Preliminary estimates of seabird bycatch by UK vessels in UK and adjacent waters.

Final Report to JNCC – Revised October 2020

Simon Northridge, Al Kingston and Alex Coram
Scottish Ocean Institute, University of St Andrews.

Summary

This report presents preliminary estimates of seabird bycatch mortality in three UK fishery sectors. As is normal with most bycatch estimation procedures, total annual bycatch is estimated by extrapolating actual recorded observations from a relatively small proportion (a sample) of observed fishing effort to the full fishing fleet level. The fisheries covered are static net (gillnet) fisheries around the UK, the offshore longline fishery (mainly for hake) and the midwater trawl fishery in the English Channel. The report does not address non-UK vessels fishing in the same area, so the mortality estimates presented here should be viewed as one component of total mortality from the areas and gear types under consideration.

These preliminary estimates are based on over 21000 monitored fishing operations (hauls) carried out under the UK Bycatch Monitoring Programme since 1997, on UK vessels. Annual sampling coverage under the BMP has been <1% of total annual UK static net effort, 1-2% of annual UK longline effort and roughly 5% of annual UK midwater trawl effort. A minimum of ten seabird species were recorded since 1997, totalling 587 individuals during that period. The most frequently recorded species were guillemots (in gillnet and midwater trawl fisheries) and fulmars (in longline fisheries).

Preliminary estimates are provided for 2016 and 2017 based on official fishing effort statistics for those years, and by geographical strata: northern and southern longline fishing strata, coastal and offshore static net strata and a midwater trawl stratum for the English Channel. Estimates are also provided by the relevant regions of the Marine Strategy Framework Directive (MSFD).

Preliminary estimates of overall fulmar bycatch in the offshore longline fishery are very imprecise and could lie between 2200 and 9100 per annum. Estimates for guillemots may lie between 1800 and 3300 per annum, mainly from static net fisheries. Most other seabird species caught in the fisheries included in this analysis are likely taken in the dozens per year, except for cormorants and gannets, which may number in the hundreds.

The estimates relate to fishing effort by UK registered vessels only, though vessels from other nations are known to operate in at least some of the strata considered. We do not have access to foreign vessel fishing effort data or their operational characteristics. These estimates must be considered preliminary as some are derived from very small samples sizes, and potential sampling biases have not been addressed.

Introduction

In July 2018 the UK Department for the Environment, Food and Rural Affairs (Defra) asked the Joint Nature Conservation Committee (JNCC) to develop a UK marine bird bycatch Plan of Action (PoA) to: "*Deliver a coherent approach to understand and where necessary reduce marine bird bycatch in UK fisheries, through engagement and dialogue with all interested parties and the implementation of subsequent recommendations*". Stemming from that request and subsequent developments in the PoA, the work described in this report was commissioned at the end of 2018 by the JNCC and provides an initial assessment of the likely scale of seabird bycatch in certain broad gear types by UK vessels in UK and adjacent waters. This assessment does not consider bird bycatch by non-UK fleets operating in UK or adjacent waters (though effort by those fleets is known to be significant in some areas) mainly because data on bird bycatch rates in those fleets are either unavailable or considered unreliable. However, international efforts (via ICES and OSPAR) are beginning to assess bycatch levels and possible population impacts from all fishing fleets operating in NE Atlantic waters.

This preliminary assessment is based on data collected solely under the UK Bycatch Monitoring Programme (BMP) which is an at-sea observer data collection programme focussed on quantifying protected species bycatch. The BMP is managed by the Sea Mammal Research Unit (SMRU), part of the Scottish Oceans Institute at the University of St Andrews. Other fishery-dependent data collection programmes operate in the UK, but those other programmes have historically had the primary focus of quantifying commercial fish species discard rates, mainly in demersal trawl fisheries. Sampling designs (i.e. metier[1] selection) and on-deck data collection protocols within those programmes are not optimised for monitoring protected species bycatch and data from those programmes have been shown to be inadequate for quantifying marine mammal bycatch (ICES 2016). Consequently, data from those programmes have not been included in this preliminary analysis but will be considered in future, with the knowledge that data collection protocols in those programmes have been upgraded in recent years.

Under the BMP trained fisheries observers have been placed on board UK fishing vessels since 1996 to collect operational, environmental and catch/bycatch data, in order to estimate bycatch rates of a variety of protected species. Initially the main focus of the programme was on small cetacean bycatch, but observers were asked to record details of all species in the catch, including other marine mammals, protected elasmobranchs and seabirds.

Sampling between 1996 and 2004 was generally focussed in a few specific static net and midwater trawl fisheries with known or expected small cetacean bycatch. In 2005 sampling under the programme was broadened to include a wider range of static net and midwater trawl fisheries as required by EU Regulation 812/2004, and further sampling was also conducted to meet the monitoring requirements of Article 12 of the Habitats Directive and international agreements including the Agreement on the Conservation of Small Cetaceans in the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS), the International Convention on the Regulation of Whaling (ICRW) and the Oslo and Paris Conventions (OSPAR). More recently, since 2010, sampling efforts have been expanded to include longline and ring net fisheries since 2018, with the explicit purpose of quantifying seabird bycatch rates in those particular gear types.

The Marine Strategy Framework Directive (MSFD – Directive 2008/56/EC) and related European Commission Decisions and the recent adoption of the EU Plan of Action for reducing incidental bycatch of seabirds in fishing gears (EU-PoA: COM/2012/0665 final) now provide a firm context for seabird bycatch assessment. Although seabird bycatch data have been collected for many years under the BMP, to date no synoptic overview or assessment has been conducted. This report is the first attempt to do so, and as such it presents a basic overview and analysis of the existing data, which may be subject to some substantial biases that are discussed later. It is intended to provide initial estimates of the possible scale of seabird bycatch to help inform and direct future monitoring needed to fill any significant gaps in knowledge, reduce uncertainty associated with bycatch or help in the development of suitable mitigation approaches where appropriate. However, it is important to recognise that bycatch mortality is likely to be just one of several sources of anthropogenic mortality affecting seabird populations.

Currently the BMP focuses on three main gear types: static net (or gillnet) fisheries, midwater (or pelagic) trawl fisheries and longline fisheries. Figure 1 shows the distribution of monitored hauls since the programme began in 1996 by broad gear type. The BMP has also collected data from other

[1] Metier is a widely used term in fisheries science to identify fishery sectors, usually defined by their operational characteristics, and is derived from the French word métier - an occupation, trade, or profession.

gear types, including demersal trawls, ring nets and pots, but these are not included in this analysis due to relatively low observation levels to date.

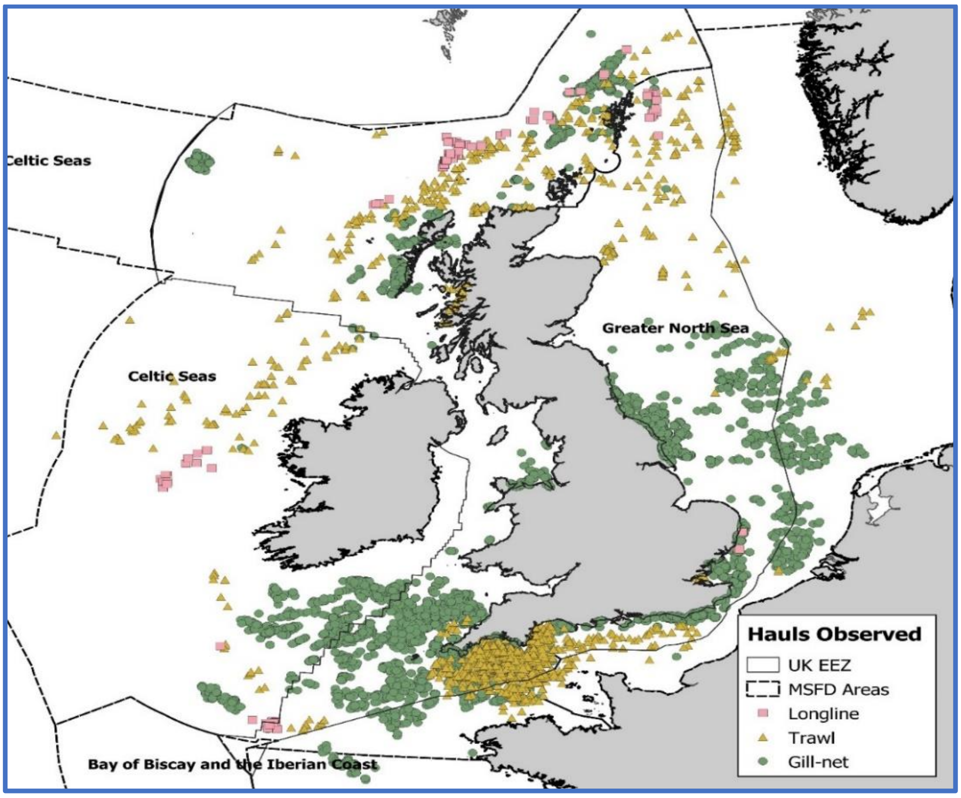


Figure 1: *Geographical distribution of sampled hauls under the BMP since 1996 by main gear type.*

To date the BMP has collected data from over 21,000 monitored fishing operations from all around the UK and adjacent waters, on vessels ranging from less than 5 m to over 70 m in length. Table 1 summarises this sampling effort by relevant gears in terms of number of hauls, days at sea and trips.

Table 1: Overview of sampling effort 1996 to 2018.

Gear type	Hauls	Days at sea	Trips	Mean hauls per day at sea
Static net	18916	4885	2842	3.87
Midwater trawl	2239	1848	597	1.21
Longline	103	122	16	0.87
Totals	21261	6855	3455	

The cumulative number of total monitored hauls by year and ICES Subarea is shown in Figure 2 and provides a visual representation of how sampling distribution under the BMP has evolved over the life of the programme. Up to 2006 most sampling had occurred in the North Sea (Subarea 4) but since 2006 sampling levels have been higher in the Celtic Sea (Subarea 7 - including English Channel). Across the programme's duration, low levels of sampling have been conducted in the West of Scotland (Subarea 6) mainly due to relatively low levels of static net effort in this area. Small amounts of sampling in Subareas 2 (Norwegian Sea) and 8 (Biscay) are not presented.

