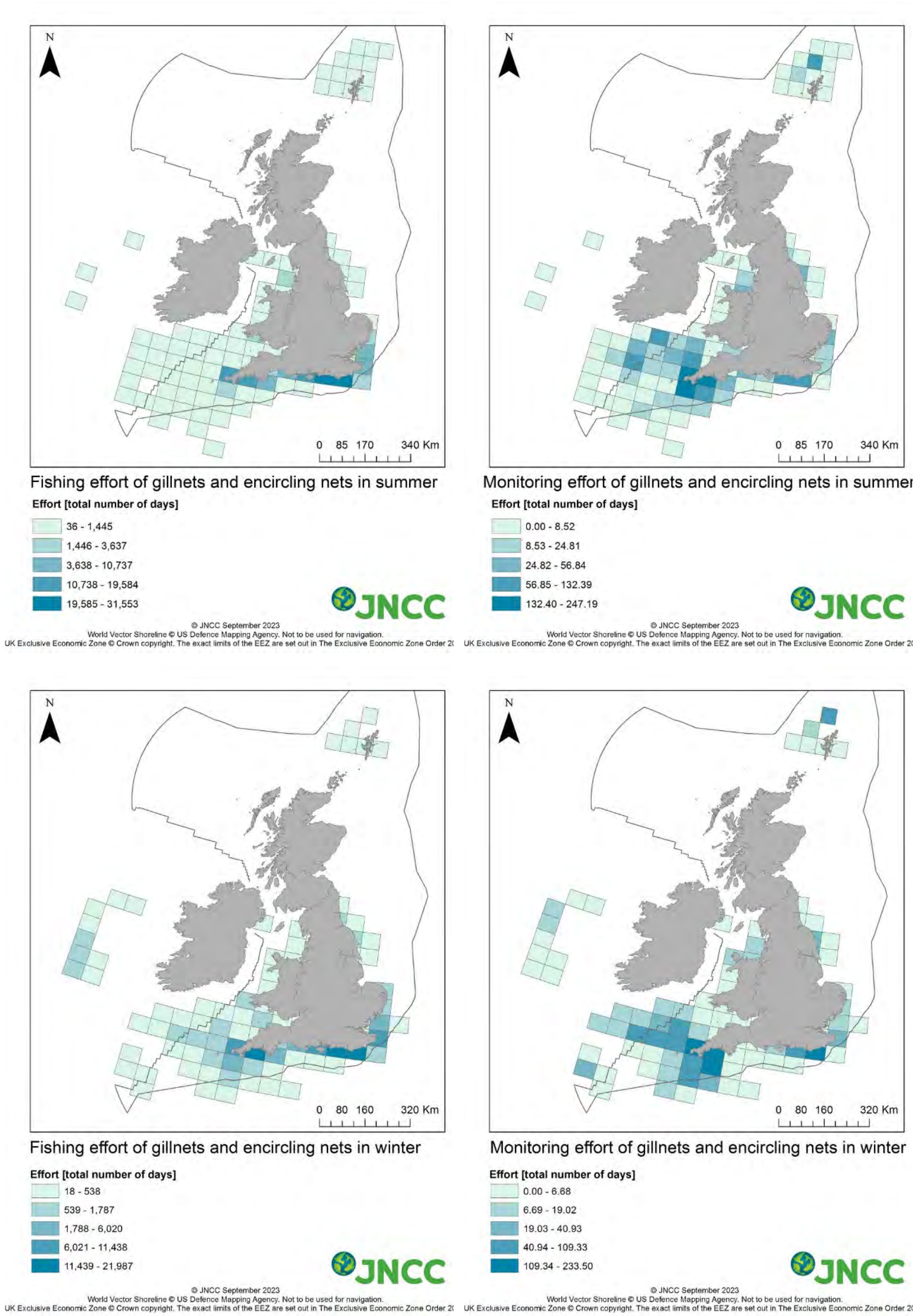

Figure 7. Total fishing (left) and monitoring effort (right) of gillnets and encircling nets between 2010 and 2019 in summer (top) and in winter (bottom).

In summer, 68% of all locations with gillnets and encircling nets had monitoring coverage. Fishing and monitoring distributions were similar in 42% of rectangles. In 58% of rectangles the monitoring effort category was lower than the fishing effort category (Table 6).

In winter, 64% of areas with gillnets and encircling nets were also monitored. The distributions of fishing and monitoring effort agreed in 38% of this area and was lower in 62% of the area (Table 6).

Table 6. Percentage of ICES rectangles falling into PCC categories for gillnets and encircling nets in summer (top) and winter (bottom).

Summer		**Monitoring effort**			
		None	**Low**	**Medium**	**High**
Fishing effort	**Low**	25.26%	0%	0%	0%
	Medium	6.32%	17.89%	25.26%	0%
	High	0%	0%	8.42%	16.84%

Winter		**Monitoring effort**			
		None	**Low**	**Medium**	**High**
Fishing effort	**Low**	25.58%	0%	0%	0%
	Medium	10.47%	16.28%	22.09%	0%
	High	0%	0%	9.30%	16.28%

When the PCC comparison is mapped, in both summer and winter, gillnets and encircling nets fishing and monitoring distributions were often similar, or there was only slightly lower monitoring effort. Only very few locations had moderately lower monitoring (e.g. at some areas close to Shetland, further offshore in Atlantic waters in the Southwest, and in winter in the Irish Sea; Figure 8).

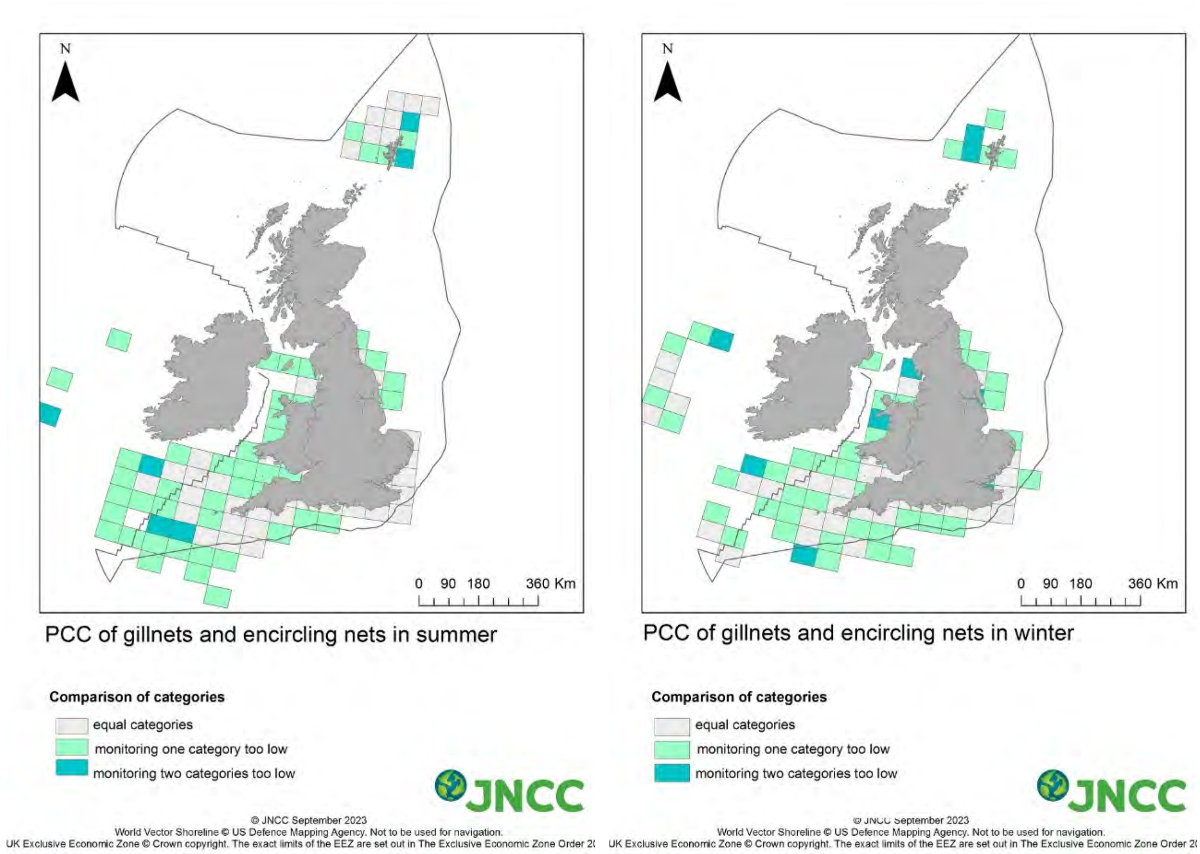

Figure 8. PCC score differences of gillnets and encircling nets in summer (left) and winter (right).

3.1.7 Hooks and Lines

Hooks and lines account for 5% of the total fishing effort of British vessels (Table 3). In summer, the highest fishing effort of this gear type is found around the Scottish east coast and the Northern Isles, the English Channel coast and around Cornwall, and some moderate effort along the northern continental shelf edge. During winter, the effort is more pronounced along the shelf edge and less so at the east coast of Scotland (Figure 9).

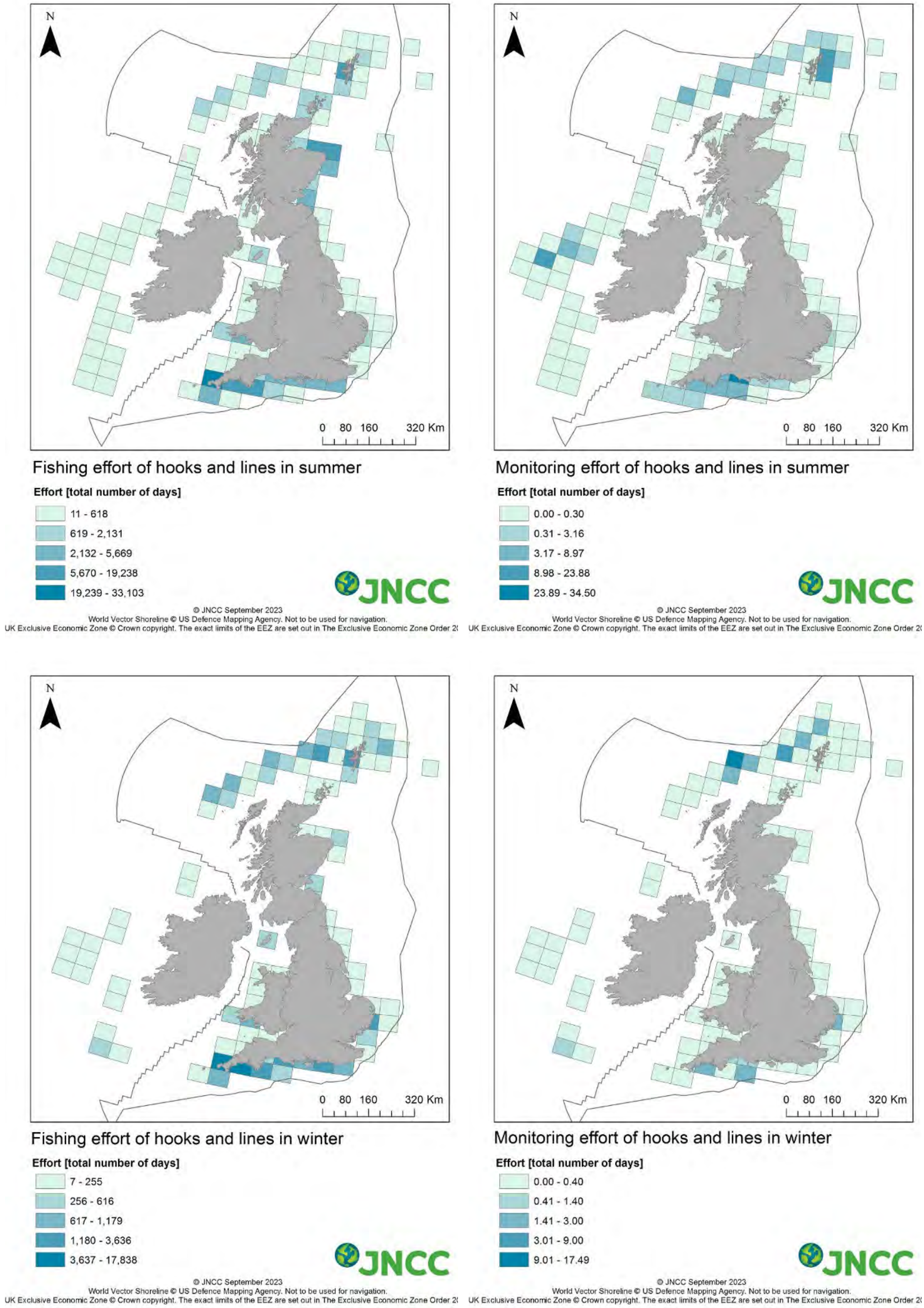

Figure 9. Total fishing (left) and monitoring effort (right) of hooks and lines between 2010 and 2019 in summer (top) and in winter (bottom).

In summer, only 25% of all locations with hooks and line fishing had monitoring coverage. Fishing and monitoring distributions were similar in 11% of rectangles. Only 3% of the monitored areas had a higher monitoring effort category than fishing effort category, and in 85% it was lower (Table 6).

In winter, the monitored proportion of the areas with hooks and lines fishing was only 15%. The distributions of fishing and monitoring effort agreed in 3% of rectangles. The monitoring category was lower in 96% of rectangles (Table 6).

Table 7. Percentage of ICES rectangles falling into PCC categories for hooks and lines in summer (top) and winter (bottom).

Summer		**Monitoring effort**			
		None	**Low**	**Medium**	**High**
Fishing effort	**Low**	22.41%	1.72%	0.86%	0%
	Medium	37.93%	3.45%	6.03%	2.59%
	High	14.66%	1.72%	5.17%	3.45%

Winter		**Monitoring effort**			
		None	**Low**	**Medium**	**High**
Fishing effort	**Low**	26.97%	0%	0%	0%
	Medium	48.31%	0%	0%	0%
	High	10.11%	4.49%	6.74%	3.37%

When the PCC score differences are mapped out for the summer, there are only a few areas with monitoring and fishing distribution similar, mainly far offshore to the west of Ireland, in the western Channel and at some parts of the continental shelf. To the west of Ireland and east of Shetland there are a couple of areas where monitoring effort is higher than the fishing effort, but in most areas the monitoring is lower, often moderately too low, but also in larger areas severely too low (no monitoring where there is high fishing effort), e.g. at the east coast of Scotland (where handline mackerel fishing is prominent), at the Northern Isles, and in smaller areas at the continental shelf, the Isle of Man, the Pembrokeshire coast and in the eastern Channel (Figure 10).

In winter, there are only few areas around the Cornwall coast left with similar fishing and monitoring effort distributions. Most of the fished waters have too low monitoring, with severely under-monitored areas at the continental shelf, east of Shetland, around the Isle of Man, Pembrokeshire coast, the western Channel and far offshore in Atlantic waters west of the Channel (Figure 10).

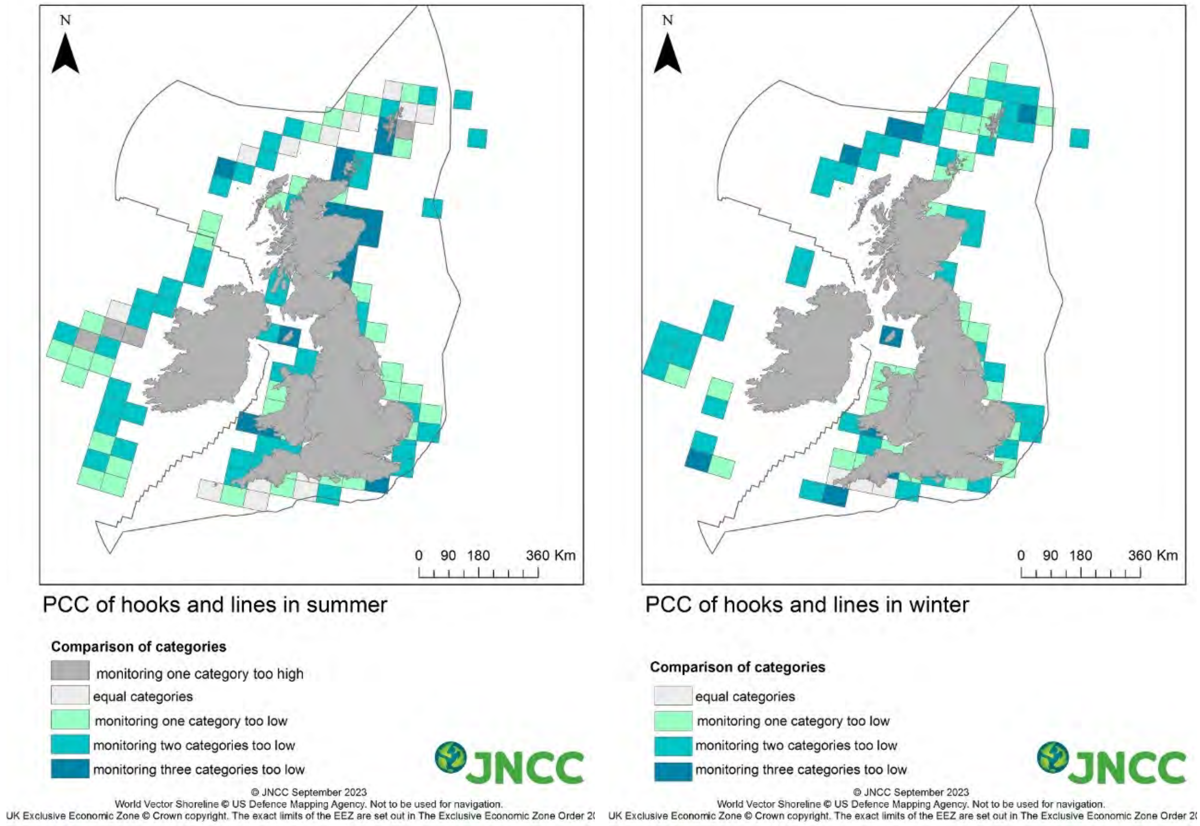

Figure 10. PCC score differences of hooks and lines in summer (left) and winter (right).