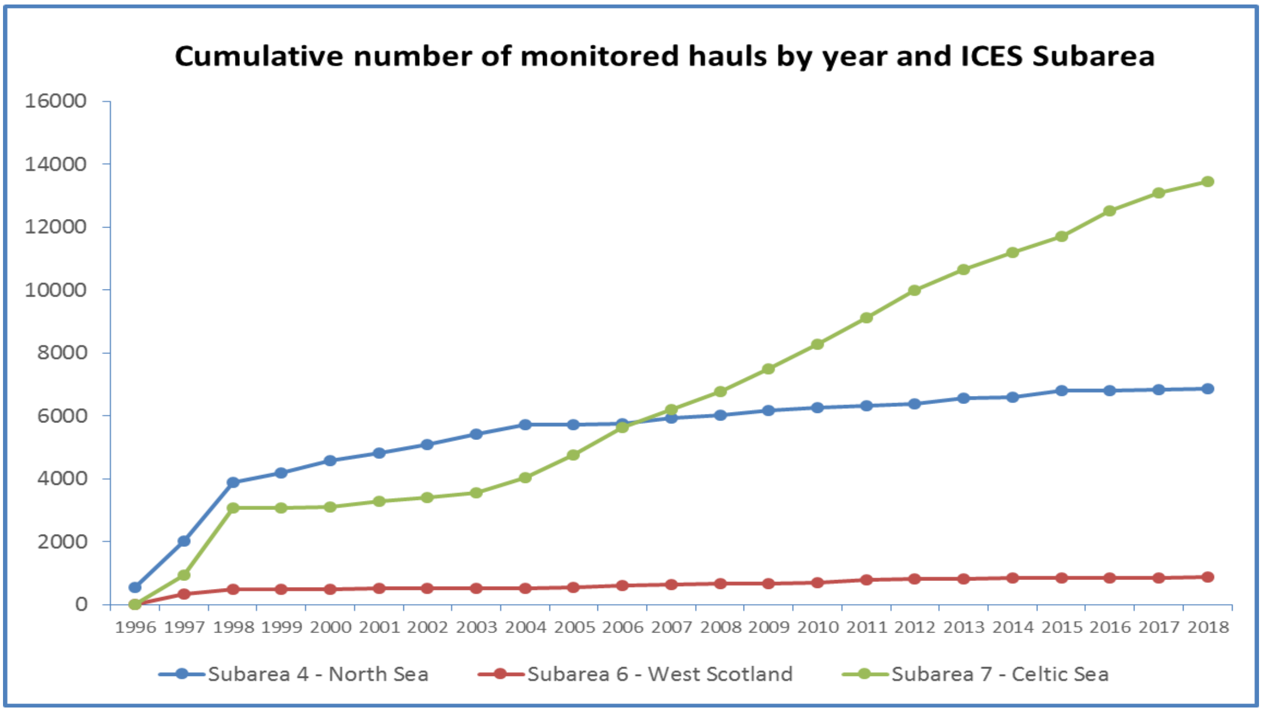


Figure 2: *Cumulative number of hauls monitored by year and ICES Subarea.*

Methods

BMP data preparation

All data collected under the BMP are held in a central database. Initial data extractions were made by gear type and then a significant manual data cleaning and preparation process was undertaken to ensure data entry formats were compatible and any missing records were identified and where possible cross-checked. Validation checks were then carried out to highlight any unusual records that may result simply from data entry errors. In some fisheries, where hauling occurs over extended periods, hauls may not be fully sampled but observers provide an estimate of observation coverage. We have used this estimated coverage level to raise observed bycatch numbers in partial haul observations to the full haul level in those instances. A single cleaned and checked data table per gear type was produced containing haul level information for multiple parameters including area, season, vessel size, target species, gear type and seabird bycatch numbers by species.

Seabird data summary

Ten different seabird species were identified in the sampling effort detailed in Table 1. A few bycaught individuals (all gulls) could not be positively identified to species level, and for the purposes of this analysis are classed collectively as 'gull sp.' Table 2 lists the species recorded by gear type.

At least four species were reported bycaught in offshore longline fisheries but over 90% of these observations were of fulmars. The majority of seabirds (all species combined) recorded bycaught in longline fisheries were dead and are likely to have been caught during line setting operations. A small proportion (circa 4%) were classed as live bycatch, caught during hauling and released. We do not have an estimate for post capture survival so have included all bycaught individuals (live and dead) in the mortality estimates for now.

Table 2: Number of seabirds recorded by gear type.

Species reported	Static net	Midwater trawl	Longline
Cormorant	40	2	
Fulmar	11		176
Gannet	15		9
Great black-backed gull			2
Great northern diver	1		
Guillemot	267	27	
Gull sp.	10		2
Herring gull	4		
Kittiwake			1
Razorbill	12	3	
Shag	5		

Midwater trawling was associated with reported bycatch of three species of diving birds, namely guillemot, razorbill and cormorant. Approximately 85% of recorded bycatch from midwater trawls was of guillemots.

The highest species diversity was associated with static nets (with at least eight species recorded). Guillemots account for roughly 75% of bycatch observations in static net fisheries. Figures 3-7 below show the recorded locations of observed seabird bycatch by species and gear type.