3.1.8 Beam trawls

Beam trawls are responsible for just below 3% of the total fishing effort of British vessels (Table 3). Beam trawling appears in all English coastal waters, with higher effort in the south-west, in the western Channel where it stretches further offshore into Atlantic waters. There are also large areas in the North Sea around Dogger Bank with moderate beam trawl activity (Figure 11).

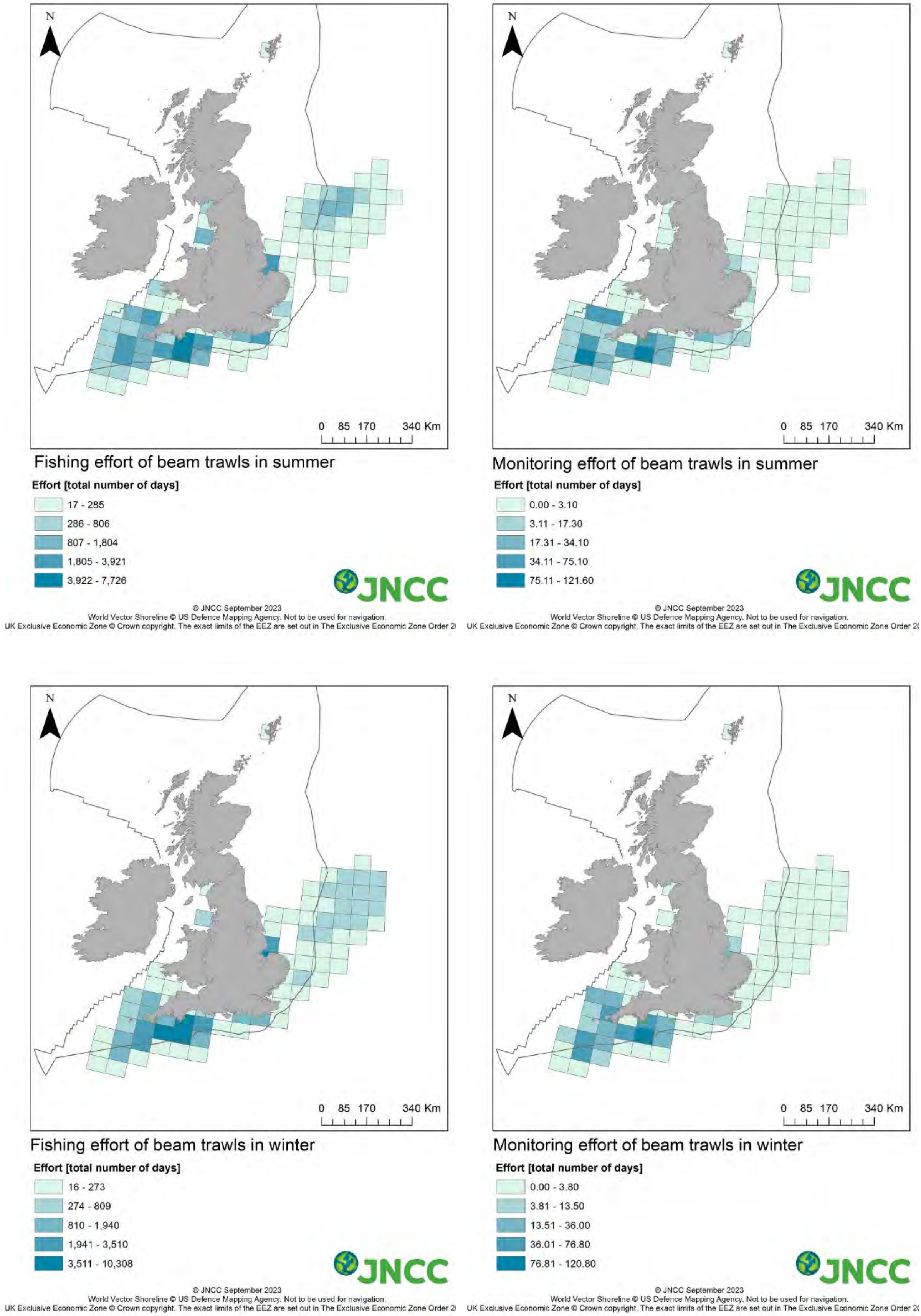

Figure 11. Total fishing (left) and monitoring effort (right) of beam trawls between 2010 and 2019 in summer (top) and in winter (bottom).

In summer, of all rectangles with beam trawling 44% had monitoring coverage. Fishing and monitoring distributions were similar in 24% of rectangles. In 1% of rectangles the monitoring effort category was higher than the fishing effort category, and in 75% of rectangles the monitoring effort category was lower (Table 8).

In winter, beam trawling had monitoring coverage in 39% of the trawled area. The distributions of fishing and monitoring effort agreed in 14% of this area and monitoring was lower in 86% of the area (Table 8).

Table 8. Percentage of ICES rectangles falling into PCC categories for beam trawls in summer (top) and winter (bottom).

Summer		**Monitoring effort**			
		None	**Low**	**Medium**	**High**
Fishing effort	**Low**	23.53%	2.35%	1.18%	0%
	Medium	28.24%	9.41%	10.59%	0%
	High	4.71%	0%	9.41%	10.59%

Winter		**Monitoring effort**			
		None	**Low**	**Medium**	**High**
Fishing effort	**Low**	25.00%	0%	0%	0%
	Medium	36.25%	10.00%	3.75%	0%
	High	0%	0%	15.00%	10.00%

When the PCC comparison is mapped for the summer season, beam trawl fishing and monitoring distributions are similar, or slightly below proportional monitoring effort, in the Channel and west of the Channel. Areas where monitoring effort is moderately or strongly too low are in the Irish Sea and offshore around Dogger Bank in the North Sea. At Liverpool Bay and at Dogger Bank there is no monitoring at all in areas with high fishing effort (Figure 12).

In winter, beam trawl proportional fishing and monitoring effort is similar in a few areas, but most rectangles show proportionally too low (slightly and moderately) monitoring effort compared to fishing effort (Figure 12).

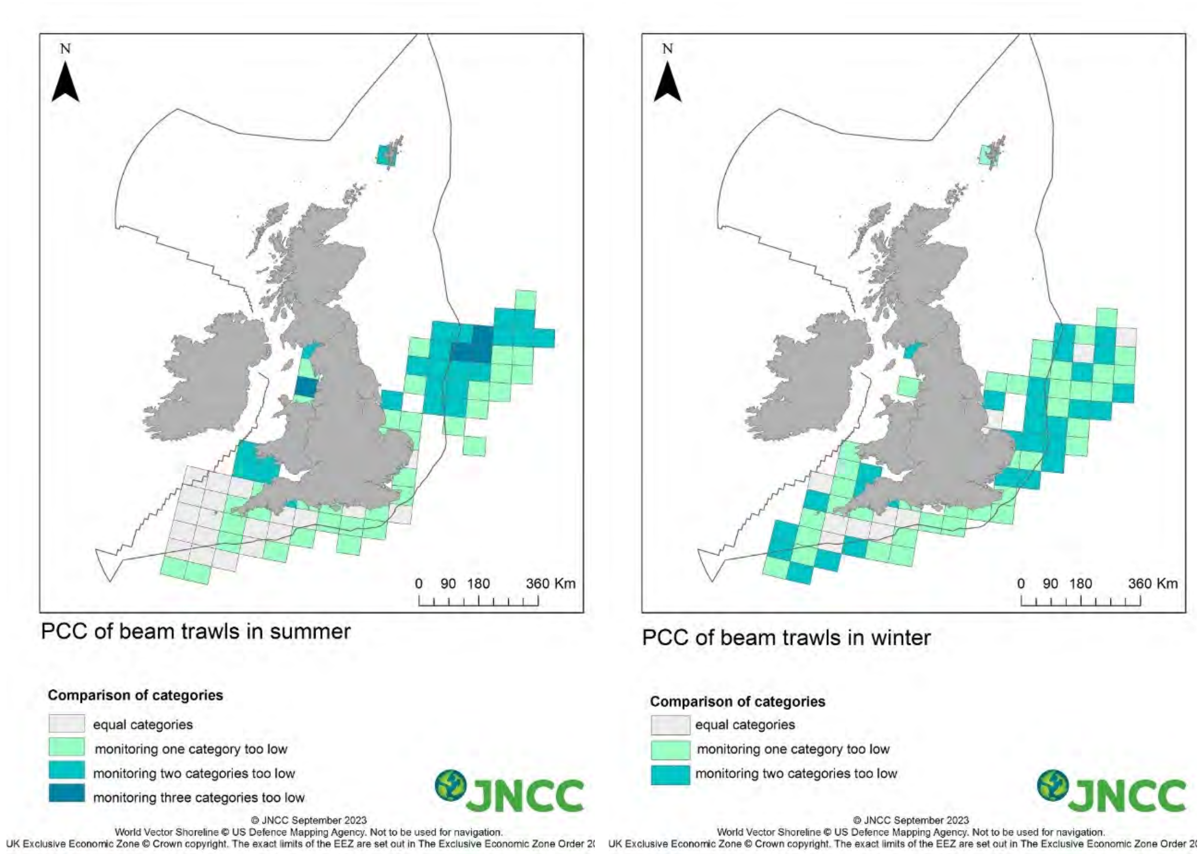

Figure 12. PCC score differences of beam trawls in summer (left) and winter (right).

3.1.9 Pelagic trawls and seines

In terms of fishing effort, pelagic trawls and seines are responsible for the smallest proportion of the total fishing effort of British vessels at only 0.6% (Table 3). In summer, the effort of pelagic trawls and seines is highest around the Northern Isles, in the western Irish Sea and at the southern Cornwall coast. In winter, higher effort is also found along the continental shelf edge, east of Ireland and in the west and east parts of the Channel (Figure 13).

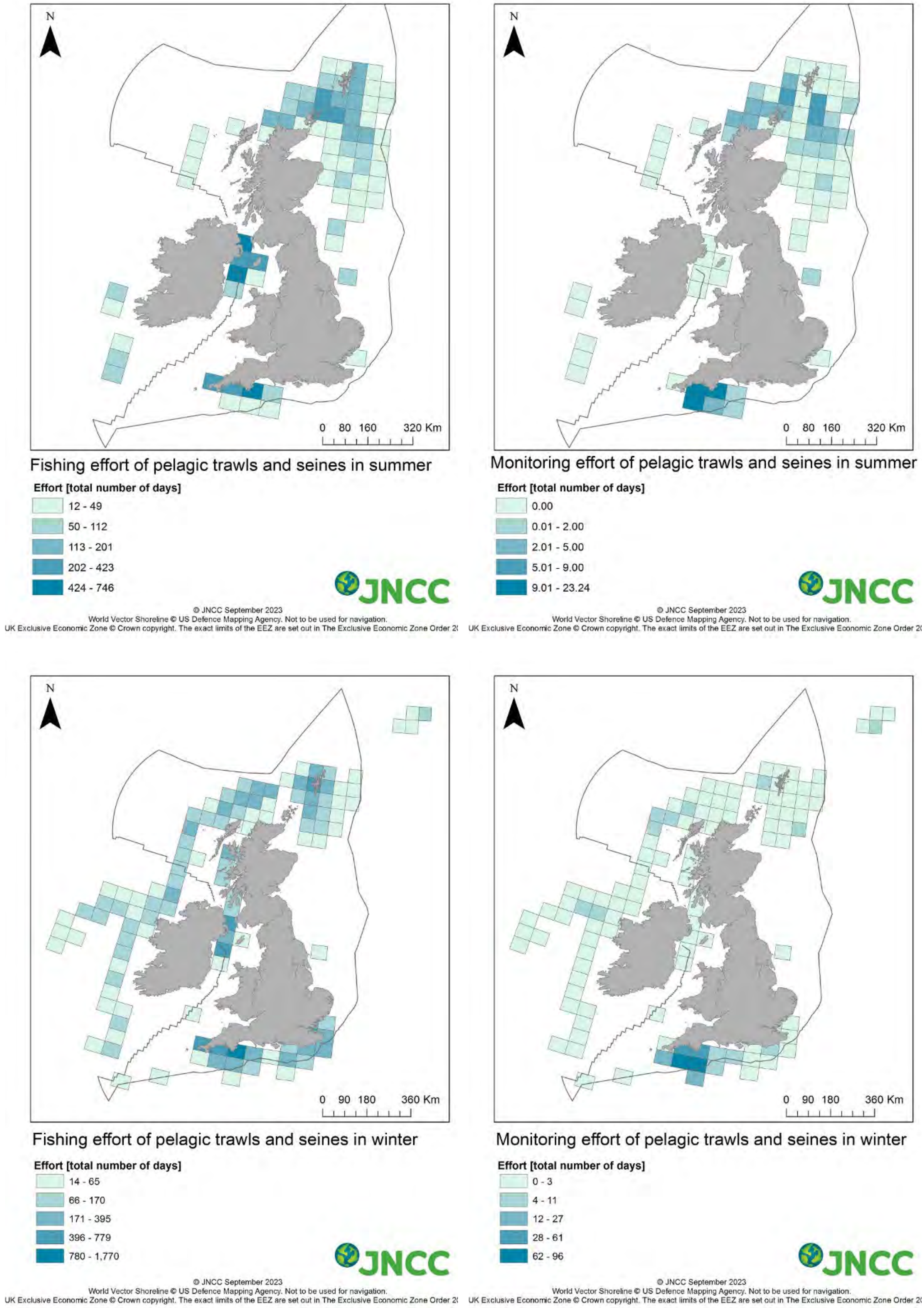

Figure 13. Total fishing (left) and monitoring effort (right) of pelagic trawls and seines between 2010 and 2019 in summer (top) and in winter (bottom).

In summer, 36% of areas where pelagic trawls and seines fishing takes place were also monitored for bycatch. Fishing and monitoring distributions were similar in 11% of rectangles. In 89% the monitoring effort category was lower than the fishing effort category (Table 9).

In winter, 37% of the fished area was also monitored for bycatch. The distributions of fishing and monitoring effort agreed in 15% of rectangles. The monitoring category was higher than the fishing category in 5% and lower in 80% of rectangles (Table 9).

Table 9. Percentage of ICES rectangles falling into PCC categories for pelagic trawls and seines.

Summer		**Monitoring effort**			
		None	**Low**	**Medium**	**High**
Fishing effort	**Low**	25.68%	0%	0%	0%
	Medium	37.84%	9.46%	1.35%	0%
	High	0%	0%	16.22%	9.46%

Winter		**Monitoring effort**			
		None	**Low**	**Medium**	**High**
Fishing effort	**Low**	18.10%	6.03%	1.72%	0%
	Medium	33.62%	9.48%	3.45%	3.45%
	High	11.21%	4.31%	3.45%	5.17%

The map with the PCC score differences in summer reveals that most of the monitored areas have (slightly or moderately) lower monitoring. Only a few areas around Orkney, in the western Irish Sea and around Cornwall show proportionate monitoring to the fishing effort (Figure 14).

In winter, the picture is more varied. Areas with similar monitoring effort and fishing effort distributions are found in the North Sea at Fladen Ground, in parts of the continental shelf edge, northwest of Ireland and in large parts of the western Channel. In some of these areas, for example in southern Channel waters, the monitoring effort category is higher than the fishing effort category. At the same time, there are areas which are in the severely too low monitoring category, e.g. at the northeast Irish sea, around the Isle of Skye, and in the south and east Channel (Figure 14).

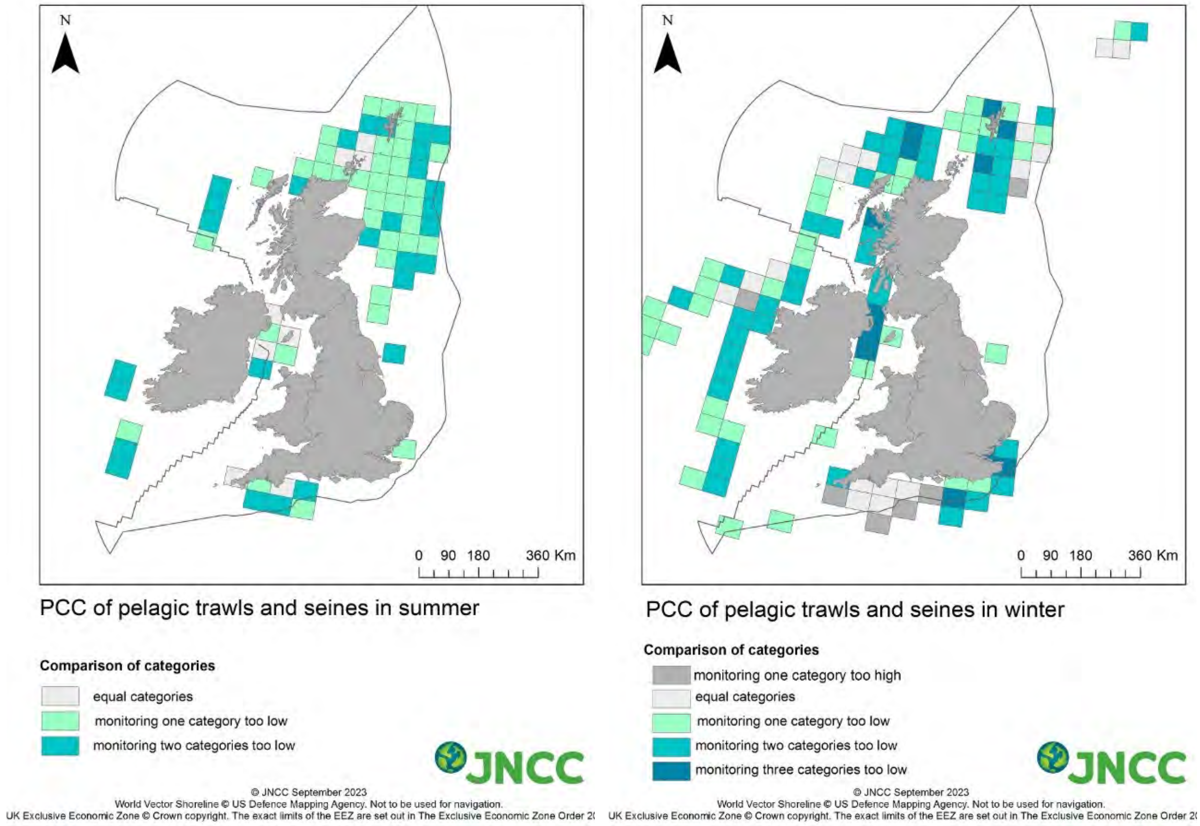

Figure 14. PCC score differences of pelagic trawls and seines in summer (left) and winter (right).

3.2 Comparison of potential monitoring effort gaps with marine bird distributions

3.2.1 Traps

Like demersal trawls and seines and beam trawls, traps pose a potential bycatch risk to marine bird at the surface and at benthic depths (Table 1). The marine bird community at risk from traps is therefore identical to that described for demersal trawls and seines, with the same distribution in summer and winter.

Since the bycatch monitoring effort on traps was so small at the time of the analysis, it was not possible to conduct a PCC analysis for this gear type. However, to identify where birds with a potential bycatch risk from traps might encounter these gears, we mapped those areas with any fishing effort from traps, as they are essentially un-monitored throughout most of their area of activity.

Trap fishing effort is distributed across large parts of all UK waters apart from those being further offshore. It therefore coincides in summer with large densities of marine birds with a potential bycatch risk to traps across all Scottish waters, waters on the English east coast and around the Cornwall coastline. During winter, they coincide with elevated densities mostly within Scottish waters (Figure 15).

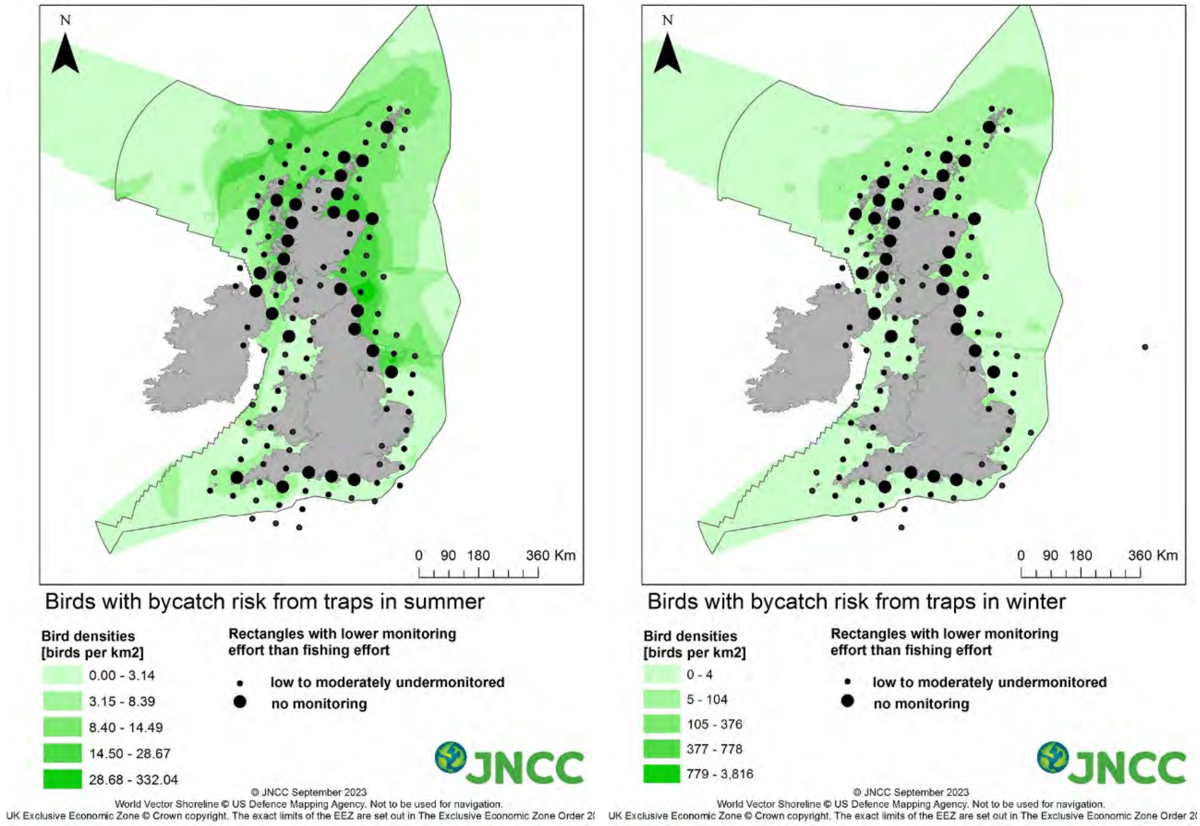

Figure 15. Bird community potentially impacted by traps in summer (left) and winter (right). Included are bird species with a suggested entrapment risk of 5 from Bradbury *et al.* (2017). 'Low and moderately under-monitored' refers to areas with monitoring effort one or two PCC categories lower than the fishing effort. The dots represent the data of individual ICES rectangles.

Table 10. Marine bird community in potentially too low monitoring gaps of traps.

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
Atlantic puffin	11.63	68.61	1.02	27.44
black guillemot	0.50	98.26	0.82	98.31
common eider	0.66	98.46	11.77	99.30
common guillemot	41.52	73.55	32.85	67.01
common scoter	0.81	97.35	5.49	99.22
great cormorant	0.23	98.28	0.71	84.41
long-tailed duck	-	-	5.47	98.96
northern fulmar	21.33	27.48	24.84	26.84
northern gannet	14.46	52.92	6.11	42.08
razorbill	8.81	87.18	7.09	81.70
European shag	0.05	100.00	3.67	99.28

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
velvet scoter	-	-	0.16	95.62
total	100.00	52.43	100.00	50.78

[1]: Population is defined as the population displayed in the map.

In theory, many bird species have large parts of their populations in the rectangles with monitoring gaps for traps (Table 10), including black guillemot common eider, common scoter, great cormorant, long-tailed duck, European shag, and velvet scoter with greater than 90% of their populations. However, some literature suggests that marine bird species recorded to be bycaught by traps in UK waters are cormorant and shag. Higher densities of these species occur only close to the coastline (hence we altered the colour scheme to make the high bird densities visible, Figure 16). A large part, 84% and 99%, of the populations of these two species fall into the monitoring gaps (Table 10). While their hotspots in England (e.g. at Liverpool Bay, around the Cornwall coastline, the Thames estuary, the north Norfolk coast, and the Wash) occur in low to moderately under-monitored areas, in Scotland their distribution hotspots often coincide with no monitoring at all (e.g. along the Moray coast and around Orkney).

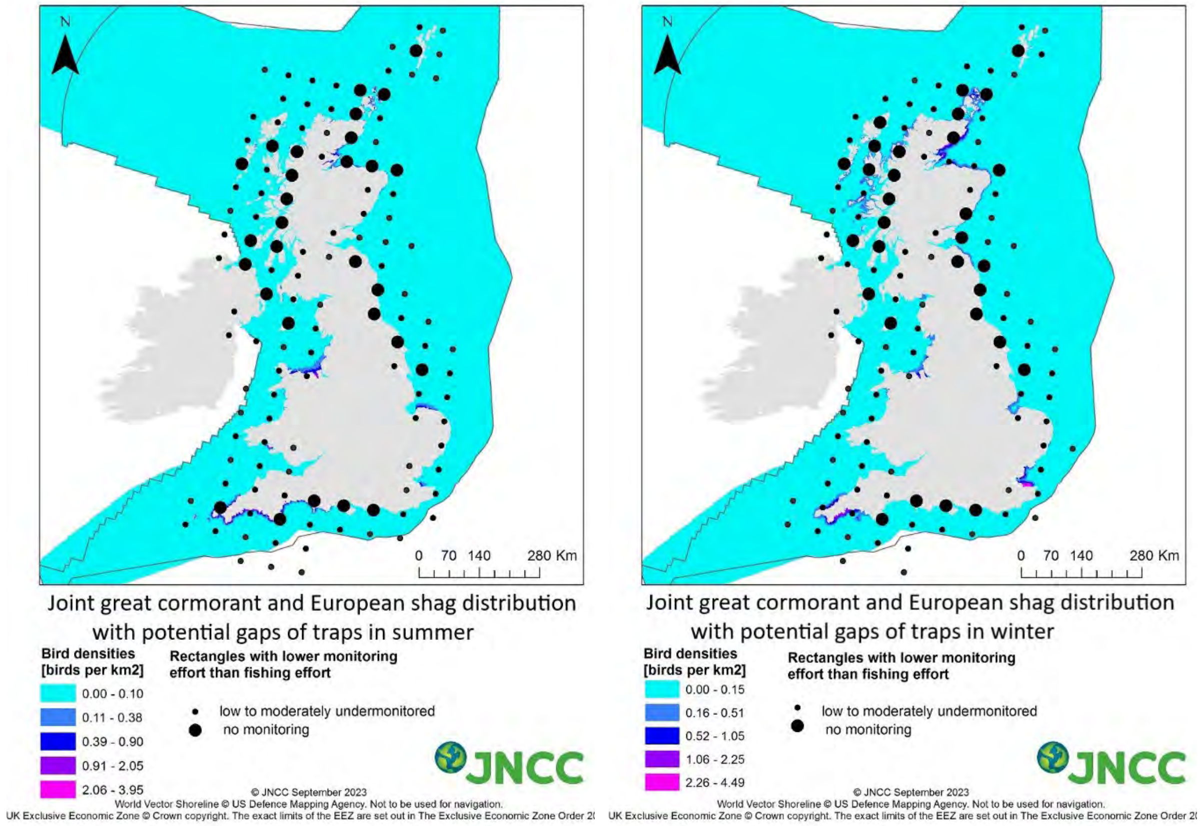

Figure 16. Joint distribution of great cormorant and European shag in summer (left) and winter (right), with the potential monitoring gaps for traps. ‘Low and moderately under-monitored’ refers to areas with monitoring effort one or two PCC categories lower than the fishing effort. The dots represent the data of individual ICES rectangles.

3.2.2 Demersal trawls and seines

Demersal trawls and seines can pose a bycatch risk to marine birds at the surface and at the benthic water depths in shallow water (Table 1).

For demersal trawls and seines, areas with proportionally lower monitoring were found in the North Sea outside of the UK EEZ, in the Irish Sea and all around Ireland. There were three apparently severely under-monitored ICES rectangles in the northern Irish Sea, although this could be an artefact as Northern Irish monitoring effort data was not included in the analysis.

In summer, the marine bird community with a bycatch risk from demersal trawls and seines is distributed mostly around Scotland, with highest densities along the continental shelf edge and on the east coast of Scotland and northern England. The east coast of Scotland is also where the highest densities of this community coincide with a potentially too low monitoring effort (Figure 17). There are also large potentially under-monitored areas outside of the UK EEZ south of Ireland and in the North Sea, but we don’t have marine bird densities for these areas.

During winter, densities of the marine bird community can be much higher than those during summer, however, they are much more localised and at levels that they barely feature on the map. Winter densities around Scotland are elevated and they coincide with potentially too low monitoring again at the east coast of Scotland but also along parts of the continental shelf edge (Figure 17).

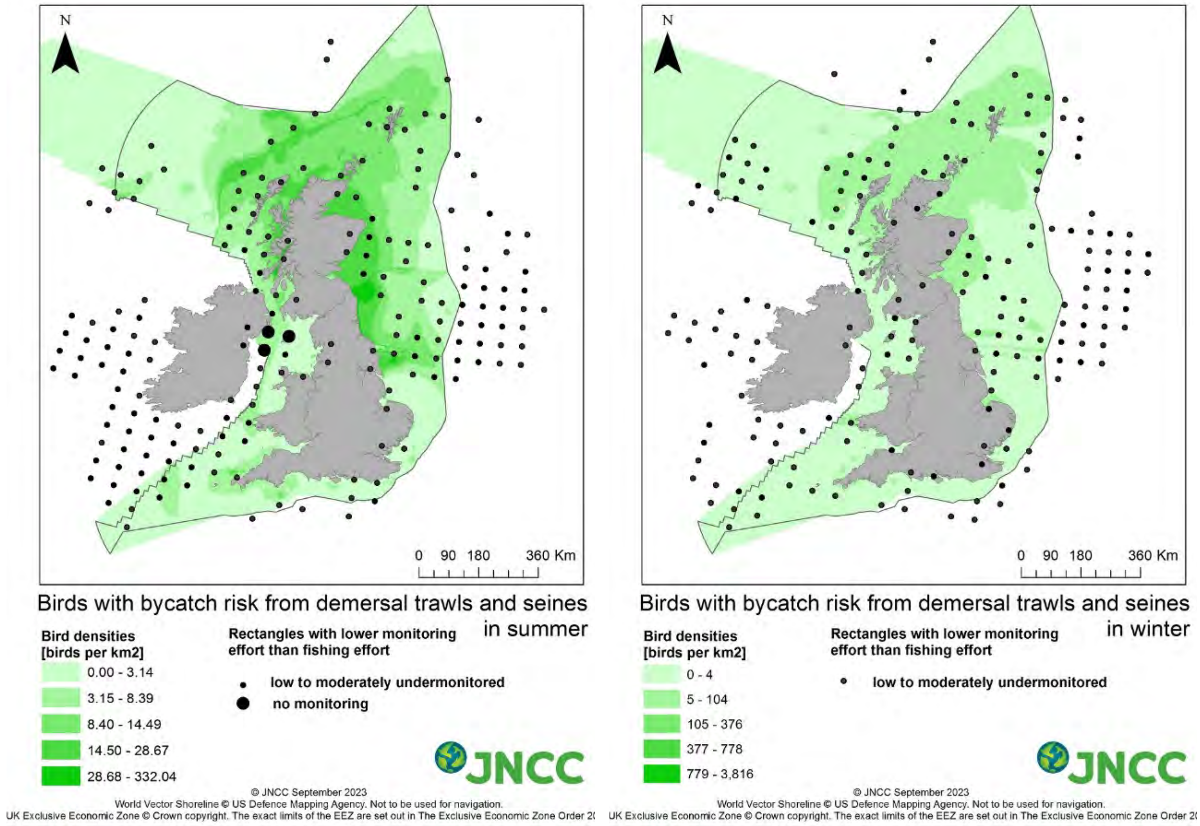

Figure 17. Bird community potentially impacted by demersal trawls and seines in summer (left) and winter (right). Included are bird species with a suggested entrapment risk of 5 from Bradbury *et al.* (2017). 'Low and moderately under-monitored' refers to areas with monitoring effort one or two PCC categories lower than the fishing effort. The dots represent the data of individual ICES rectangles.