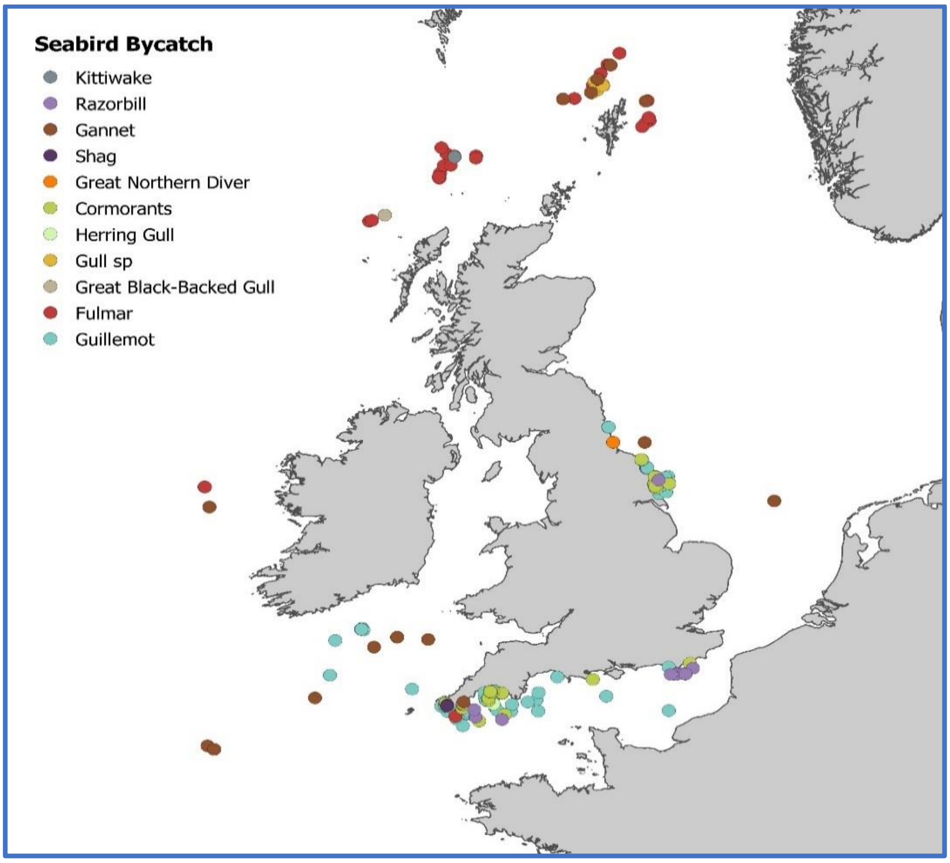


Figure 3: *Observed bycatch by species 1996 to 2018 – all gears.*

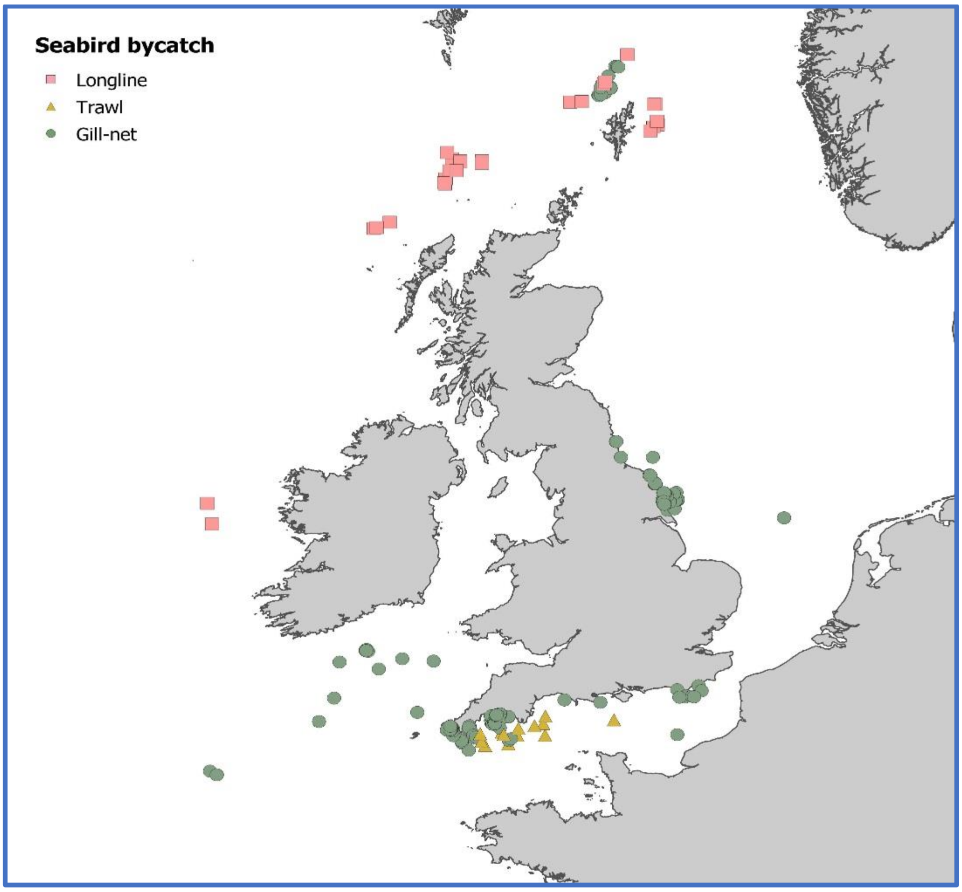


Figure 4: *Observed bycatch by gear type 1996 to 2018 – all species.*

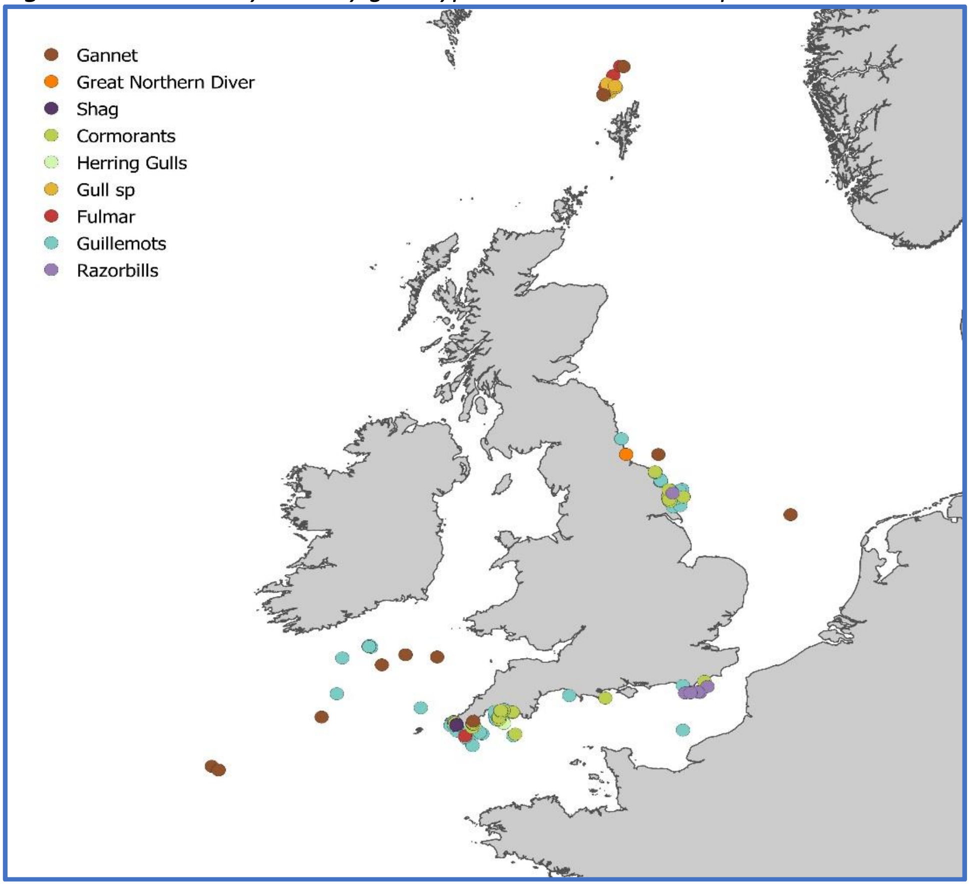


Figure 5: *Observed static net bycatch by species 1996 to 2018.*

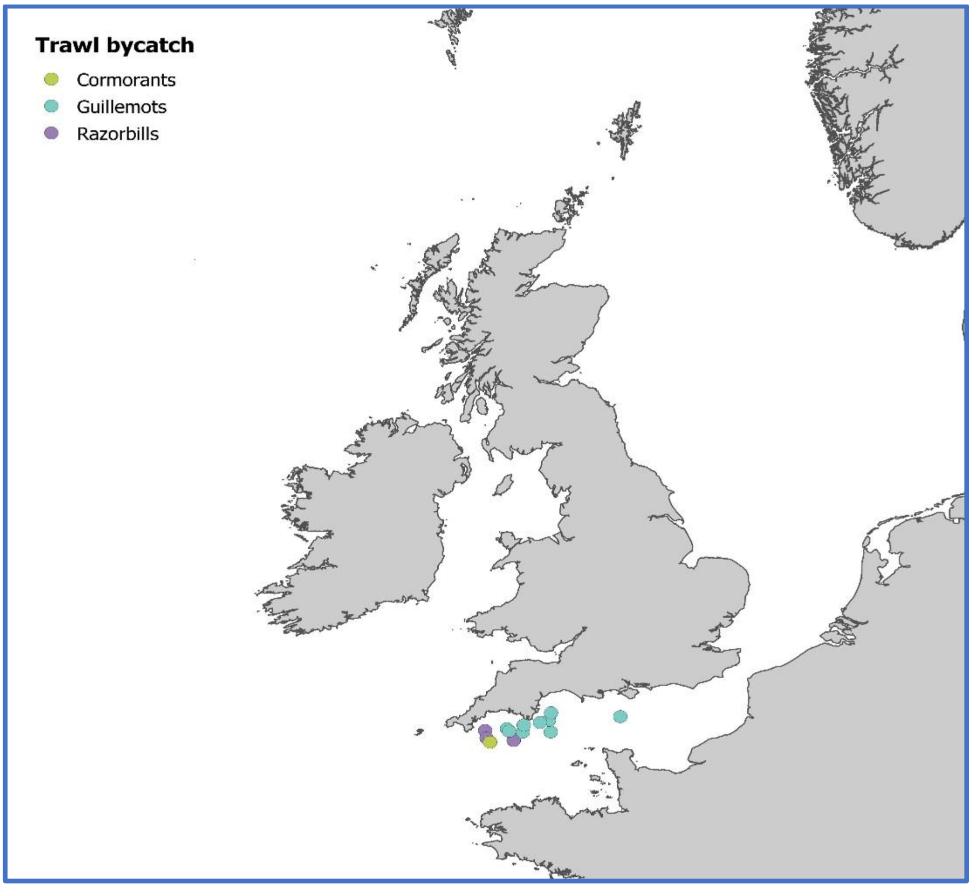


Figure 6: *Observed midwater trawl bycatch by species 1999 to 2018.*

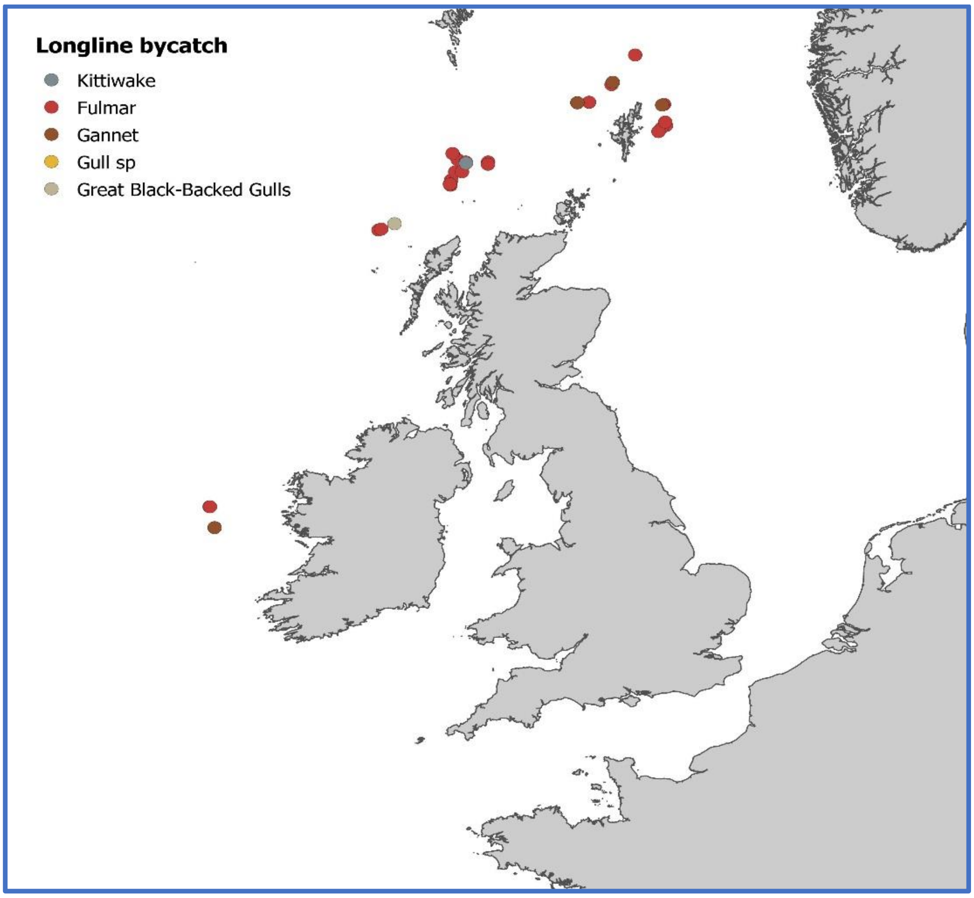


Figure 7: *Observed longline bycatch by species 2010 to 2018.*

Stratifying bycatch estimates

Stratification is a commonly used method in bycatch estimation and is used to aggregate sampled units of fishing effort (typically hauls) and total fishing effort statistics into appropriate groupings based on known or perceived operational or bycatch rate similarities. Under-stratifying (too few strata) can mean that fisheries with very different characteristics are grouped and the potentially important distinction between them is lost in subsequent mortality estimations, leading to a loss of precision in estimates. Over-stratifying (too many strata) means that fisheries with no observed bycatch (either because sampling rates or bycatch rates are low) will fall out of subsequent mortality estimations and will thus affect the overall estimates, leading to potential biases.

Prior to generating mortality estimates we undertook some preliminary exploratory analysis of the BMP data to identify any obvious strata with similar species-specific bycatch rates within each broad gear type. We have not done this formally due to time constraints and because there are bycatch records for less than 600 individual seabirds of just ten confirmed species, meaning for most species/gear combinations there are simply too few records as yet to determine robust fine scale strata from which to extrapolate total mortality estimates. Given these two constraints we have kept the number of strata to a meaningful minimum.

Within the static net dataset there was a weak suggestion that there may be a seasonal component to the bycatch rates of some species (cormorant, gannet, guillemot and razorbill), with slightly higher observed bycatch rates during the winter months. However, it is not clear what factor/s is driving this or even if this is a true reflection of a seasonal pattern in bycatch rates. A more detailed statistical analysis, which is beyond the scope of this work, would be required to address this. Sample sizes are small and group sizes among observed bycatch events are quite variable and indicate non-independence of bycaught individuals in some circumstances, which also confounds the interpretation. The operational characteristics (net lengths, soak times etc.) and patterns of effort in static net fisheries are also subject to subtle fluctuations driven by environmental factors (prevailing weather, tides etc.) and target species catch rates, so any seasonal pattern in seabird bycatch rates could be driven by underlying fishery related factors rather than seasonal variation associated with bird density or behaviour. Consequently, for now we assume no seasonal differences in seabird bycatch rates and generate preliminary mortality estimates without any seasonal stratification.

There is more convincing evidence in the static net data of differences in seabird bycatch rates observed between coastal (i.e. vessels under 10 m) and offshore vessels (vessels over 10 m). These are shown by species in Table 3.

Table 3: Seabird bycatch from 1996 to 2018 by gillnet vessel size category (LOA= Length overall).

Seabirds in gillnet fisheries	**Number recorded**		**Bycatch rate (per 1000 hauls)**	
	Over 10 m LOA	**Under 10 m LOA**	**Over 10 m LOA**	**Under 10 m LOA**
No of observed hauls	7110	11806		
Cormorant	6	34	0.84	2.88
Fulmar	11	0	1.55	0.00
Gannet	13	2	1.83	0.17
Great Northern Diver	0	1	0.00	0.08
Guillemot	30	237	4.22	20.07
Herring Gull	1	3	0.14	0.25
Razorbill	0	12	0.00	1.02
Gull Spp.	10	0	1.41	0.00
Shag	0	5	0.00	0.42

Bycatch rates of gannets and fulmars appear to be higher from vessels of over 10 m in length (which typically work further offshore), while bycatch rates of guillemots, cormorants, razorbills and shags appear to be higher from vessels under 10 m which typically work within territorial waters. Consequently, there is some justification (but as yet poorly explored) to stratify seabird bycatch in static net fisheries between under and over 10 m vessels. However, it would be useful to explore other associated parameters better to understand the reasons for this apparent difference before forming firm conclusions.

Within the BMP midwater trawl dataset there appear to be strong seasonal and area effects. All seabird bycatch observations came from midwater trawl fisheries targeting bass and sprat generally in relatively coastal waters in the English Channel. These two fisheries operate during the autumn to spring period but the bass fishery in the Channel is no longer active due to management measures aimed at protecting spawning aggregations of bass. The majority of bycatches reported from these fisheries occurred during the core winter months, which may reflect the fact that alcids are more abundant in the Channel in winter where these fisheries operate, while cormorants are more abundant in coastal areas generally. UK vessels operating in the bass fishery generally worked with the trawl headline in close proximity to the surface, which can cause disturbance and may encourage alcids and cormorants to dive as the trawl approaches which may also lead to higher bycatch rates than fisheries where the gear is towed well below the surface.

Another important point is that the relatively small midwater trawl vessels (10-30 m) that operate in the bass and sprat fisheries in the English Channel typically sort their catch on deck, while larger midwater vessels (50-70 m) that target mainly mackerel and herring in offshore waters to the north and west of the UK normally pump their catch directly from the codend into refrigerated seawater tanks. This means that bycatch occurrences may be less apparent to observers on those larger boats. This may lead to biases in reporting efficiency on these larger vessels. Consequently, for expedience, here we assume that seabird bycatch data from the larger vessels may be compromised, and we restrict our estimates, based on bycatch rates calculated from observations in ICES Divisions 7d and 7e, to the “small” vessel midwater trawl fisheries operating in the English Channel and southern North Sea (ICES Divisions 7de & 4c).

Among the records of seabird bycatch collected from longline fisheries, two distinctions can be made. Firstly, we note that there are at least two different longline fisheries operating around the UK. One fishery involves large vessels (over 20 m) fishing offshore in the northern North Sea (4a) and western waters (mainly 6a,7bcj) targeting mainly hake, while a much smaller fishery (based on fishing effort statistics) by coastal or under 10 m vessels also operates in the English Channel and North Sea targeting various species including cod and ray. We have made most observations in the former fishery (>100 hauls) but have only monitored three hauls to date in the coastal fishery, so confine our estimates of seabird bycatch to the offshore longline fleet. The number of days at sea longlining by the coastal fleet is only about 10% of that of the offshore fleet and gear usage per day at sea (in terms of line lengths/number of hooks) is also much lower. We also note that there appears to be a latitudinal gradation in seabird bycatch within the offshore fishery, with lower observed rates in ICES Divisions 7abcfhjk (‘Southern region’) and higher observed rates in 4a and 6a (‘Northern region’). This provides reasonable justification for stratifying the offshore longline observer and fleet effort data, and the calculation of subsequent bycatch estimates, into two broad geographic regions. It is also worth noting that based on observer data collected to date, seabird mitigation measures (tori lines, offal disposal routines) appear to be used fairly routinely which are likely to reduce bycatch rates below unmitigated levels and for this analysis we assume that observed usage of such measures is representative of the wider UK fleet.

For this preliminary assessment, based on the exploratory findings described above, where we allow the existing data to form the stratification approach, we have used the following initial primary strata for the production of bycatch estimates:

1) **Static nets**:
   (A) All one fleet.
   (B) Two strata by vessel size category: over and under 10 m (as a reasonable proxy for 'offshore' and 'coastal' activity respectively).

2) **Midwater trawls:**
   (A) Midwater trawlers working in the English Channel and southern North Sea.

3) **Longlines:** Exclude small vessels, then:
   (A) All one fleet.
   (B) Two strata - Northern / Southern regions.

Although these seven strata were the most obvious based on the available data, there was also a policy need to estimate bird bycatch according to the marine regions described under the Marine Strategy Framework Directive (MSFD)[2]. We have therefore also included a second analytical step by further stratifying the data by the two MSFD regions covering UK waters – the Celtic Seas and the Greater North Sea. Those estimates are presented in Annex 2.

Extrapolations using fishing effort

Data used to calculate bycatch rates are collected on the basis of the number of seabirds per observed fishing operation or haul under the BMP. However, the number of hauls is generally not reported within official vessel logbooks for over 10 m vessels, or within sales notes: all that is available from logbooks and sales note data are the number of days at sea. Therefore, the number of hauls in the wider, non-observed, fleet needs to be estimated from the number of hauls per day recorded by the observers. The number of days at sea is recorded by the Marine Management Organisation (MMO)/Marine Scotland for each trip, by area and gear type, for all UK registered vessels. That means we can summarise the amount of fishing effort by the UK fleet in terms of the strata described previously, and also by the total estimated number of hauls by stratum calculated using the observer data. We have used fishing effort data from two years 2016 and 2017 (the most recent years data available), to help illustrate possible inter-annual fluctuations in bycatch levels associated with changes in fishing effort. These data are shown in Table 4.

[2] https://water.europa.eu/marine/regions

Table 4: 2016 and 2017 fishing effort for UK fleet by stratum.

Gear Type	Year	Strata	Reported days at sea UK fleet	Observed average hauls per day	Estimated no of hauls
Fixed nets	2016	ALL	33581	4.39	147424
Fixed nets	2017	ALL	29087	4.39	127720
Fixed nets	2016	> 10 m	5661	3.49	19732
Fixed nets	2016	< 10 m	27920	4.57	127692
Fixed nets	2017	> 10 m	4881	3.49	17014
Fixed nets	2017	< 10 m	24206	4.57	110706
Midwater trawls	2016	7de, 4c	550	1.47	809
Midwater trawls	2017	7de, 4c	540	1.47	794
Longlines - hake-ling	2016	ALL	3273	0.86	2815
Longlines - hake-ling	2017	ALL	3602	0.86	3098
Longlines - hake-ling	2016	4a/6a	2232	0.86	1920
Longlines - hake-ling	2016	7	1041	0.86	895
Longlines - hake-ling	2017	4a/6a	2673	0.86	2298
Longlines - hake-ling	2017	7	930	0.86	800

It is clear that static net fisheries account for the vast majority of fishing effort within the gear types dealt with here, and account for about 85% of the total days at sea considered in this analysis. Approximately 85% of static net days at sea are attributable to under 10 m vessels but this is a slightly misleading statistic in terms of representing actual fishing effort because larger offshore vessels typically use much longer net fleets than smaller coastal boats, so in terms of "true" effort (i.e. if presented as km/hr) this difference would almost certainly be less marked, but provides another strong argument for stratifying the static net data by vessel size class.