In both summer and winter, the marine bird community within UK waters present in this area of lower monitoring comprises 43% of the mapped UK population. In terms of absolute numbers, this community is dominated by guillemots and fulmars. However, when the relative proportion of the individual species populations are considered, over 50% of the populations of black guillemot, eider, common guillemot, common scoter, long-tailed duck, and razorbill are found in this area in summer and/or the winter (Table 11).

Table 11. Marine bird community in potential monitoring gaps of demersal trawls and seines.

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
Atlantic puffin	9.55	46.23	1.80	41.14
black guillemot	0.37	59.56	0.54	55.06
common eider	0.41	50.57	7.82	56.12
common guillemot	34.69	50.43	24.70	42.84
common scoter	0.34	33.42	3.40	52.35

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
great cormorant	0.13	45.09	0.26	26.73
long-tailed duck	-	-	3.65	56.08
northern fulmar	32.89	34.77	43.99	40.43
northern gannet	14.80	44.45	7.13	41.75
razorbill	6.81	55.32	4.56	44.71
European shag	0.02	30.14	2.10	48.35
velvet scoter	-	-	0.04	19.81
total	100.00	43.03	100.00	43.18

[1]: Population is defined as the population displayed in the map.

3.2.3 Gillnets and encircling nets

Gillnets and encircling nets pose a potential bycatch risk to marine birds across all three water depths, surface, pelagic and benthic.

In both summer and winter, gillnets and encircling nets had only few locations with moderately too low monitoring, e.g. at some areas close to Shetland, further offshore in Atlantic waters in the Southwest UK, and in winter in the Irish Sea.

The marine bird community which is potentially susceptible to bycatch from gillnets and encircling nets is found in highest densities in Scottish waters, particularly on the Scottish east coast and along the continental shelf edge. There are also pockets of elevated densities along the English east coast (in summer), further offshore in the North Sea towards Dogger Bank, and in a few locations in the English Channel (Figure 18). Mainly during summer, a few of these areas coincide with potential monitoring gaps (e.g. around Shetland and the east coast of England).

Due to the higher levels of gillnet and encircling net fishing in English waters, a comparatively small part (10–12%) of the marine bird community at risk is found in areas which might be proportionally under-monitored in this fishery. In summer, the species with the largest population proportion occurring in potential monitoring gaps is the northern gannet (with 21%) and in winter the great cormorant (46%) (Table 12).

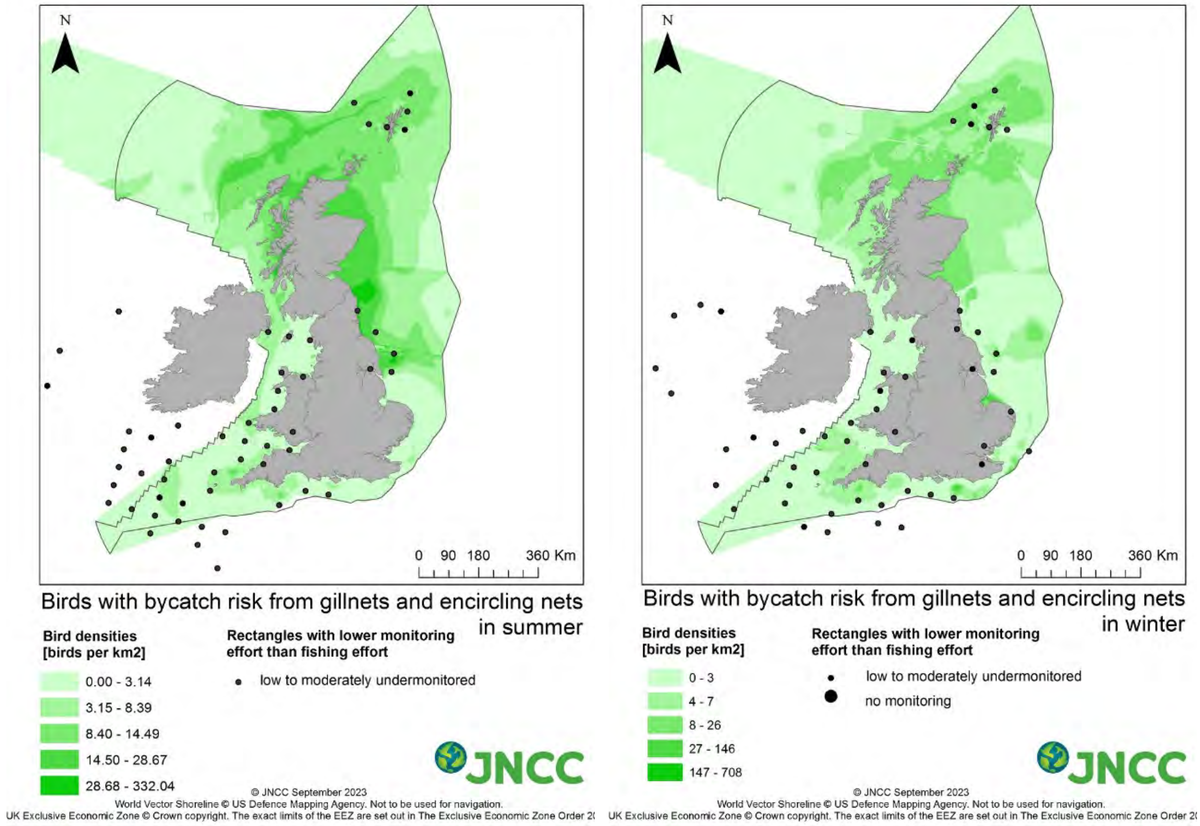

Figure 18. Bird community potentially impacted by gillnets and encircling nets in summer (left) and winter (right). Included are bird species with a suggested entrapment risk of 5 from Bradbury *et al.* (2017). 'Low and moderately under-monitored' refers to areas with monitoring effort one or two PCC categories lower than the fishing effort. The dots represent the data of individual ICES rectangles.

Table 12. Marine bird community in potential monitoring gaps of gillnets and encircling nets.

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
Atlantic puffin	10.15	13.58	1.21	7.01
black guillemot	0.13	5.58	0.15	3.79
common eider	0.43	14.66	2.99	10.16
common guillemot	26.22	10.53	18.32	8.05
common scoter	0.61	16.48	0.99	3.85
great cormorant	0.18	17.48	1.80	46.20
little auk	-	-	0.19	1.48
long-tailed duck	-	-	0.66	2.59
northern fulmar	32.69	9.55	43.35	10.09
northern gannet	25.81	21.42	27.15	21.06

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
razorbill	3.76	8.44	2.63	6.53
European shag	0.03	10.98	0.56	3.23
velvet scoter	-	-	0.02	2.38
Total	100.00	11.89	100.00	10.39

[1]: Population is defined as the population displayed in the map.

Northridge *et al.* (2020) found that the main species bycaught by static nets is common guillemot representing about 75% of all bycaught species. When mapping the guillemot density distribution, some mapping artifacts in the summer guillemot distribution data became visible, which are absent in the original published map by Bradbury *et al.* (2017). The original map is added in the Annex as Figure 25 for reference. There is a high density of guillemots along the northeast English coastline which is, due to the artefacts, not visible in Figure 19.

During summer, most of the guillemot hotspots occur around Scotland and along the northeast coast of England (not visible in the figure below but see the original map in Figure 25). The hotspot along the English coastline coincides with low to moderately under-monitored areas for gillnets and encircling nets. However, during winter they are also found in greater numbers at Dogger Bank and around the Devon and Cornwall coastline. The areas around the Devon and Cornwall coastline are also located in some rectangles with low to moderately under-monitored areas for gillnets and encircling nets, but the highest densities occur mainly in rectangles with good coverage (Figure 19).

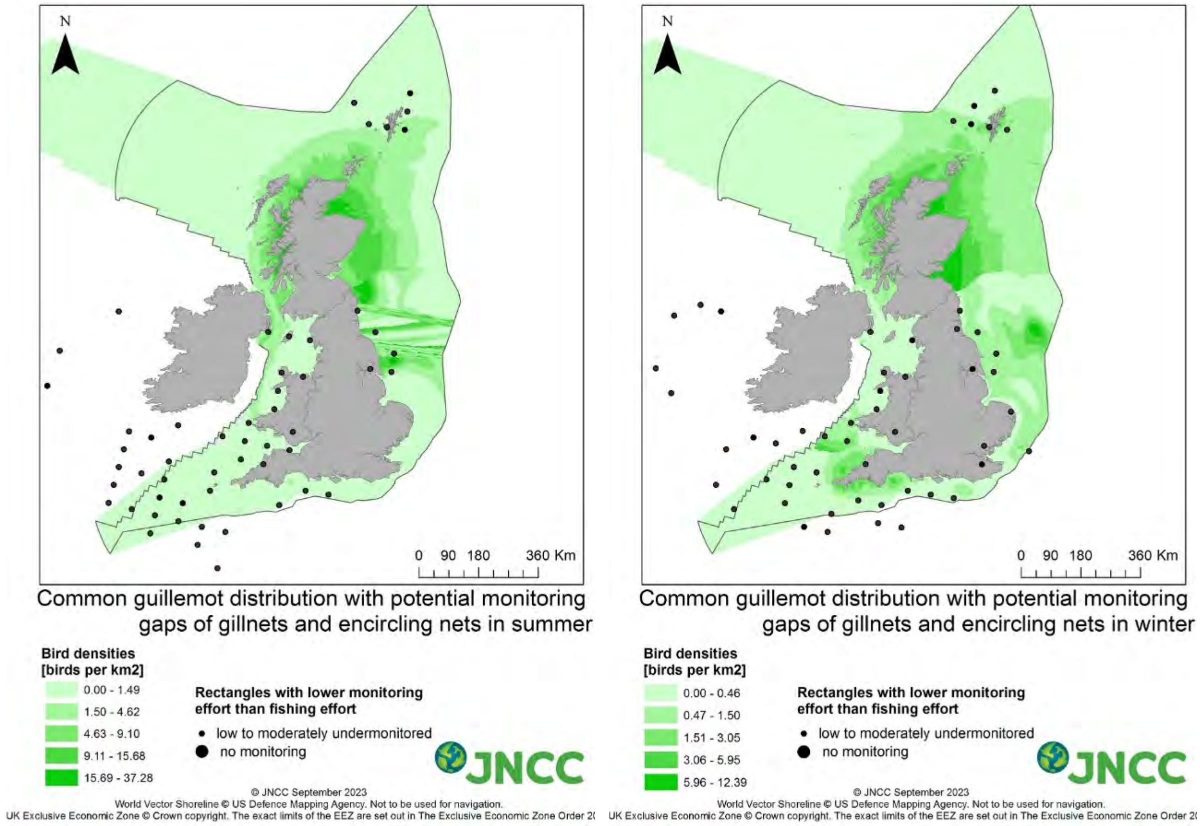

Figure 19. Map showing common guillemot distribution in summer (left) and winter (right), with the potential monitoring gaps for gillnets and encircling nets. 'Low and moderately under-monitored' refers to areas with monitoring effort one or two PCC categories lower than the fishing effort. The dots represent the data of individual ICES rectangles.

3.2.4 Hooks and lines

Like gillnets and encircling nets, hooks and lines can pose a potential bycatch risk to marine birds at all three water depths (Table 1). According to Bradbury *et al.* (2017), the potentially affected marine bird community is therefore the same as for gillnets and encircling nets with the same density distribution across UK waters.

The analysis of PCC scores identified that there are only a few areas where monitoring and fishing effort distributions were similar. In most areas where hooks and line fishing occurs monitoring effort is in a lower category than the fishing effort, and is severely too low (i.e. there is no monitoring at all where there is high fishing effort) in most areas, e.g. at the east coast of Scotland, at the Northern Isles, and in smaller areas at the continental shelf, the Isle of Man, the Pembrokeshire coast and in the eastern English Channel. During winter, severely under-monitored areas are found at the continental shelf, east of Shetland, around the Isle of Man, Pembrokeshire coast, the western Channel and far offshore in Atlantic waters west of the English Channel, inside and outside of the EEZ.

In summer, the potential monitoring gaps coincide with high densities of the marine bird community at risk at areas along the continental shelf edge, around the Northern Isles, the east coast of Scotland, the east coast of England and to a lesser degree around Cornwall. In winter, the picture is similar (Figure 20).

Of the total marine bird community potentially at risk, the potential monitoring gaps hold between 34% (summer) and 39% (winter) of the total UK population. In summer 67% of both common scoter and great cormorant populations, and 60% of the European shag population fall into this potential monitoring gap. In winter, 76% of common scoter, 58% of great cormorant, 59% of long-tailed duck and 72% of velvet scoter are found in these areas (Table 13).

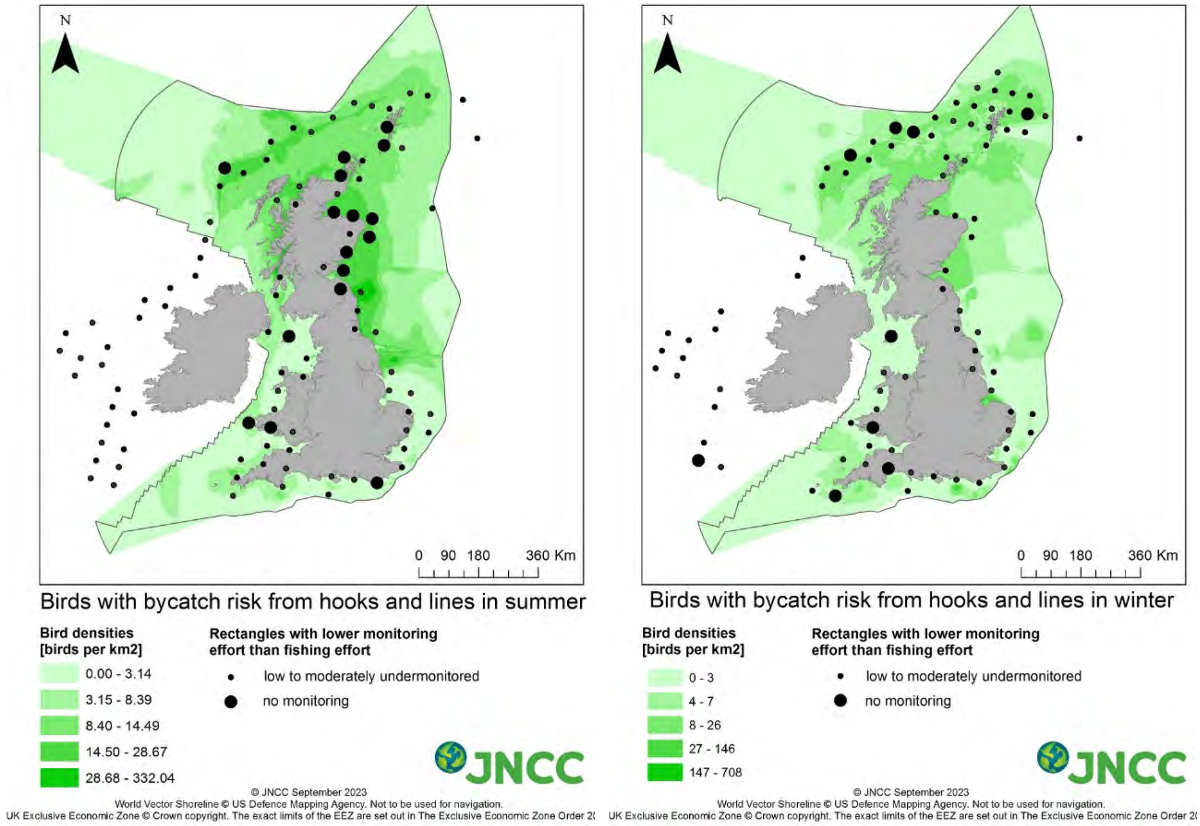

Figure 20. Maps showing bird community potentially impacted by hooks and lines in summer (left) and winter (right). Included are bird species with a suggested entrapment risk of 5 from Bradbury *et al.* (2017). 'Low and moderately under-monitored' refers to areas with monitoring effort one or two PCC categories lower than the fishing effort. The dots represent the data of individual ICES rectangles.

Table 13. Marine bird community in potential monitoring gaps of hooks and lines.