Group size and probability distribution

The majority of seabird bycatch incidents per haul were recorded as involving a single individual. The main exceptions to this relate to guillemots in static nets and midwater trawls and fulmars in longlines, where relatively large numbers have been recorded within the same haul (max 8, 17 and 49 respectively). The group sizes for each of these are plotted in Figures 8 and 9. Note that the plot for guillemot does not include the number of hauls with zero bycatch. Over 18,000 static net and 2,200 midwater trawl hauls had no associated guillemot bycatch making it difficult to display the full range of group sizes graphically without altering the y-axis to a logarithmic scale to accommodate zero entries. Other species were occasionally recorded in groups of up to four individuals.

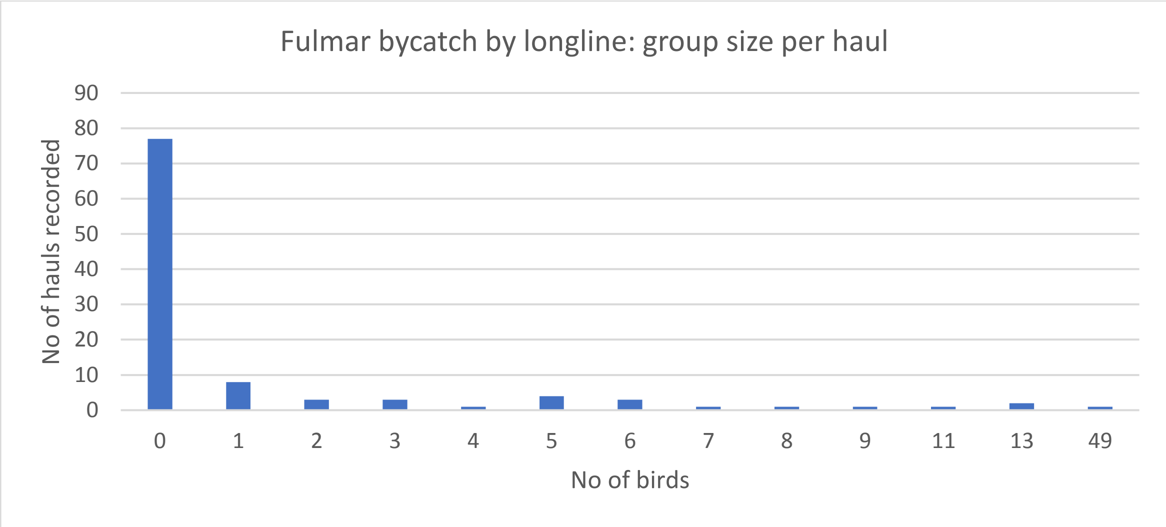


Figure 8: *Fulmar group size per haul.*

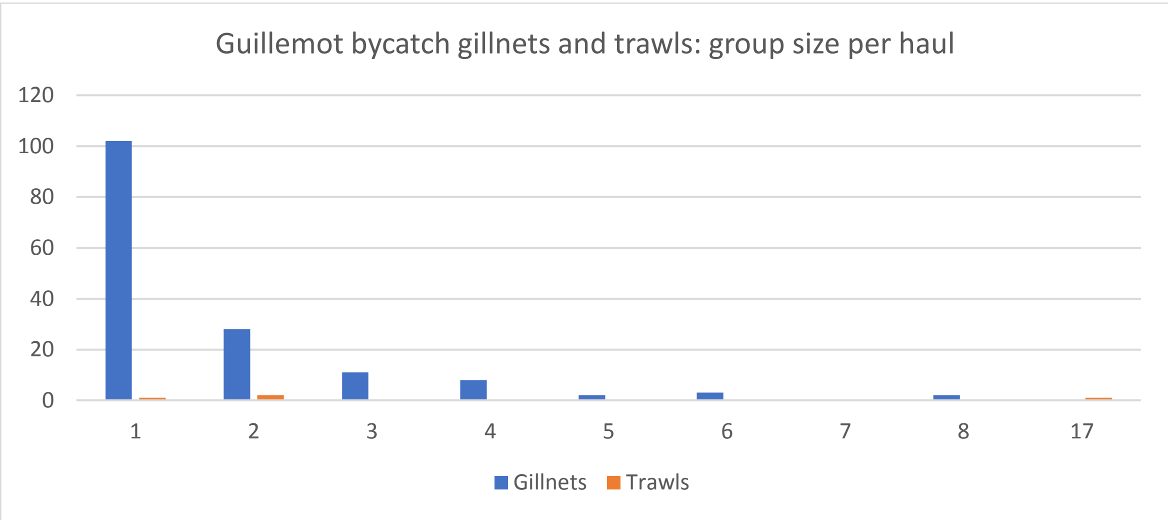


Figure 9: *Guillemot group size per haul (note: for presentational purposes as described above the number of hauls with zero bycatch is not represented here).*

Estimation procedure

With the limited data available we have used bootstrapped resampling of the sample data to generate 95% confidence limits around the extrapolated bycatch estimates. For each fishery stratum we have prepared a table (dataframe) for use within custom written code using the software package R (R Core Team, 2015) containing a record for each observed haul, with the number of birds recorded bycaught, by species. For each stratum we also calculated an estimated number of hauls per year (for 2016 and 2017) for the unobserved fleet, based on the number of days at sea by gear type using data provided by the MMO explicitly for the purpose of bycatch estimation (Table 4).

We have then used the function 'sample' in R (R Core Team, 2015) to sample our observed hauls within each fishery stratum a fixed number of times with replacement, taking the mean bycatch rate for that sample and multiplying that by the estimated number of hauls in the whole fleet to obtain an estimate of the total bycatch. This was repeated 10,000 times to generate 10,000 estimates of the total bycatch for each stratum. 95% confidence intervals were generated using the 2.5% and 97.5% quantiles of the resampled bycatch estimates for each stratum using the function 'quantile' (R Core Team 2015).

The results are presented below in Figures 10 to 20 as probability histograms of the total estimated number of seabirds bycaught by species for each stratum, and each year (2016 and 2017). Point estimates and upper and lower 95% confidence limits are also tabulated for each species in each fishery stratum in Annex 1. However, we encourage readers to focus on the histograms as these give a better visual impression of the range of likely bycatch by species and fishery stratum resulting from this methodology. Point estimates are often over-emphasised in discussion and particularly when uncertainty is high should really be viewed as the "least-worst" rather than "best" estimate.

It is worth re-iterating that the estimates produced here are based on observations undertaken across parts of the UK fleet over a 20-year period. These long-term data were then used to generate essentially multi-annual bycatch rates, which have then been applied to fishing effort data for each of two single years (2016 or 2017) for the relevant fishery stratum. This means there is a temporal "mismatch" between many of the observed bycatch records and the year for which the estimates are being generated. This is an accepted technique for producing bycatch estimates from sampling programmes with low frequency observations such as the BMP, but it assumes no significant underlying trend in bycatch rates over the time period those rates have been calculated. Further analysis would be needed to explore this assumption but given the small sample sizes it may not be possible to test this satisfactorily, so for now we simply note this as a possible weakness in the analytical approach used here.

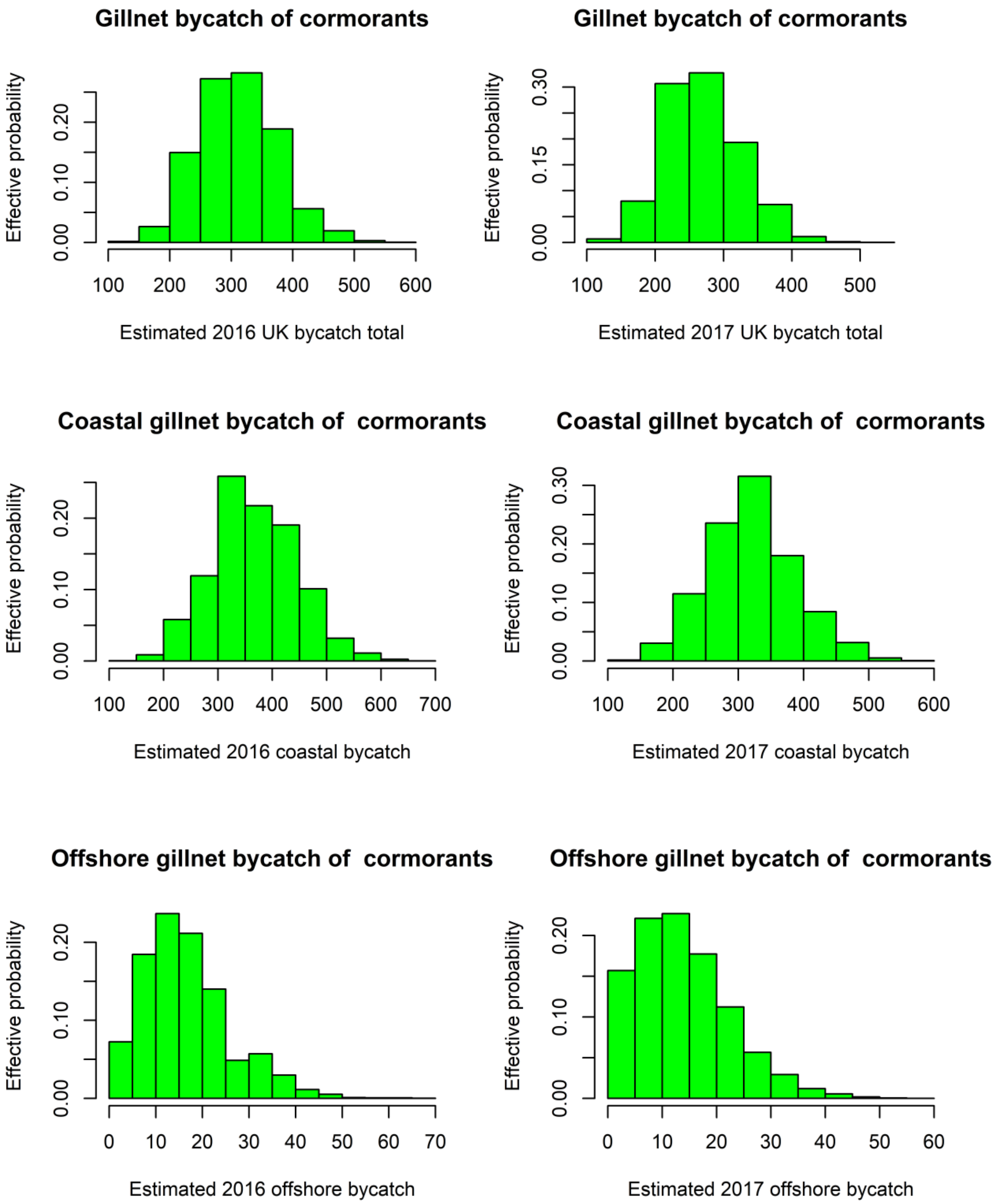
There are numerous other caveats associated with estimates calculated in this way from sparse data, so the numbers should be treated with caution and in context. However, they provide a useful starting point for discussion and development rather than definitive and robust answers about the true scale of seabird bycatch in the UK fisheries considered here.