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
Atlantic puffin	11.26	43.63	1.13	24.44
black guillemot	0.28	35.82	0.27	26.32
common eider	0.39	37.89	2.87	36.50
common guillemot	33.28	38.69	17.80	29.27
common scoter	0.85	67.25	5.21	75.87
great cormorant	0.24	66.82	0.61	58.47

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
little auk	-	-	0.47	14.10
long-tailed duck	-	-	4.02	58.56
northern fulmar	33.25	28.12	51.03	44.45
northern gannet	13.99	33.61	12.42	36.06
razorbill	6.42	41.64	2.53	23.49
European shag	0.05	59.90	1.49	32.53
velvet scoter	-	-	0.15	71.50
Total	100.00	34.41	100.00	38.87

[1]: Population is defined as the population displayed in the map.

Northridge *et al.* (2020) found in their preliminary analysis that over 90% of seabird bycatch in UK waters by hooks and lines are fulmars. Fulmar distribution hotspots occur during summer and winter largely along the northern continental shelf edge, and during winter in addition at Fladen Ground south of Shetland (Figure 21).

The hotspots of northern fulmar along the northern continental shelf edge coincide with rectangles which have been identified as being under-monitored for hooks and lines (Figure 21).

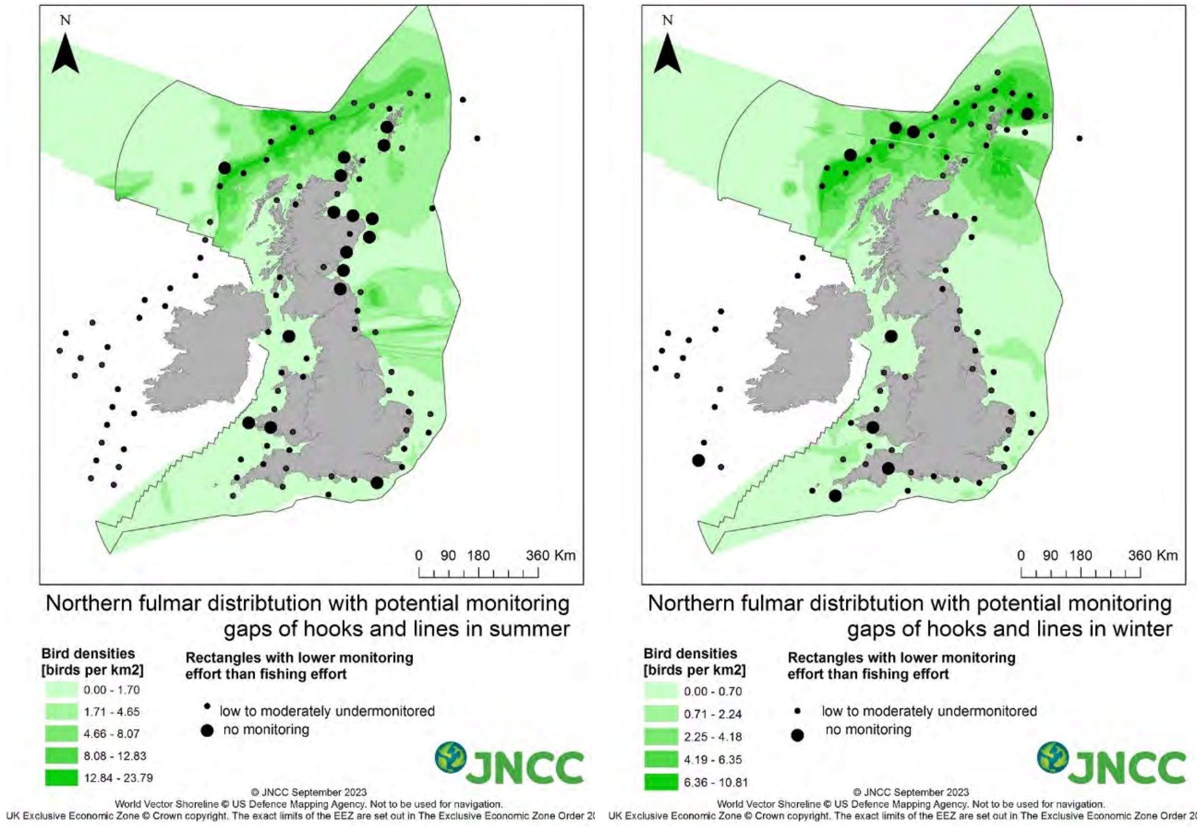

Figure 21. Northern fulmar distribution in summer (left) and winter (right), with the potential monitoring gaps for hooks and lines. ‘Low and moderately under-monitored’ refers to areas with monitoring effort one or two PCC categories lower than the fishing effort. The dots represent the data of individual ICES rectangles.

3.2.5 Beam trawls

As with demersal trawls and seines, beam trawls can pose a bycatch risk to marine birds at the surface and at the benthic water depths in shallow water (Table 1).

In summer, the monitoring effort of beam trawls is moderately or strongly proportionally too low in the Irish Sea and offshore around Dogger Bank in the North Sea. In Liverpool Bay and at Dogger Bank there appears to be no monitoring at all (or very little if this is due to data redaction). During winter, the areas with potentially too low monitoring are more extensive, stretching along much of the English coastline and offshore into the southern North Sea.

The marine bird community with a bycatch risk from beam trawls is the same as that for demersal trawls and seines, with the same distribution. However, since most of the beam trawl activity is in the southern half of UK waters while elevated densities of the marine bird distribution at risk is in northern UK waters, there is not much overlap, with 7–8% of the bird community potentially at risk falling into this area (Table 14). The only area with elevated bird numbers in a potential monitoring gap is in summer at the eastern edge of the UK EEZ in the central North Sea.

However, in summer, there are also two species where a significant part of the mapped population is present in the potential monitoring gap: 51% of the common scoter population and 75% of the European shag population. In winter, 51% of the mapped common guillemot population occurred in the potential gap (Table 14).

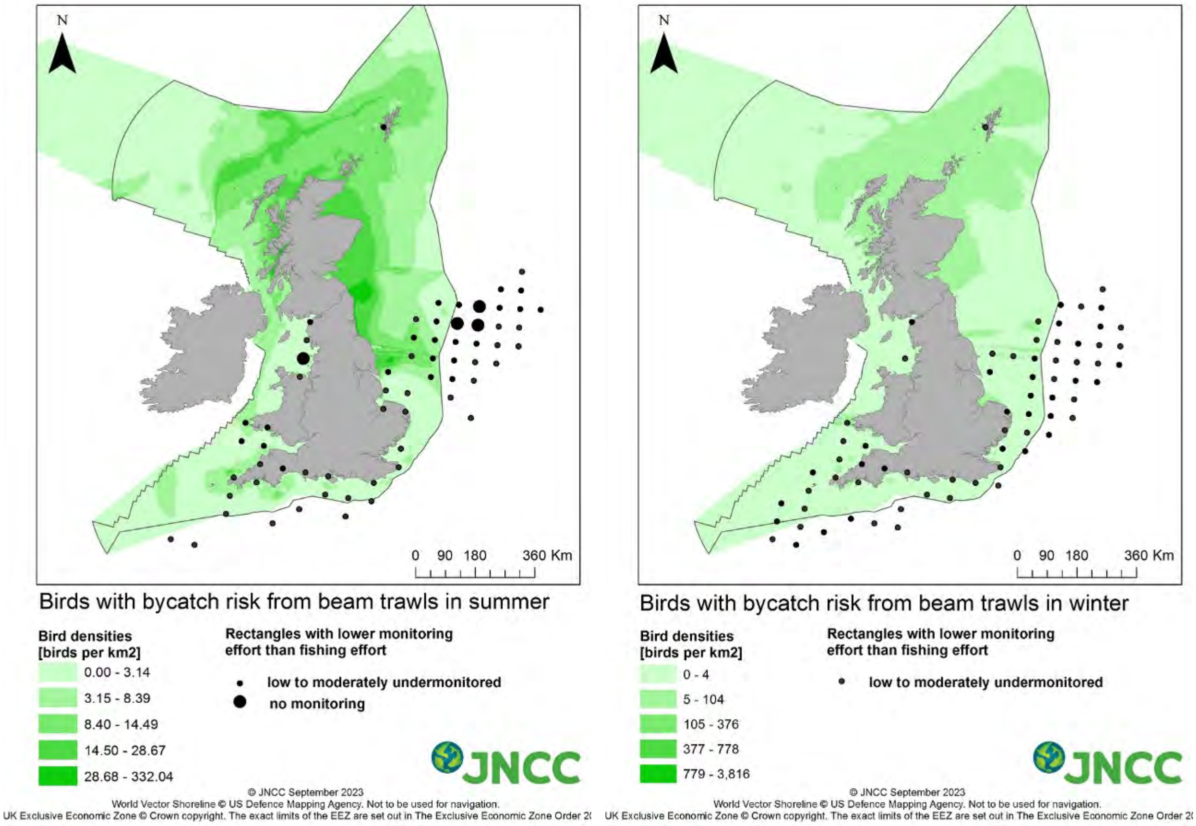

Figure 22. Bird community potentially impacted by beam trawls in summer (left) and winter (right). Included are bird species with a suggested entrapment risk of 5 from Bradbury *et al.* (2017). 'Low and moderately under-monitored' refers to areas with monitoring effort one or two PCC categories lower than the fishing effort. The dots represent the data of individual ICES rectangles.

Table 14. Marine bird community in potential monitoring gaps of beam trawls.

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
Atlantic puffin	7.26	6.27	0.94	3.71
black guillemot	0.1	2.94	0.12	2.18
common eider	0.37	8.08	3.09	3.82
common guillemot	29.5	7.65	51.24	15.33
common scoter	2.95	51.78	3.05	8.07
great cormorant	0.38	24.24	1.8	31.53
long-tailed duck	-	-	0.86	2.27
northern fulmar	25.29	4.77	26.31	4.17
northern gannet	30.21	16.19	3.99	4.03
razorbill	3.67	5.32	7.82	13.22

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
European shag	0.27	75.01	0.72	2.87
velvet scoter	-	-	0.07	6.15
total	100	7.68	100	7.45

[1]: Population is defined as the population displayed in the map.

3.2.6 Pelagic trawls and seines

Pelagic trawls and seines pose a potential bycatch risk to marine bird at the sea surface and at pelagic depths, however, not at benthic water depths (Table 1).

In summer, most rectangles have slightly or moderately too low monitoring effort relative to fishing effort. In winter, there are rectangles which are severely under-monitored, e.g. the northeast Irish Sea, around the Isle of Skye, the south-east English Channel, at the continental shelf edge in the north, and around Shetland.

The marine bird community potentially at risk to be bycaught from pelagic trawls and seines is found in elevated densities in Scottish waters and in English waters off the east coast and along the English Channel and around Cornwall. Overlap between potentially under-monitored areas with high densities occur during summer in larger areas in Scottish waters and in some areas along the English east coast. During winter, there are additional areas in the Eastern Channel and offshore of the Thames estuary with high numbers of potentially vulnerable marine birds (Figure 23).

Between 32% (summer) and 37% (winter) of the marine bird community potentially at risk occurs in these potentially under-monitored areas. The species with largest population proportions in these potential gaps are the Atlantic puffin and common guillemot in summer (both 37%), and black guillemot and northern fulmar in winter (both with 43%) (Table 15).

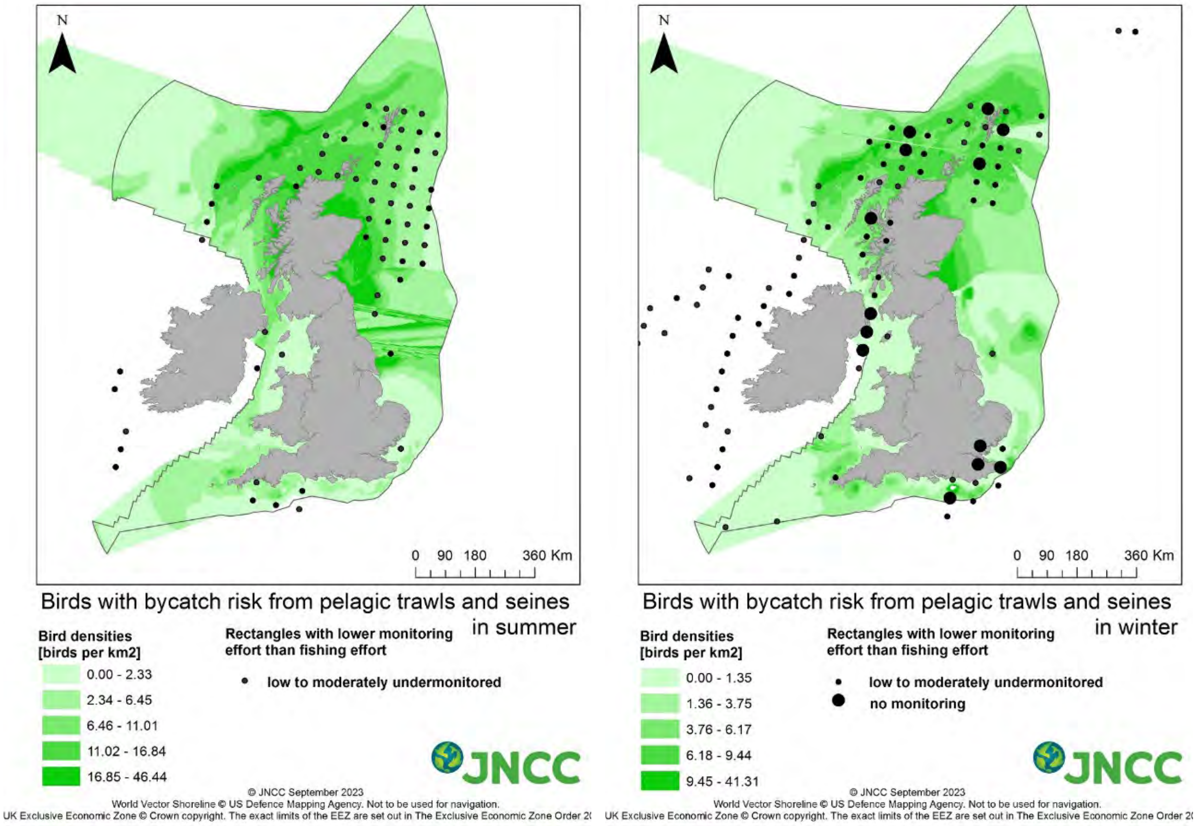

Figure 23. Bird community potentially impacted by pelagic trawls and seines in summer (left) and winter (right). Included are bird species with a suggested entrapment risk of 5 from Bradbury *et al.* (2017). 'Low and moderately under-monitored' refers to areas with monitoring effort one or two PCC categories lower than the fishing effort. The dots represent the data of individual ICES rectangles.

Table 15. Marine bird community in potential monitoring gaps of pelagic trawls and seines.

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	**Proportion of this species' population[1] in monitoring gaps [%]**	**Bird community composition in monitoring gaps [%]**	**Proportion of this species' population[1] in monitoring gaps [%]**
Atlantic puffin	10.60	37.20	0.98	18.31
black guillemot	0.14	16.77	0.52	43.33
common guillemot	35.19	37.07	20.10	28.48
great cormorant	0.06	14.41	0.39	32.62
little auk	-	-	0.59	15.10
northern fulmar	39.86	30.54	57.65	43.28
northern gannet	9.42	20.50	14.69	36.75
razorbill	4.70	27.65	3.79	30.34
European shag	0.02	26.52	1.29	24.16

Species	Summer		Winter	
	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]	Bird community composition in monitoring gaps [%]	Proportion of this species' population[1] in monitoring gaps [%]
Total	100.00	31.42	100.00	36.60

[1]: Population is defined as the population displayed in the map.

Northridge *et al.* (2020) indicated that the species with most recorded bycatch incidents in UK waters from pelagic trawls and seines is common guillemot. In summer, common guillemot hotspots occur mostly around the Scottish coastline, stretching from the Scottish east coast and Northumberland coast into the North Sea, and close to the Flamborough Head coastline (Figure 24). During winter, there are additional hotspots around Dogger Bank in the North Sea and around the Cornwall coastline. It is only during winter that some of these hotspots on the west coast of Scotland coincide with monitoring gaps of pelagic trawls and seines.

Beside guillemots, cormorants, gannets, and razorbills were also documented as being bycaught by pelagic trawls and seines. Their combined distribution (Annex, Figure 27) is similar to the guillemot distribution (Figure 24).