Results

Results are provided for the seven fishery strata for two individual years, 2016 and 2017. Fishing effort data from other years could be used to look for long-term trends but this would be a time-consuming procedure and outside the scope of this work. In the absence of significantly increased bycatch monitoring levels such an analysis would only really reflect trends in fishing effort over time because the associated bycatch rates are calculated on a multi-annual basis. Probability histograms are presented below by species for each fishery stratum. The 'effective probabilities' given represent the proportion of 10,000 resamples falling within each of ten bycatch 'bins'.

Cormorant (*Phalacrocorax carbo*)

Cormorants were recorded bycaught in static net and midwater trawl fisheries, but not to date in longline fisheries. They are much more frequently recorded from the coastal static net sector than the offshore sector, presumably because they are more closely associated with coastal waters where most small boat netting effort is concentrated. Mortality in the relevant fishery strata appears to be in the region of several hundred individuals per annum but varies depending on how the data are stratified. Cormorant bycatch in midwater trawls in the English Channel appears to be fairly uncommon and probably amounts to no more than a few individuals per year.



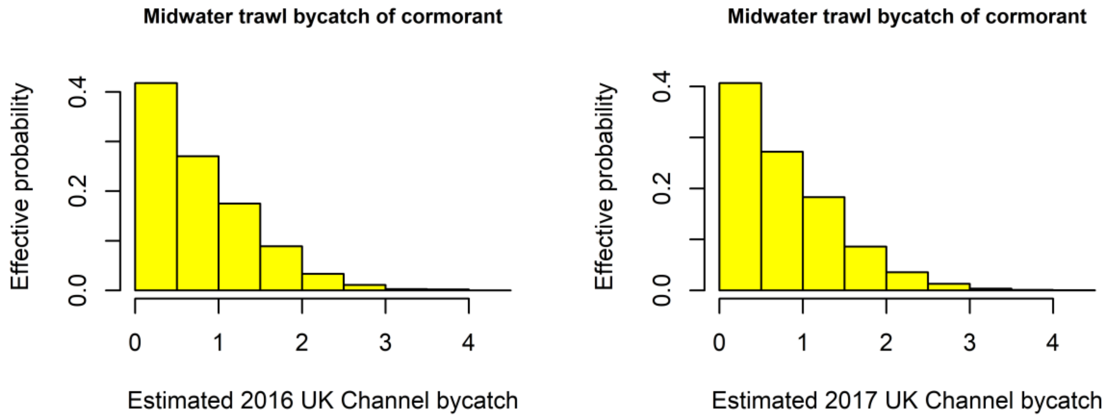
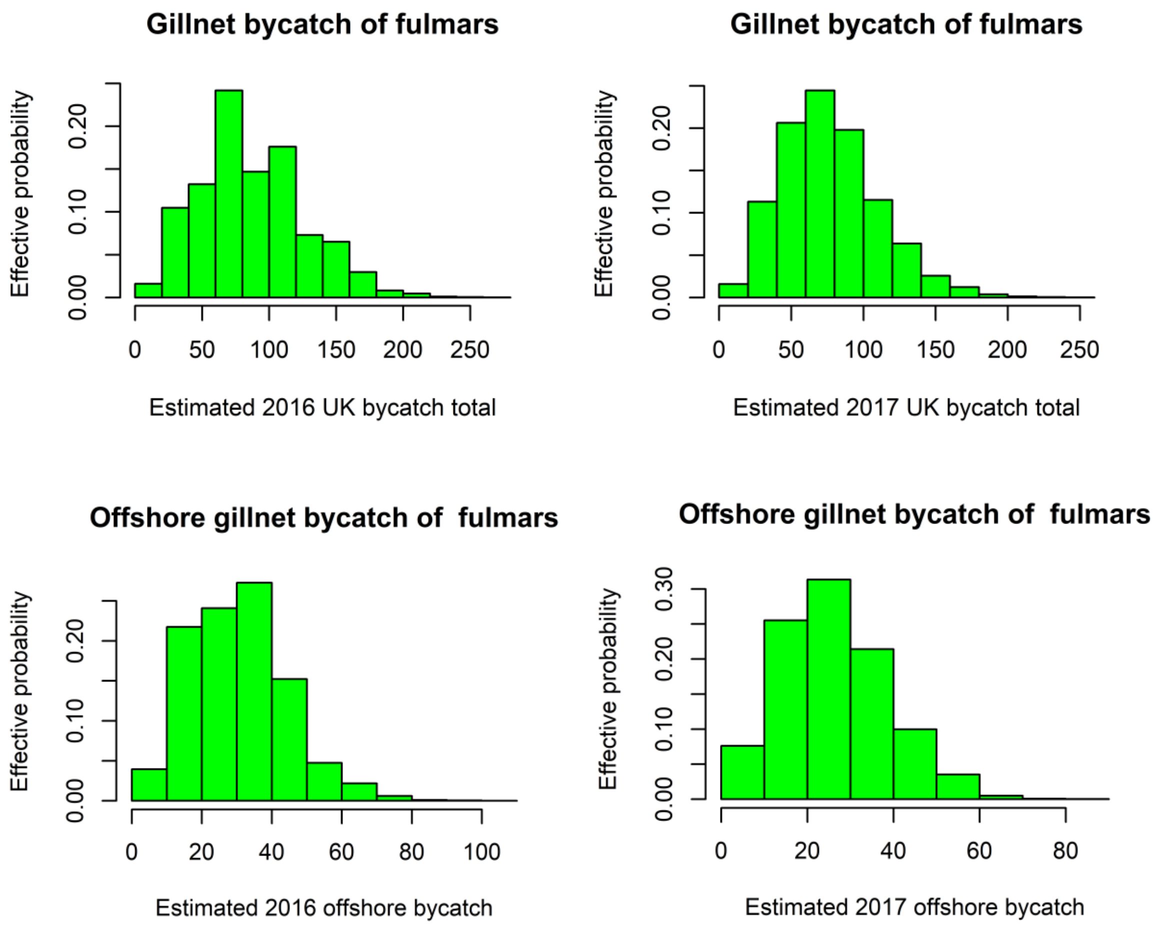


Figure 10: *Probability histograms for cormorant by strata.*

Fulmar (*Fulmarus glacialis*)

Fulmar bycatch has been recorded in offshore static net and longline fisheries. Estimated bycatch appears to be much more significant in longline fisheries but shows a latitudinal component with bycatch levels considerably higher in the northern stratum off Scotland (labelled as ICES divisions 4a and 6a below) in the limited sampling that has been achieved so far. Total bycatch by UK vessels could amount to several thousand birds a year, but the estimates are very imprecise.