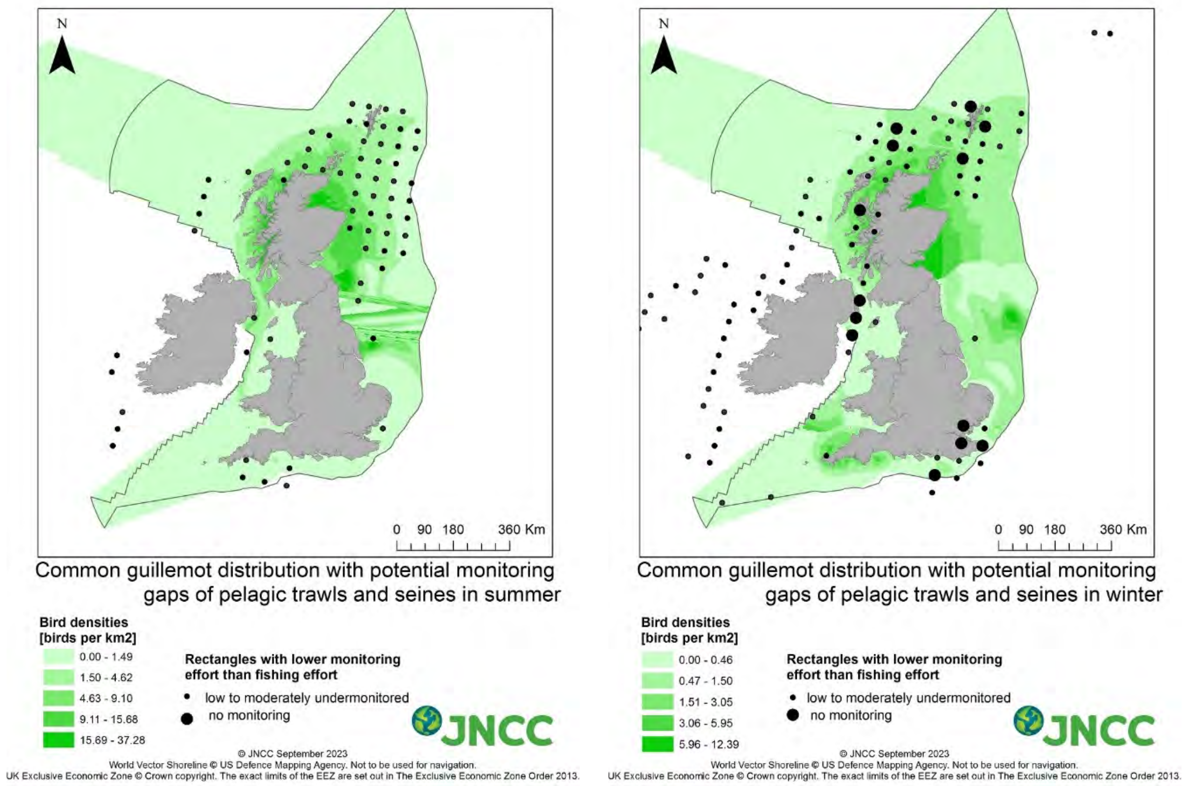

Figure 24. Common guillemot distribution in summer (left) and winter (right), with the potential monitoring gaps for pelagic trawls and seines. 'Low and moderately under-monitored' refers to areas with monitoring effort one or two PCC categories lower than the fishing effort. The dots represent the data of individual ICES rectangles.

4 Discussion

The aim of this analysis was to identify whether there are significant gaps in monitoring coverage of marine bird bycatch caused by fishing activities. Fishery bycatch has been identified as an important human pressure on marine birds (DEFRA 2022; Dias *et al.* 2019; Young & VanderWerf 2022). A broad-scale analysis was applied to identify where there may be spatial gaps in the current monitoring efforts which, if addressed, are likely to improve the data to provide more robust estimates of marine bird bycatch.

4.1 Potential monitoring gaps

Overall plotting of monitoring effort against fishing effort showed that only for demersal trawls and seines, and for beam trawls, there is a weak positive correlation between monitoring and fishing effort levels at the scale of ICES rectangles. For all other gear types, the relationship was even less clear. This might be explained by the overall low monitoring rates which would make the establishment of a clear relationship difficult. Implementing fully balanced monitoring is difficult if the overall monitoring coverage is low and the fisheries are wide ranging and have relatively unpredictable operating patterns.

For the hooks and lines category, the absence of a clear relationship between monitoring effort and fishing effort is also likely to be influenced by the largely unmonitored handline fisheries which are responsible for a large part of the total fishing effort. These handline fisheries use specific predominately coastal locations, e.g. areas in Scotland, where those ICES rectangles show a high fishing effort without any associated monitoring effort.

4.1.1 Traps

Traps are an exceptional fisheries category because they are responsible for the largest proportion of all fishing effort by British vessels (49%) yet have one of the lowest monitoring coverages (less than 0.01%). The sampling programmes considered here either focus on fisheries with high discard rates or high bycatch rates, and pots and traps are considered to have low rates for both catch components so have not been included in sampling designs thus far.

It is possible that the analysis overestimated the range of marine bird species potentially affected by traps. In our analysis, we determined that in the potential monitoring gap, in theory between 51–52% of the marine bird community possibly at risk is present. ‘Species at risk’ were defined following Bradbury *et al.* (2017), based on spatial overlap of species and a gear types at different water depths, and identified a wide spectrum of birds at risk from traps, based on their ability to forage at deeper (demersal) depths. However, in practice only great cormorant and European shag (red listed) have been reported in the past to be bycaught in traps (ICES 2013; Schirmeister 2003; Stanbury *et al.* 2021). Other studies, e.g. an extensive study on bycatch in the lobster and crab fishery in Wales, were unable to record any bird bycatch (Moore *et al.* 2023), possibly due to a different design of the traps which might prevent bird bycatch more efficiently. The absence of bycatch of other species in traps suggests that there might be an additional behavioural element which makes these species more susceptible to entrapment in pots and traps and which has not been considered by Bradbury *et al.* (2017) (Moore *et al.* 2023). Alternatively, it is also possible that traps might not have been monitored enough to show the full spectrum of (pursuit diving) species potentially susceptible to this gear type.

The analysis also overestimated the spatial area where traps could pose a bycatch risk to marine birds. The combination of high trap fishing effort and low trap monitoring effort led to all rectangles where traps occurred being identified as potentially under-monitored.

However, in practice traps do not pose a risk across all these locations. Bycatch in traps is unlikely to occur during the rapid setting or hauling of traps, but if birds are caught it is during the soaking time. Consequently, traps will only pose a significant bycatch risk to marine birds while on the sea floor and when set at a depth which can be reached by diving birds. For the species known to be bycaught by traps, European shags have been found to forage up to a depth of over 80 m, although the average diving depth is around 34 m (Natural England 2012a). The deepest recorded dive of great cormorant is at 35 m depth, but on average they dive to a depth of 12.1 m (Natural England 2012b). Any potential monitoring gaps for traps at deeper water depths can therefore be ignored for these species.

It is currently not clear whether traps pose a significant bycatch risk, including for shags and cormorants, across UK waters. This analysis indicates that there are moderately under-monitored areas around the English coastline (e.g. Liverpool Bay, Cornwall, and the Wash) where hotspots of cormorants and shags occur, including at suitable water depth range for these species to encounter actively fishing gear. The same holds for larger hotspots of these species around Scotland (e.g. the Moray coast and around Orkney), which are not monitored at all. While there is the potential that more monitoring in these areas could improve bycatch estimates for these species, there is still the question if traps indeed pose a considerable bycatch risk at all. Instead of recommending increased monitoring effort it seems therefore appropriate to take a pragmatic approach and explore (e.g. through interviews with fishers) if there is a considerable bycatch risks from traps, before evaluating how or if monitoring could be improved through potentially resource intensive wide-scale changes to current programmes. This research could also include exploration of how different trap designs and operational characteristics (typical depths, substrates, etc.) might affect bycatch risk.

4.1.2 Demersal trawls and seines

Demersal trawls and seines are responsible for the second largest proportion (23%) of all fishing effort from British vessels. A small proportion of this fishing effort (0.68%) is monitored. In demersal trawls, the main issues for seabirds are collisions with warp and monitoring cables during hauling, but they can also be trapped in the net (Sullivan *et al.* 2006; Watkins *et al.* 2008).

Between 34–36% of the monitoring effort is distributed similarly to fishing effort, the second highest agreement rate measured for the different gear types. Which leaves 61% of rectangles in summer, and 66% of rectangles in winter with lower than proportional monitoring.

In these areas with low monitoring efforts, according to the analysis a number of species occur with a large part (greater than 50%) of their UK population, namely common guillemot, razorbill, black guillemot and common eider (all amber listed), and some wintering sea ducks (common scoter, long-tailed duck – both red listed) (Stanbury *et al.* 2021). Other red-listed species, such as Atlantic puffin and European shag, come close to the 50% mark, too. However, in practice a smaller list of species, mainly gannet, gulls, cormorant and shearwaters, has been recorded as bycatch from demersal trawls and seines (ICES 2013; Oliveira *et al.* 2015; Pott & Wiedenfeld 2017), which raises the question of whether auks and seaducks have been correctly identified as being at risk from this gear type and whether gulls and shearwaters have been correctly identified as being not at risk in this analysis based on depth considerations. Potentially, like for traps, there might be other behavioural elements which should be considered in addition to water depth, e.g. some of the species recorded as bycatch are known ship followers (e.g. gannets, gulls, and shearwaters, but not cormorants; Garthe & Hüppop 1994). In the absence of any additional factors which would help to improve the selection of marine bird species at risk, and given that monitoring rates for this gear type are low and could mean that bycatch of some of the species might simply have been missed, we need to consider that bycatch might be insufficiently documented for these species, particularly as some of the high density areas (e.g. off the Scottish east coast) are under-monitored. While in over 1/3 of rectangles the monitoring effort of demersal trawls and seines is proportionate, increasing the monitoring effort off the Scottish east coast, and to the west and north of the Outer Hebrides might be beneficial.

When being towed, demersal trawls and seines operate at the sea floor and might pose a bycatch risk for species diving to those depths. It could therefore be considered that a focus on monitoring those parts of the trawl fleet fishing in waters shallow enough to be accessible for diving birds during towing might be a good approach. However, a focus on trawls in shallow water is likely to miss a potentially significant proportion of seabird bycatch, as marine bird bycatch is also known to occur during hauls of demersal gears.

4.1.3 Gillnets and encircling nets

Alongside hooks and lines, gillnets are generally considered to pose an important bycatch risk for marine bird species (Cleasby *et al.* 2022; Hedd *et al.* 2016; Zydelis *et al.* 2013) in particular for pursuit diving species and if they tend to densely aggregate like auks and shearwaters (Montevecchi 2001). About 7% of all fishing effort of British vessels is due to gillnets and encircling nets, and just over 1% of this effort is being monitored for marine bird bycatch. The distribution of monitoring effort is like that of fishing effort in 38–42% of the rectangles, the highest agreement rate across the fishing gears. Which leaves 58–62% of rectangles potentially being under-monitored at current levels.

Like for beam trawls, a large part of the fishing effort takes place in English inshore and offshore waters, except for an area around Shetland. Consequently, of the overall marine bird community potentially at risk, a comparatively small proportion (10–12%) is found in those areas which might be considered under-monitored. In summer, the species with the largest part of its population (21%) occurring in these areas is the northern gannet (amber listed) and in winter it is great cormorant (46%) (green listed). Although there are gaps in gillnet and encircling nets monitoring, these gaps do not appear to coincide with particularly high densities of susceptible species.

Northridge *et al.* (2020) found that the main species bycaught by static nets is guillemot (about 75% of total), but there is also a high diversity of species which are caught in small numbers (cormorant, fulmar, gannet, great northern diver, herring gull (and further unidentified gulls), razorbill and shag). While the auks, cormorants and shags are mostly caught by vessels under 10 m length, which are typically associated with inshore waters, the more wide-ranging gannets and fulmars are caught by vessels over 10 m length which usually operate further offshore.

Because guillemots are a substantial part of bycatch from gillnets and encircling nets, we looked at the distribution of guillemots compared to the potential monitoring gaps in gillnets. One of the high-density common guillemot areas off the northeast coast of England in summer coincides with a potential monitoring gap. This is also an area which has been identified as having high bycatch rates (Northridge *et al.* 2023), likely a result of the high common guillemot densities. However, the largest parts of common guillemot high density areas have no gillnet and encircling nets fishery at all and during winter, when the bycatch rates of guillemots are highest (Northridge *et al.* 2023), the area off the northeast coast of England does not hold large aggregations of guillemots (Figure 26). Another bycatch rate hotspot north of Shetland (Northridge *et al.* 2023), however, appears to coincide partly with high densities of guillemots as well as being a relatively under-monitored area.

If it is an aim to improve the bycatch monitoring of gillnets and encircling nets, some minor changes in the distribution of monitoring effort might be informative.

4.1.4 Hooks and lines

Hooks and line fisheries are considered to pose one of the highest bycatch risks to marine birds. Seabirds vulnerable to longline fisheries are usually those feeding at or near the surface, often attempting to steal bait from hooks, like petrels (e.g. northern fulmar), gulls and skuas (Montevecchi 2001). They are responsible for just over 5% of all fishing effort of British vessels, and only 0.1% of this effort is monitored for marine bird bycatch. The agreement rates between the distributions of fishing effort and monitoring effort are particularly low for hooks and lines with only between 3–11% agreement. This leaves 85–96% of the rectangles under-monitored.

The monitoring of hooks and lines shows some significant gaps. The overall monitoring rate of these gears is low in general, and there are monitoring gaps (e.g. inshore at the east coast of Scotland, Orkney, Shetland and at coastal Wales and offshore along the northern continental shelf edge).

However, some of these perceived monitoring gaps are a misrepresentation due to this gear group aggregating gear types with very different bycatch risk. While offshore longline fishing is known to pose a bycatch risk to marine birds (Kingston *et al.* 2023; Northridge *et al.* 2020) and is monitored at a low level, the majority of the hook and lines fishing effort inshore comes from handline- and rod-and-line fishing, which are rarely monitored as bycatch rates are not currently considered to be significant (Blackmore *et al.* 2023). Consequently, most of the inshore monitoring gaps are due to fishing effort by handlines (mainly targeting mackerel), but these ‘monitoring gaps’ are unlikely to be of concern. The under-monitored rectangles along the continental shelf edge to the north and west of Scotland are associated with the offshore longline fishery which operates over a wide area from the Celtic Sea to the Shetland Isles and may constitute a genuine monitoring gap, particularly if bycatch rates there differed from the surrounding areas that have had some monitoring. Most bycatch estimates are produced at the scale of ICES Division and the calculated rates would be a mean of observed rates at that scale, extrapolated to the effort in that Division. Under-monitored areas would constitute a problem if the rates were significantly higher/lower than the rates calculated from other parts of the same Division because that would introduce bias. This general area coincides with areas of high observed fulmar bycatch rates (Northridge *et al.* 2023). There is also a high bycatch rate variation, so continued or increased monitoring in this area will also improve understanding of the sources of this variation.

For hooks and lines, potentially under-monitored areas hold between 34% (summer) and 39% (winter) of the total UK population of marine birds potentially at risk. Many of the species within this community occur with large parts of their populations (often 60–70%) in these potential monitoring gap areas. However, similarly to traps, the diverse marine bird community considered at risk from hooks and lines in this analysis has not actually been recorded as bycatch. Northridge *et al.* (2020) found in their preliminary analysis that over 90% of seabird bycatch in UK waters by hooks and lines are fulmars, with much smaller amounts of gannets and some gull species (e.g. great black-backed gull and kittiwake). Most of these birds are likely to have been caught during line-setting operations, however, a small proportion has been classed as live bycatch and are caught during hauling (Northridge *et al.* 2020; Young & VanderWerf 2022). There is a latitudinal and seasonal gradient in bird bycatch within the offshore longline fishery, with lower bycatch rates recorded in southern UK waters and higher bycatch rates in the north (Northridge *et al.* 2020) and higher rates observed in summer and lower in winter. This is important for sampling design considerations and stratification when producing bycatch estimates.

Northern fulmar, the main species observed as bycatch from offshore longlines (Kingston *et al.* 2023; Northridge *et al.* 2020), is an amber listed species with an unfavourable conservation status in Europe (Stanbury *et al.* 2021). The most recent seabird census

(2015–2021) revealed that the fulmar breeding population in all Britain, Ireland, the Isle of Man and the Channel Islands has decreased by 35% compared to the last census in 1998–2002 (Burnell *et al.* 2023). When the distribution of northern fulmar is compared to the observed monitoring gaps for hooks and lines, the large under-monitored areas along the continental shelf edge are particularly noticeable in winter and this can be considered a monitoring gap which could lead to the bycatch of northern fulmars being insufficiently documented at that time of year (1,000–2,000 individuals per year, Kingston *et al.* 2023). This has prompted mitigation work in collaboration with industry which is underway. However, some additional monitoring of the fleet fishing along the continental shelf, particularly in the winter/early spring period when monitoring levels are low, would help improve the precision and reduce bias of bycatch estimates (Kingston *et al.* 2023).

4.1.5 Beam trawls

Beam trawls are responsible for just under 3% of the total fishing effort from British vessels. Just over 1% of this effort is monitored for marine bird bycatch. In this gear the agreement between fishing and monitoring effort lies between 14–24%, leaving 75–86% of the rectangles ‘under-monitored’.

In the potential monitoring gap of beam trawls, a comparatively small part of the marine bird population at risk is present (7–8%), mainly due to most of the marine bird community aggregating in Scottish waters while beam trawling is taking place mostly in English waters. According to the analysis, two species occur with a large part of their population in the monitoring gap areas: 52% of the population of common scoter and 75% of the population of European shag – both are red listed. However, there are currently no bycatch reports of marine birds from beam trawls in the literature that we know of. Given that marine bird hotspots and beam trawling activity show little spatial overlap, and that there is no bird bycatch reported from this gear type, it seems unlikely that beam trawling poses a significant risk to marine birds in UK waters. Changes to bycatch monitoring of beam trawls are therefore unlikely to be necessary or beneficial to seabird bycatch estimation.

4.1.6 Pelagic trawls and seines

Pelagic trawls and seines are the gear category with the lowest fishing effort in this analysis, with only 0.6% of the total fishing effort of British vessels. Of these, a comparatively large proportion (2.4%) are being monitored for marine bird bycatch. In summer, the distributions of pelagic trawls and seines fishing and of the respective monitoring effort are in 11–15% in agreement with each other, the second lowest agreement rate between the gears. In 80–89% of the rectangles the monitoring effort is lower than expected given the fishing effort. In summer, under-monitored rectangles occur mainly in the northern North Sea and north of Scotland. During winter, there a couple of areas that have not been monitored at all in the time period considered here: around Shetland, at the northern continental shelf edge, around the Isle of Skye (likely to be due to the West-coast Sprat fishery), at the east coast of Northern Ireland and in the vicinity of the Thames estuary. Additional rectangles with too low monitoring compared to fishing effort occur in waters around northern Scotland and to the west of Ireland.

In these potential monitoring gaps, between 32% (summer) and 37% (winter) of the marine bird community potentially at risk occur. Individual species with a high percentage of their UK population being present in those potential gaps were Atlantic puffin and common guillemot in summer, both with 37% of their population, as well as black guillemot and northern fulmar, both with 43% of their winter population, and all of these being amber listed.

Northridge *et al.* (2020) found that the main species bycaught by midwater trawls in the English Channel are guillemots (about 85%), and to a smaller extend cormorants and razorbills. Pierce *et al.* (2002) noted that in the Scottish mackerel (*Scomber scombrus*), herring (*Clupea harengus*), "maatje" herring (herring caught just before their first spawning) and argentines (*Argentina silus*) fisheries, northern gannets were bycaught in small numbers. The species recorded as bycatch reflect to some degree the species identified in the analysis as being at risk from pelagic trawls and seines.

A bycatch monitoring distribution for pelagic trawls and seines that more closely matched the fishing distribution could therefore improve the documentation of bycatch incidents for some of the species identified as being present in potential monitoring gap areas.

4.2 Overall approach

The broadscale approach applied in the analysis worked reasonably well, however, there were some shortfalls worth highlighting.

Some of the gear types should have been disaggregated to allow more focussed conclusions. This is particularly apparent for hooks and lines, where gear types with different bycatch risks, distributions and monitoring rates were aggregated (i.e. handlines and larger scale longline fisheries). While this could be addressed in the discussion, it would have been preferable to keep those gear types separate. Similarly, pots and traps might also have benefited from not being aggregated as much as they were.

We found in later stages of the analysis, when monitoring gaps were compared to bird distributions, that the bird communities identified by Bradbury *et al.* (2017) to be potentially at risk from different gears did not always accurately reflect current knowledge about marine bird species bycatch in UK fisheries. In particular, bycatch recorded from hooks and lines, traps and gillnets and encircling nets differed from the species spectrum at risk suggested by Bradbury *et al.* (2017). We felt that the approach from Bradbury *et al.* (2017) did not address the risks for longlines adequately, with e.g. shearwaters having an entrapment risk of 4, a similar category as red-breasted merganser and common scoter. Gulls and terns on the other hand had an entrapment risk of 2. While their assessments of bycatch risks at different depth of the water column is useful and necessary, for some gear types there are likely to be other additional behavioural factors which play a role in how sensitive a species is to bycatch by a given gear type. For each gear group, we have therefore compared the bird species potentially being at risk as identified by Bradbury *et al.* (2017) with those species currently being recorded as bycatch of that gear type.

Bycatch risk during different parts of the fishing operations is highly influenced by the behavioural traits of the seabird species in question. For some gear types, water depth could be used to delimit the areas where species are at risk of bycatch. This is the case for traps, but potentially also for demersal trawls and seines for species that do not actively interact with vessels during hauling operations.

4.3 Outlook

On a broad scale, current monitoring efforts reflect the distribution of UK fishing effort, despite the low monitoring coverage of most gear types. However, this analysis has identified some potential monitoring gaps which, if addressed, could help to improve the data on marine bird bycatch in UK waters. Within the current catch sampling programmes there is likely to be limited scope to significantly address these gaps because these programmes have primary objectives that are not focussed on sensitive species bycatch and will need to continue to meet those objectives as a priority. However, some minor adjustments to sampling designs could potentially be made by redirecting some observer effort within the gear types considered by the catch sampling programmes, provided that did not impact on the programmes main objectives and if there was a clear steer on which monitoring gaps should be prioritised.

There is potentially more scope to adjust sampling designs within the BMP because that programme has a primary objective of collecting data on the full range of sensitive species. Developing new sampling designs is a task that is being undertaken by the BMP consortium and which this report will usefully inform.

It is likely that Electronic Monitoring (EM) may be made mandatory for compliance purposes for some specific fleets in the UK and may be used more widely within catch and bycatch focussed programmes so it will be worth exploring if this will also provide an opportunity to further improve the representativeness of monitoring data that are used to support bycatch assessments for seabirds and other taxa.

4.4 Conclusions

4.4.1 Traps

For cormorants and shags: improved monitoring in some areas could improve bycatch estimates for these species, and potentially also for other species which might have been overlooked in terms of bycatch by traps. There is currently only anecdotal evidence suggesting that there might be very little bycatch in traps, and other studies suggest that there is no bird bycatch at all in (for example) the lobster and crab fisheries in Wales. Since there is no clear evidence-based picture of how much bycatch risk traps pose, and given the high levels of overall effort, it might be appropriate to initially conduct a study (e.g. through literature review and/or interviews with fishers) to obtain a better understanding of seabird bycatch in traps. This could include considerations about different trap types and water depths at which they are set and would helpfully inform if trap fisheries should be monitored directly.

4.4.2 Demersal trawls and seines

While in over 1/3 of rectangles the monitoring effort is well placed, bycatch monitoring of demersal trawls and seines in other areas is less representative of fishing effort. Currently, there are very few records of marine bird bycatch from these gear types, despite this gear group having the largest total amount of monitoring, and improving the monitoring is therefore of relatively low priority. However, there are some monitoring gaps so some marine bird bycatch could have been missed. Monitoring could potentially be improved by increasing efforts on the Scottish east coast and to the west and north of the Outer Hebrides, which will improve the data for estimating bycatch rates for a wider range of species. Although considerations of water depth could focus monitoring effort in areas where marine bird bycatch may occur during towing, this might miss bycatch of marine birds that aggregate around the gear at the surface during hauling.

4.4.3 Gillnets and encircling nets

Due to the limited overlap between gillnets fishing efforts and marine bird hotspots, the distribution of monitoring is currently likely to be sufficiently well placed, apart from small potential under-monitored areas where increased monitoring could be beneficial (e.g. north of Shetland, where fishing effort appears to overlap with high common guillemot densities). However, this is a fishery with known larger bycatch risks and if it is an aim to improve current monitoring efforts, consideration could also be given to increasing monitoring effort (currently at just over 1% of fishing effort) to improve the precision of estimates.

4.4.4 Hooks and lines

The analysis of the hooks and lines fishery has been confounded by the aggregation of quite different gear types in this group, the offshore longline fishery, and the mainly inshore handline fishery. The latter is unlikely to pose a significant risk of marine bird bycatch, so the focus of monitoring efforts should be on the offshore longline fishery. Some improvements to monitoring of longline fishing along the continental shelf edge would be useful, particularly in winter, as this area shows potentially relatively high bycatch rates, and some rectangles are currently under-monitored. The species most frequently bycaught in this fishery in this region is northern fulmar, an amber listed species.

Like with traps, there are only anecdotal reports of bycatch in handline/rod and line fisheries, and there is a general assumption that they do not pose a significant risk. However, given the lack of evidence, an initial basic study (e.g. interviews with fishers) could be useful to establish that there is indeed no significant bycatch risk from handline/rod and line fisheries.

4.4.5 Beam trawls

No recommendation for improvement of beam trawl bycatch monitoring as there is currently no significant known bycatch risk to marine birds.

4.4.6 Pelagic trawls and seines

For guillemots and some other species, increased monitoring efforts particularly to the north of Scotland could be beneficial to improve estimates of bycatch rates.

References

Anderson, O.R.J., Thompson, D. & Parsons, M. 2022. Seabird bycatch mitigation: evidence base for possible UK application and research. *JNCC Report 717*. JNCC, Peterborough, ISSN 0963-8091. https://hub.jncc.gov.uk/assets/dbed3ea2-1c2a-40cf-b0f8-437372f1a036

Benjamins, S., Kulka, D.W. & Lawson, J. 2008. Incidental catch of seabirds in Newfoundland and Labrador gillnet fisheries, 2001–2003. *Endanger. Species Res*. 5, 149–160.

Blackmore, R.J., Winger, P.D., Bitton, P.-P., Bayse, S., Whittaker, K. & Montevecchi, W.A. 2023. The effects of LED handline attachments on Atlantic cod (*Gadus morhua*) catch efficacy and bycatch. *Fish. Res*. 258, 106543.

Bradbury, G., Shackshaft, M., Scott-Hayward, L., Rexstad, E., Miller, D. & Edwards, D. 2017. Risk assessment of seabird bycatch in UK waters. Report to Defra under contract MB0126. 2017.

Bradbury, G., Trinder, M., Furness, B., Banks, A.N., Caldow, R.W.G. & Hume, D. 2014. Mapping Seabird Sensitivity to offshore wind farms. *PLoS ONE* 9. https://doi.org/10.1371/journal.pone.0106366

Burnell, D., Perkins, A.J., Newton, S.F., Bolton, M., Tierney, T.D. & Dunn, T.E. 2023. Seabirds Count: a census of breeding seabirds in Britain and Ireland (2015–2021). Lynx Nature Books, Barcelona, Spain.

Cleasby, I.R., Wilson, L.J., Crawford, R., Owen, E., Rouxel, Y. & Bolton, M. 2022. Assessing bycatch risk from gillnet fisheries for three species of diving seabird in the UK. *Mar. Ecol. Prog. Ser*. 684, 157–179.

DEFRA. 2022. Marine wildlife bycatch mitigation initiative.

Dias, M.P., Martin, R., Pearmain, E.J., Burfield, I.J., Small, C., Phillips, R.A., Yates, O., Lascelles, B., Borboroglu, P.G. & Croxall, J.P. 2019. Threats to seabirds: a global assessment. *Biol. Conserv*. 237, 525–537.

Garthe, S. & Hüppop, O. 1994. Distribution of ship-following seabirds and their utilization of discards in the North Sea in summer. *Mar. Ecol. Prog. Ser*. 1–9.

Glemarec, G., Kindt-Larsen, L., Lundgaard, L.S. & Larsen, F. 2020. Assessing seabird bycatch in gillnet fisheries using electronic monitoring. *Biol. Conserv*. 243, 108461.

Hedd, A., Regular, P.M., Wilhelm, S.I., Rail, J.-F., Drolet, B., Fowler, M., Pekarik, C. & Robertson, G.J., 2016. Characterization of seabird bycatch in eastern Canadian waters, 1998–2011, assessed from onboard fisheries observer data. *Aquat. Conserv. Mar. Freshw. Ecosyst.* 26, 530–548. https://doi.org/10.1002/aqc.2551

ICES. 2013. Report of the Workshop to review and advise on Seabird Bycatch (WKBYCS) 14-18 October 2013, Copenhagen, Denmark. (ICES CM 2013/ACOM No. 77).

ISSCFG. 2016. International Standard Statistical Classification of Fishing Gear.

Kingston, A., Northridge, S., Paxton, C.G.M. & Forti Buratti, J.P. 2023. Improving understanding of Seabird Bycatch in Scottish Longline Fisheries and Exploring Potential Solutions. Scottish Government.

Kirchhoff, K. 1982. Wasservogelverluste durch die Fischerei an der schleswig-holsteinischen Ostseeküste. *Vogelwelt* 103, 81–89.

Li, Y., Jiao, Y. & Browder, J.A. 2016. Assessment of seabird bycatch in the US Atlantic pelagic longline fishery, with an extra exploration on modeling spatial variation. ICES *J. Mar. Sci.* 73, 2687–2694.

Mendel, B., Sonntag, N., Wahl, J., Schwemmer, P., Dries, H., Guse, N., Müller, S. & Garthe, S. 2008. Profiles of seabirds and waterbirds of the German North and Baltic Seas. distribution, ecology and sensitivities to human activities within the marine environment, Naturschutz und Biologische Vielfalt. Bundesamt fuer Naturschutz, Bonn.

Merkel, F.R. 2004. Impact of hunting and gillnet fishery on wintering eiders in Nuuk, Southwest Greenland. *Waterbirds* 27, 469–479.

Miles, J., Parsons, M. & O'Brien, S. 2020. Preliminary assessment of seabird population response to potential bycatch mitigation in the UK-registered fishing fleet (Report prepared for th Department of Environmental Food and Rural Affairs No. Project Code ME6024). Joint Nature Conservation Committee.

Montevecchi, W.A. 2001. Interactions between fisheries and seabirds, in: Biology of Marine Birds. CRC Press, pp. 545–576.

Moore, A.B., Heney, C., Lincoln, H., Colvin, C., Newell, H., Turner, R., McCarthy, I.D. & Hold, N. 2023. Bycatch in northeast Atlantic lobster and crab pot fisheries (Irish Sea, Celtic Sea and Bristol Channel). *Fish. Res*. 265, 106745.

Natural England. 2012a. European shag: species information for marine Special Protection Area consultations [WWW Document]. Nat. Engl. Tech. Inf. Note TIN134. URL https://publications.naturalengland.org.uk/file/3884456 (accessed 7.11.23).

Natural England. 2012b. Great cormorant: species information for marine Special Protectoin Area consultations [WWW Document]. Nat. Engl. Tech. Inf. Note TIN140. URL https://publications.naturalengland.org.uk/file/3897615

Northridge, S., Kingston, A. & Coram, A. 2023. Regional seabird bycatch hotspot analysis *JNCC Report 726*. JNCC, Peterborough, ISSN 0963-8091 https://hub.jncc.gov.uk/assets/a00403c7-6f56-4f38-8b57-b2ab1859c564

Northridge, S., Kingston, A. & Coram, A. 2020. Preliminary estimates of seabird bycatch by UK vessels in UK and adjacent waters (No. Report to DEFRA ME6024).

Oliveira, N., Henriques, A., Miodonski, J., Pereira, J., Marujo, D., Almeida, A., Barros, N., Andrade, J., Marçalo, A. & Santos, J. 2015. Seabird bycatch in Portuguese mainland coastal fisheries: An assessment through on-board observations and fishermen interviews. *Glob. Ecol. Conserv*. 3, 51–61.

Pierce, G.J., Dyson, J., Kelly, E., Eggleton, J.D., Whomersley, P., Young, I.A., Santos, M.B., Wang, J. & Spencer, N.J. 2002. Results of a short study on by-catches and discards in pelagic fisheries in Scotland (UK). *Aquat. Living Resour*. 15, 327–334.

Pott, C. & Wiedenfeld, D.A. 2017. Information gaps limit our understanding of seabird bycatch in global fisheries. *Biol. Conserv*. 210, 192–204. https://doi.org/10.1016/j.biocon.2017.04.002

Schirmeister, B. 2003. Verluste von Wasservögeln in Stellnetzen der Küstenfischerei–das Beispiel der Insel Usedom. *Meer Mus*. 17, 160–166.

Stanbury, A., Eaton, M., Aebischer, N., Balmer, D., Brown, A., Douse, A., Lindley, P., McCulloch, N., Noble, D. & Win, I. 2021. The status of our bird populations: the fifth Birds of Conservation Concern in the United Kingdom, Channel Islands and Isle of Man and second IUCN Red List assessment of extinction risk for Great Britain. *Br. Birds* 114, 723–747.

Sullivan, B.J., Reid, T.A. & Bugoni, L. 2006. Seabird mortality on factory trawlers in the Falkland Islands and beyond. *Biol. Conserv*. 131, 495–504.

Waggitt, J.J., Evans, P.G., Andrade, J., Banks, A.N., Boisseau, O., Bolton, M., Bradbury, G., Brereton, T., Camphuysen, C.J. & Durinck, J. 2020. Distribution maps of cetacean and seabird populations in the North-East Atlantic. *J. Appl. Ecol*. 57, 253–269.