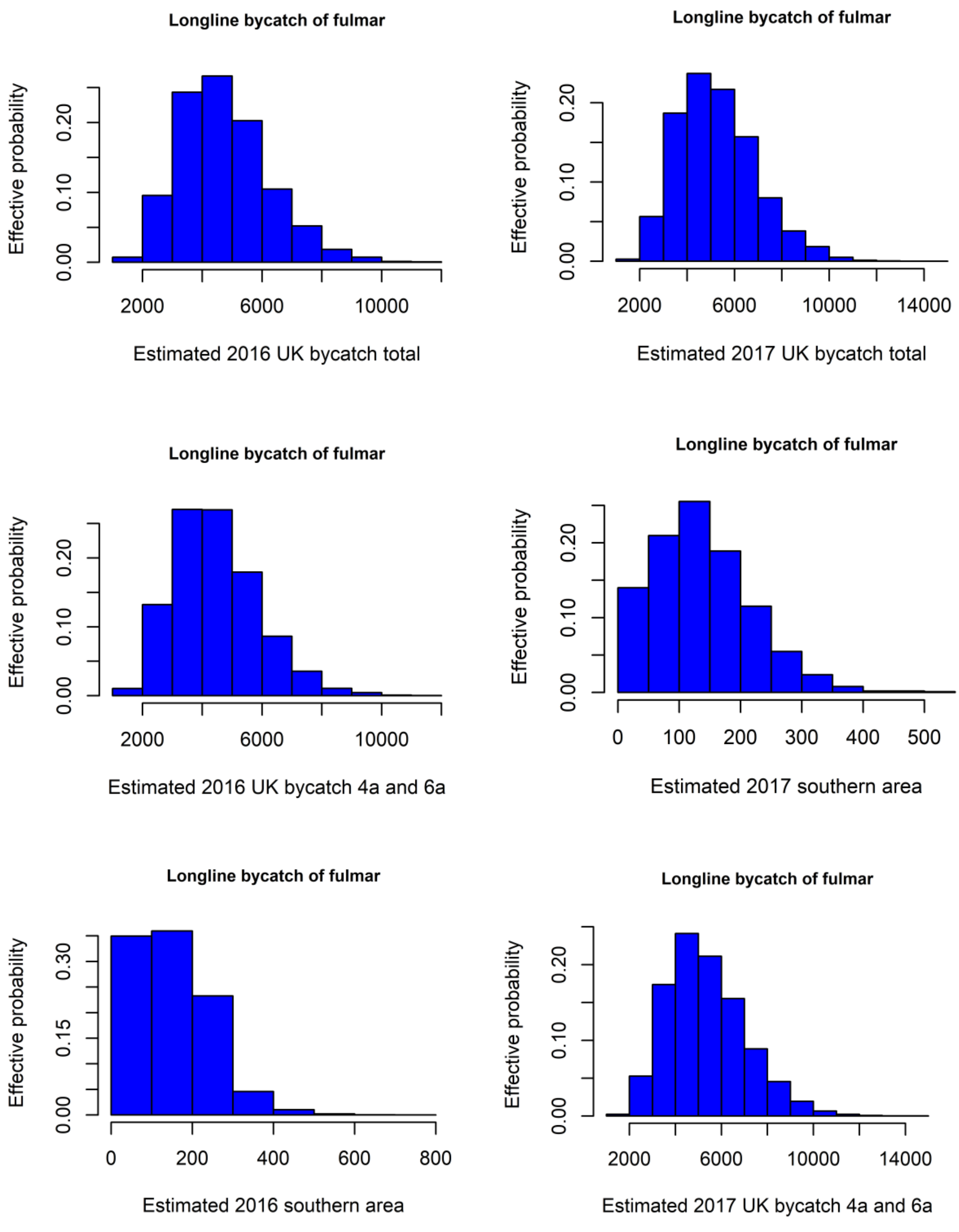
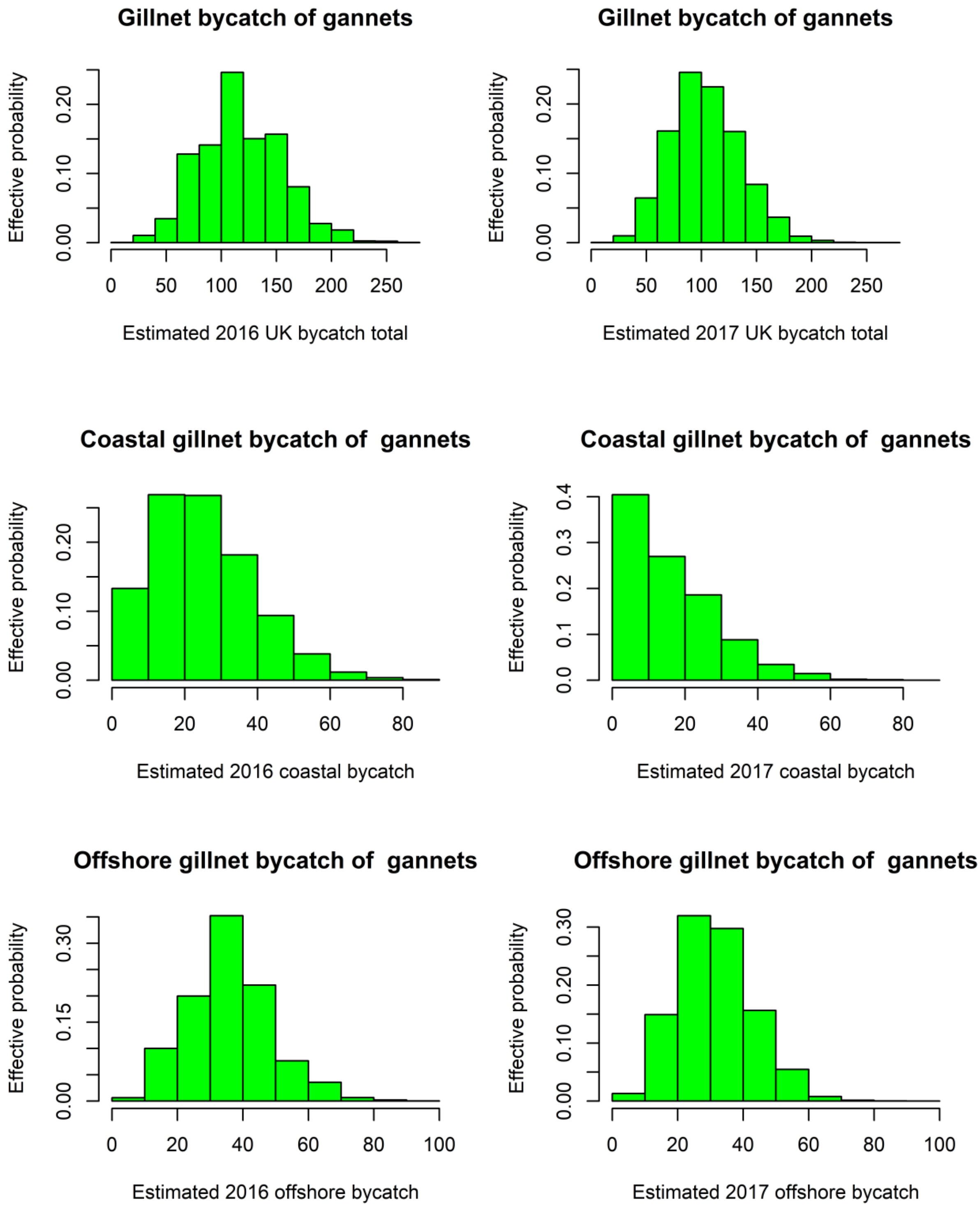


Figure 11: *Probability histograms for fulmar by strata.*

Gannet (*Morus bassanus*)

Gannet bycatch has been recorded in coastal and offshore static net and longline fisheries. Total bycatch is probably a few hundred birds a year with most deaths attributable to offshore static net fisheries and 4a and 6a (northern) longline fisheries.


Gillnet bycatch of gannets
Effective probability
0.00 0.10 0.20
0 50 100 150 200 250
Estimated 2016 UK bycatch total
Gillnet bycatch of gannets
Effective probability
0.00 0.10 0.20
0 50 100 150 200 250
Estimated 2017 UK bycatch total
Coastal gillnet bycatch of gannets
Effective probability
0.00 0.10 0.20
0 20 40 60 80
Estimated 2016 coastal bycatch
Coastal gillnet bycatch of gannets
Effective probability
0.0 0.1 0.2 0.3 0.4
0 20 40 60 80
Estimated 2017 coastal bycatch
Offshore gillnet bycatch of gannets
Effective probability
0.00 0.15 0.30
0 20 40 60 80 100
Estimated 2016 offshore bycatch
Offshore gillnet bycatch of gannets
Effective probability
0.00 0.10 0.20 0.30
0 20 40 60 80 100
Estimated 2017 offshore bycatch

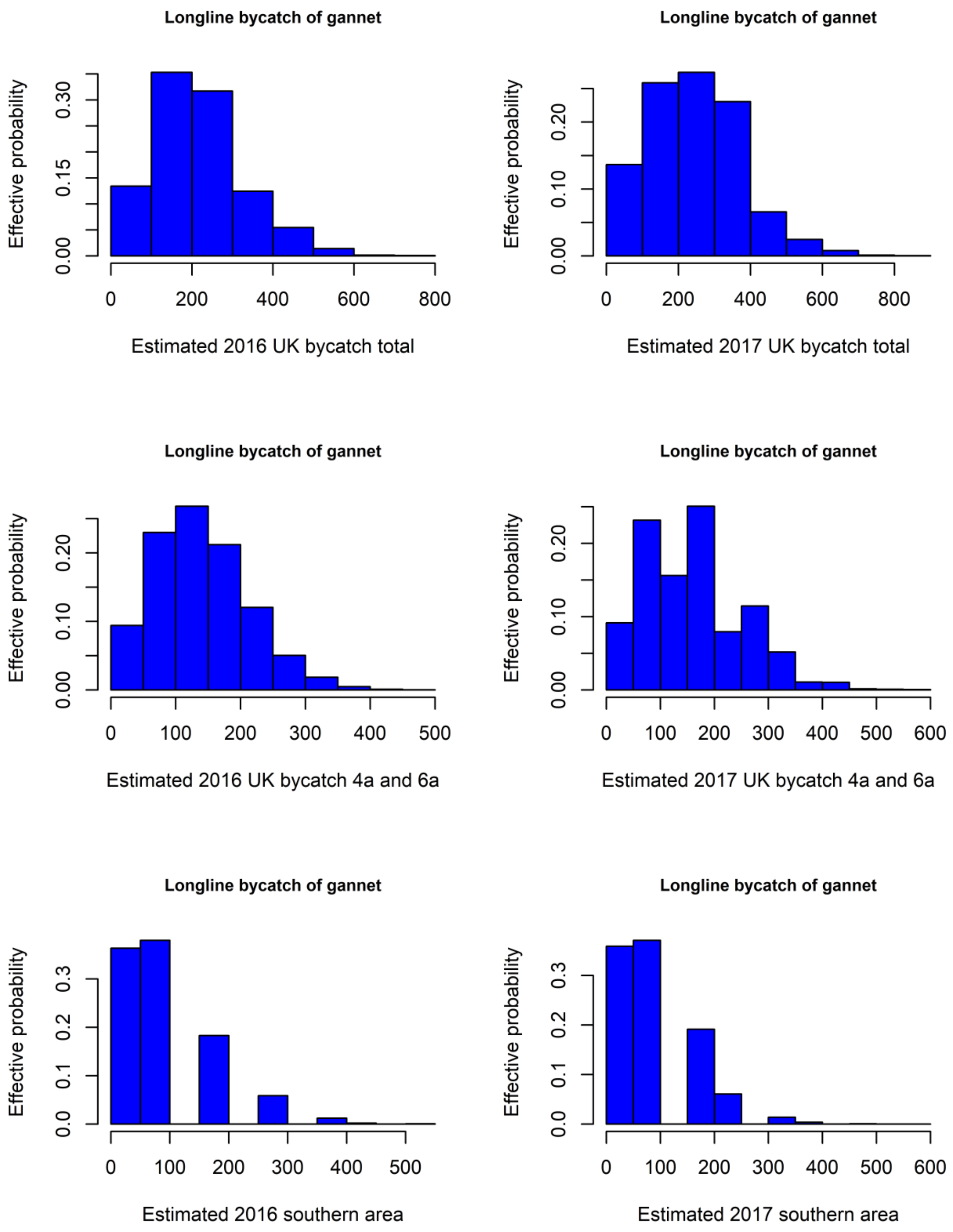


Figure 12: *Probability histograms for gannet by strata.*

Great Black-Backed Gull (*Larus marinus*)

Great black-backed gulls have so far only been recorded from longline fisheries operating in the ICES divisions 4a and 6a (northern stratum). Annual mortality is probably less than a hundred birds.