Watkins, B.P., Petersen, S.L. & Ryan, P.G. 2008. Interactions between seabirds and deep-water hake trawl gear: an assessment of impacts in South African waters. *Anim. Conserv*. 11, 247–254.

Webb, T., Bartlein, P.J. & Kutzbach, J.E. 1987. Climatic change in eastern North America during the past 18,000 years; comparisons of pollen data with model results.

Young, L. & VanderWerf, E. 2022. Conservation of Marine Birds. Academic Press.

Zydelis, R., Small, C. & French, G. 2013. The incidental catch of seabirds in gillnet fisheries: a global review. Biol. Conserv. 162, 76–88.

5 Appendix 1: Supplementary materials

5.1 Redaction of fishing effort and monitoring effort data

Details of the assessment of the necessary redaction of data has been provided by MD.

Table 16. Total fishing effort, measured in days at sea, and percentage of fishing effort, shared and redacted, over the 10-year time period.

	Days At Sea	Percent Effort
Shared	4,379,205.03	98.58
Redacted	63,113.64	1.42

Table 17. Total fishing effort, measured in days at sea, and percentage of fishing effort, shared and redacted, by gear category, over the 10-year time period.

Gear type	Days At Sea Shared	Days At Sea Redacted	Percent Shared	Percent Redacted
Beam trawls	129,593.4	3,137.04	97.64	2.36
Demersal trawls & seines	1,005,261.83	7,603.98	99.25	0.75
Dredges	334,798.87	2,011.77	99.40	0.60
Gillnets & encircling nets	319,178.05	12,529.03	96.22	3.78
Hooks & lines	220,671.99	6,348.66	97.20	2.80
Miscellaneous	218,065.63	6,949.46	96.91	3.09
Pelagic trawls & seines	24889.08	4079.11	85.92	14.08
Traps	2126746.19	20454.6	99.05	0.95

Table 18. Total fishing effort, measured in days at sea, and percentage of fishing effort, shared and redacted, by season, over the 10-year time period.

Season	Days At Sea Shared	Days At Sea Redacted	Percent Shared	Percent Redacted
Summer	2,550,556.29	34,235.38	98.68	1.32
Winter	1,828,648.74	28,878.26	98.45	1.55

Table 19. Total fishing effort, measured in days at sea, and percentage of fishing effort, shared and redacted, by area, over the 10-year time period.

	Days At Sea Shared	Days At Sea Redacted	Percent Shared	Percent Redacted
27.1	-	1,970.29	-	100.00
27.10	-	880.66	-	100.00
27.12	-	16.61	-	100.00
27.14.b	-	279.42	-	100.00
27.2.a	374.69	1,878.88	16.63	83.37

	Days At Sea Shared	Days At Sea Redacted	Percent Shared	Percent Redacted
27.2.b	73.97	1,556.67	4.54	95.46
27.3.a	-	20.17	-	100.00
27.4.a	784,257.86	6,359.76	99.2	0.8
27.4.b	735,074.75	10,746.65	98.56	1.44
27.4.c	157,147.65	2,989.12	98.13	1.87
27.5.b	829.98	503.88	62.22	37.78
27.6.a	1,039,584.98	12,492.40	98.81	1.19
27.6.b	10,444.94	3,274.28	76.13	23.87
27.7.a	508,851.25	3,609.15	99.30	0.70
27.7.b	3,248.17	1,227.36	72.58	27.42
27.7.c	6,059.58	1,403.64	81.19	18.81
27.7.d	346,580.00	1,112.48	99.68	0.32
27.7.e	517,319.52	1,967.50	99.62	0.38
27.7.f	175,826.61	693.67	99.61	0.39
27.7.g	39,867.12	698.19	98.28	1.72
27.7.h	20,928.44	2,057.09	91.05	8.95
27.7.j	25,934.61	2,311.58	91.82	8.18
27.7.k	6,758.94	1,645.75	80.42	19.58
27.8.a	41.96	1,582.13	2.58	97.42
27.8.b	-	350.67	-	100.00
27.8.c	-	24.14	-	100.00
27.8.d	-	1,074.85	-	100.00
27.8.e	-	383.87	-	100.00
27.9.a	-	2.80	-	100.00

Table 20. Total monitoring effort, measured in days at sea, and percentage of monitoring effort, shared and redacted, by gear category, over the 10-year time period.

Gear type	Days At Sea Shared	Days At Sea Redacted	Percent Shared	Percent Redacted
Beam trawls	1,458.40	1.9	99.87	0.13
Demersal trawls & seines	6,833.03	34.46	99.50	0.50
Dredges	151.00	0	100.00	0
Gillnets & encircling nets	3,712.02	122.12	96.82	3.18
Hooks & lines	210.45	15.55	93.12	6.88
Miscellaneous	6.00	0	100.00	0
Pelagic trawls & seines	600.89	86.19	87.46	12.54
Traps	7.87	0	100.00	0

5.2 Entrapment risk scores

Table 21. Entrapment risk scores from Bradbury *et al.* (2017), Table 6. Each species was assigned three scores for the entrapment risk, depending on the depth of gear in the water column. Provided are the descriptions of the scores and the number of species which were assigned a given score.

Vulnerability	Score				
	1	2	3	4	5
Surface Entrapment Risk	Species that scavenge or feed at the surface without any diving. No relevant evidence of bycatch	Surface/sub-surface feeders that may submerge to retrieve prey but are not pursuit feeders. No relevant evidence of bycatch	Diving species without relevant evidence of bycatch	Species (surface feeding or diving) with limited evidence of bycatch (e.g. from similar species, or very rare events)	Species (surface feeding or diving) known to be affected by bycatch
Number of species*	2	25	5	20	9
Pelagic (midwater) Entrapment Risk	Species that scavenge or feed at the surface without any diving. No relevant evidence of bycatch	Surface/sub-surface feeders that may submerge to retrieve prey but are not pursuit feeders. No relevant	Benthic feeders that may pass through pelagic zone and species generally restricted to shallow water. No relevant	Typically, benthic feeders which occasionally forage on pelagic prey. Limited evidence of bycatch	Birds which rely solely on pelagic prey, are active throughout the water column and have relevant

Vulnerability	**Score**				
	1	**2**	**3**	**4**	**5**
		evidence of bycatch	evidence of bycatch		evidence of bycatch
Number of species*	22	16	1	17	5
Benthic Entrapment Risk	Species that scavenge or feed at the surface without any diving. No relevant evidence of bycatch	Shallow divers which may enter the pelagic zone but not found at deeper depths. No relevant evidence of bycatch	Species which may reach the seabed through foraging. No relevant evidence of bycatch	Species which may switch to benthic prey and have deeper dive depths. May also have limited evidence of bycatch	Birds that forage almost exclusively on benthic prey. May also have specific evidence of bycatch
Number of species*	33	5	3	12	8

* final numbers following expert consensus

Table 22. Entrapment risk scores assigned by Bradbury *et al.* (2017).

Species	**Surface risk**	**Pelagic risk**	**Benthic risk**
Arctic skua	2	1	1
Arctic tern	2	2	1
Atlantic puffin	5	5	4
Balearic shearwater	4	2	2
Black guillemot	5	4	4
Black tern	2	2	1
Black-headed gull	2	1	1
Black-legged kittiwake	3	1	1
Black-throated diver	4	4	4
Common eider	4	4	5
Common goldeneye	4	4	4
Common guillemot	5	5	4
Common gull	2	1	1
Common scoter	4	4	5
Common tern	2	2	1
Cory’s shearwater	4	2	2
European storm-petrel	2	2	1
Glaucous gull	3	1	1

Species	Surface risk	Pelagic risk	Benthic risk
Goosander	4	4	4
Great black-backed gull	3	1	1
Great cormorant	5	4	5
Great northern diver	4	4	4
Great shearwater	4	2	2
Great skua	3	1	1
Great-crested grebe	4	4	3
Greater scaup	4	4	5
Grey phalarope	1	1	1
Herring gull	2	1	1
Iceland gull	2	1	1
Leach’s storm-petrel	2	2	1
Lesser black-backed gull	2	1	1
Little auk	4	5	4
Little gull	2	1	1
Little tern	2	2	1
Long-tailed duck	4	4	5
Long-tailed skua	2	1	1
Manx shearwater	4	2	2
Mediterranean gull	2	1	1
Northern fulmar	5	2	1
Northern gannet	5	3	3
Pomarine skua	2	1	1
Razorbill	5	5	4
Red-breasted merganser	4	4	4
Red-necked phalarope	1	1	1
Red-throated diver	4	4	4
Roseate tern	2	2	1
Sabine’s gull	2	1	1
Sandwich tern	2	2	1
Shag	5	4	5
Slavonian grebe	4	4	3
Sooty shearwater	4	2	2
Velvet scoter	4	4	5
White-billed diver	4	5	4

Species	Surface risk	Pelagic risk	Benthic risk
Wilson's storm-petrel	2	2	1

5.3 Additional maps

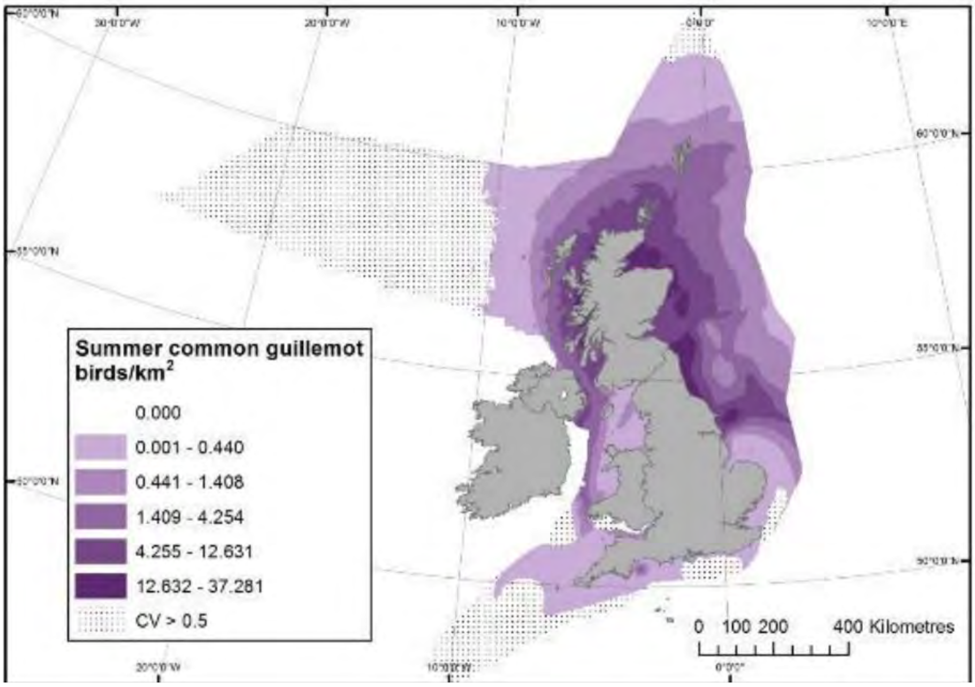

Figure 25. Common guillemot density distribution in summer (April to September), as published by Bradbury *et al.* (2017).

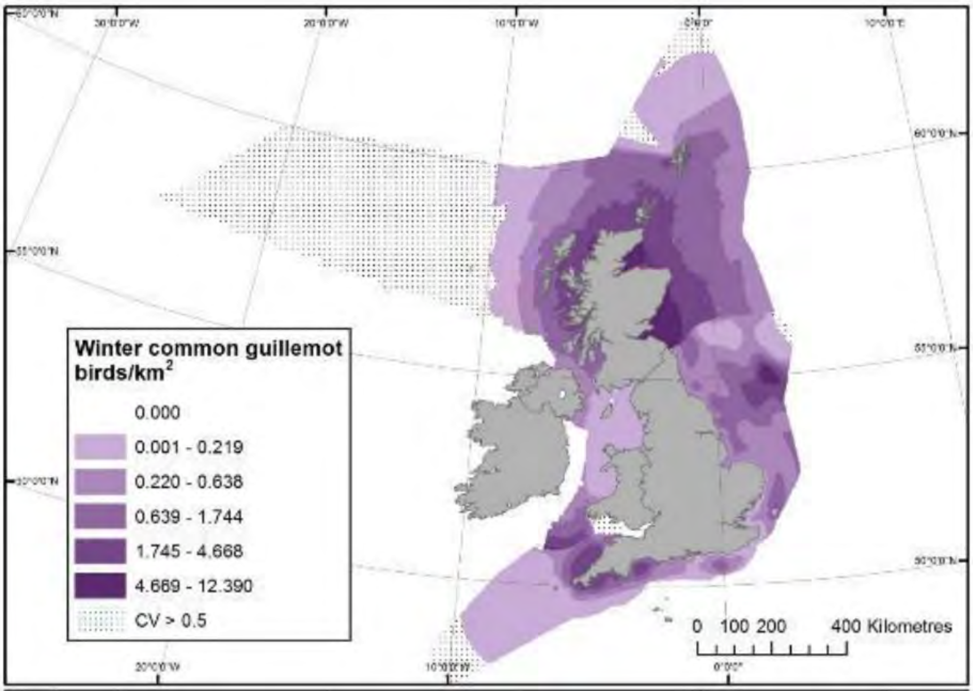

Figure 26. Common guillemot density distribution in winter (October to March), as published by Bradbury *et al.* (2017).

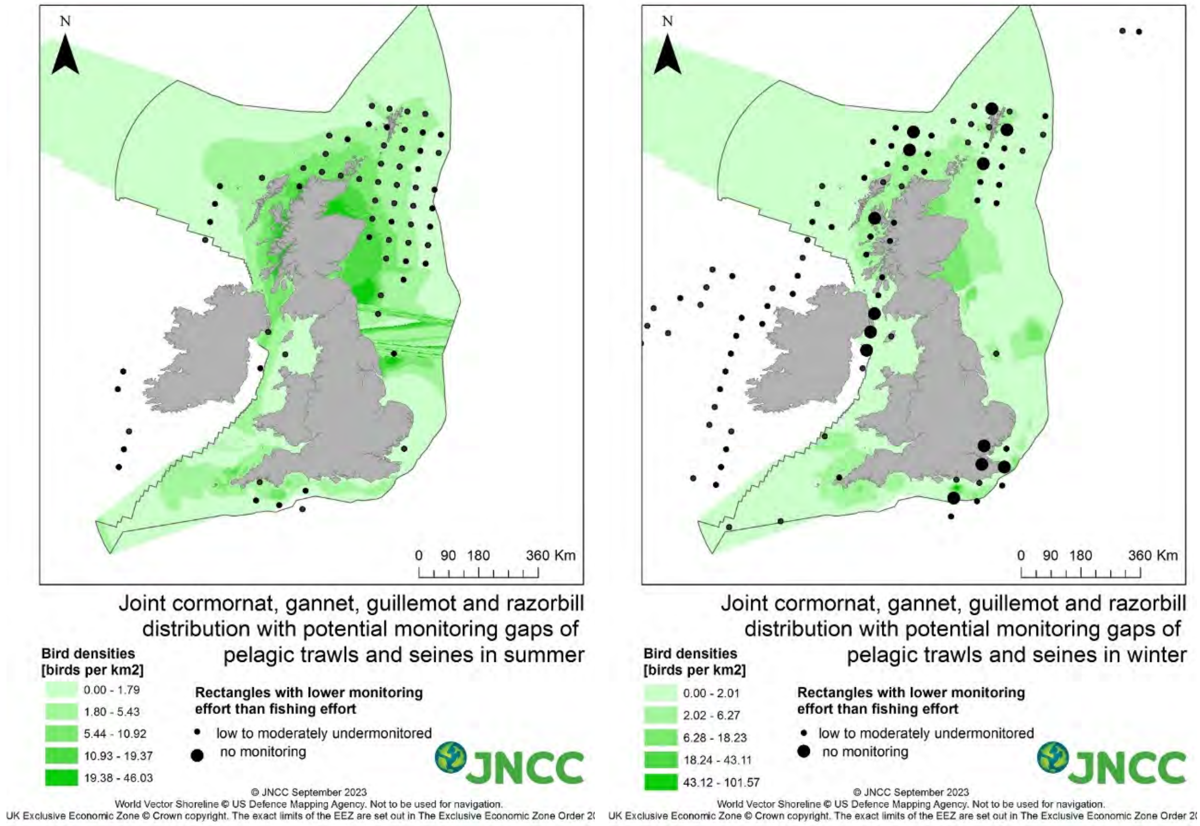

Figure 27. Joint common guillemot, northern gannet, great cormorant, and razorbill distribution in summer (left) and winter (right), with the potential monitoring gaps for pelagic trawls and seines. 'Low and moderately under-monitored' refers to areas with monitoring effort one or two PCC categories lower than the fishing effort.