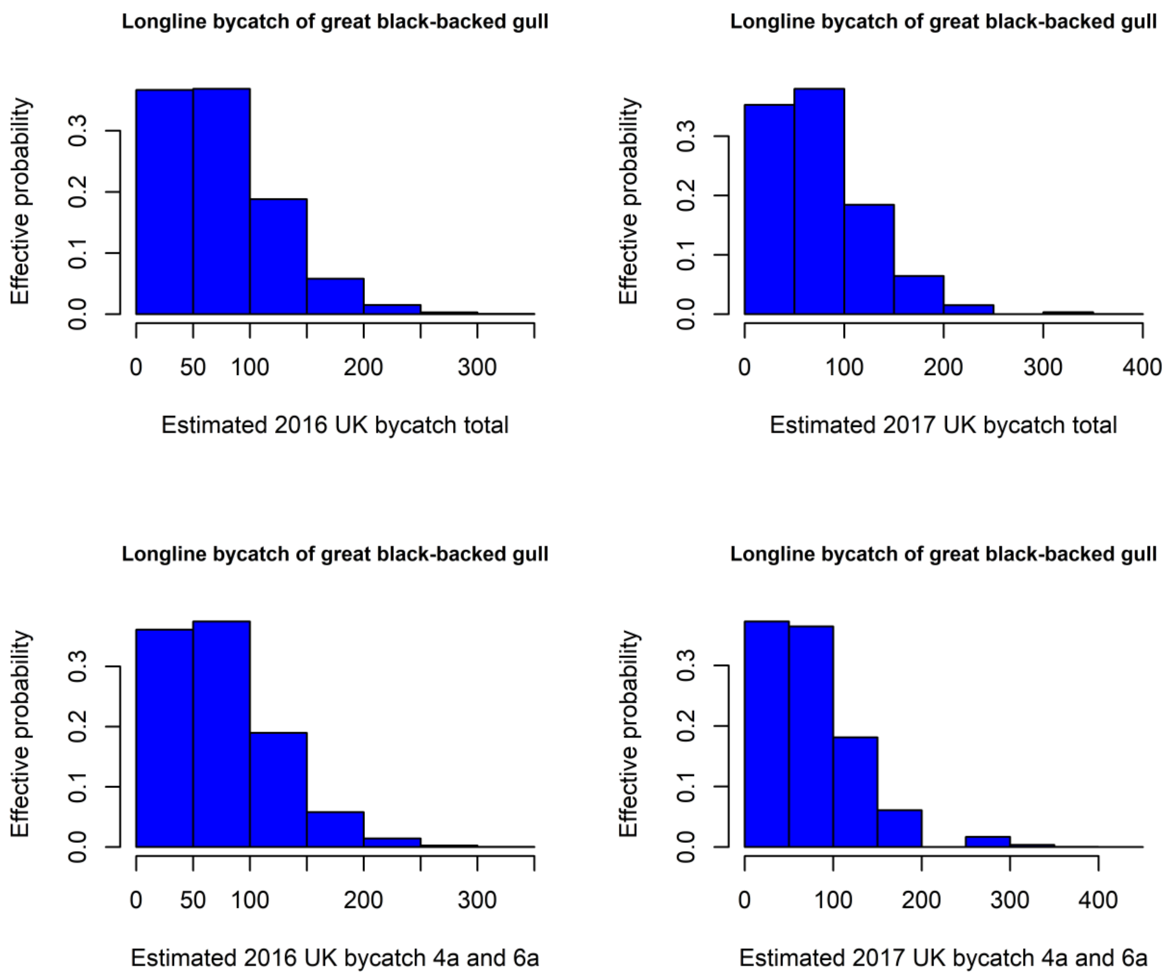
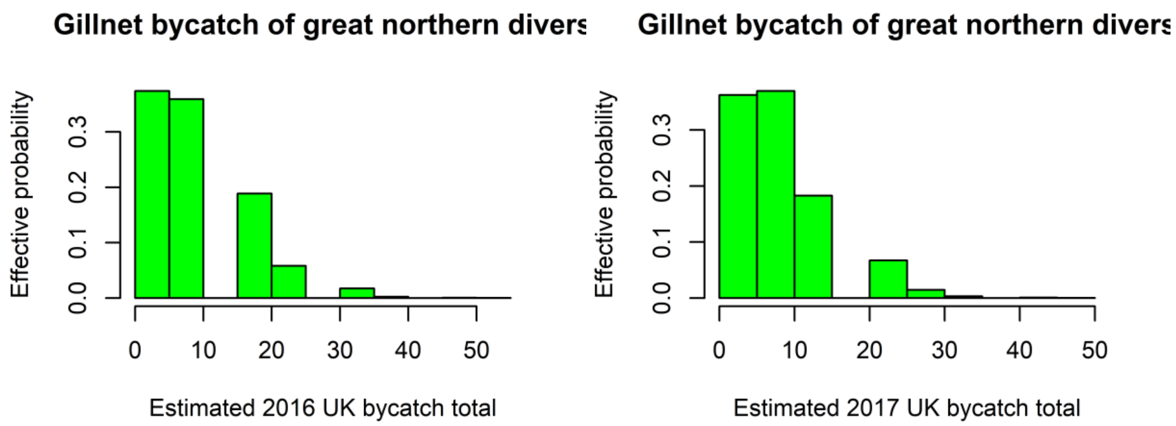


Figure 13: *Probability histograms for great black-backed gull by strata.*

Great Northern Diver (*Gavia immer*)

Great northern divers have only been recorded bycaught from coastal static net fisheries. Based on the data used in this assessment total bycatch numbers appear to be low.



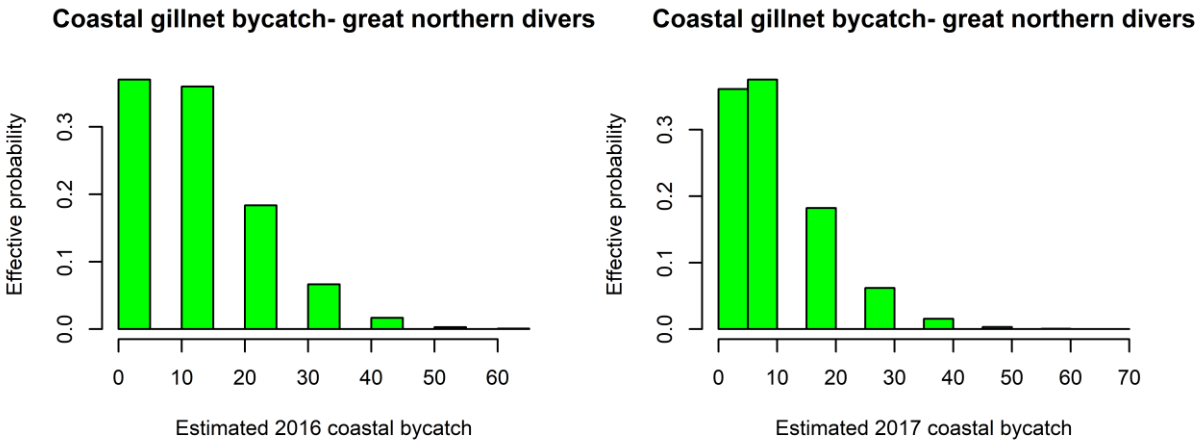
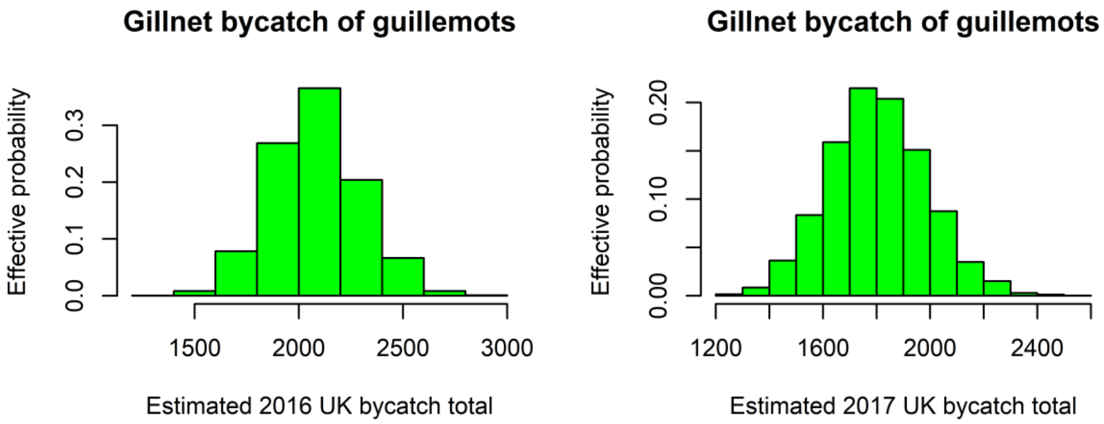


Figure 14: *Probability histograms for great northern diver by strata.*

Guillemot (*Uria aalge*)

Guillemots have been recorded bycaught in both coastal and offshore static net fisheries. Annual bycatch mortality appears to be in the region of a few thousand individuals per year, with most of this attributable to coastal net fisheries.



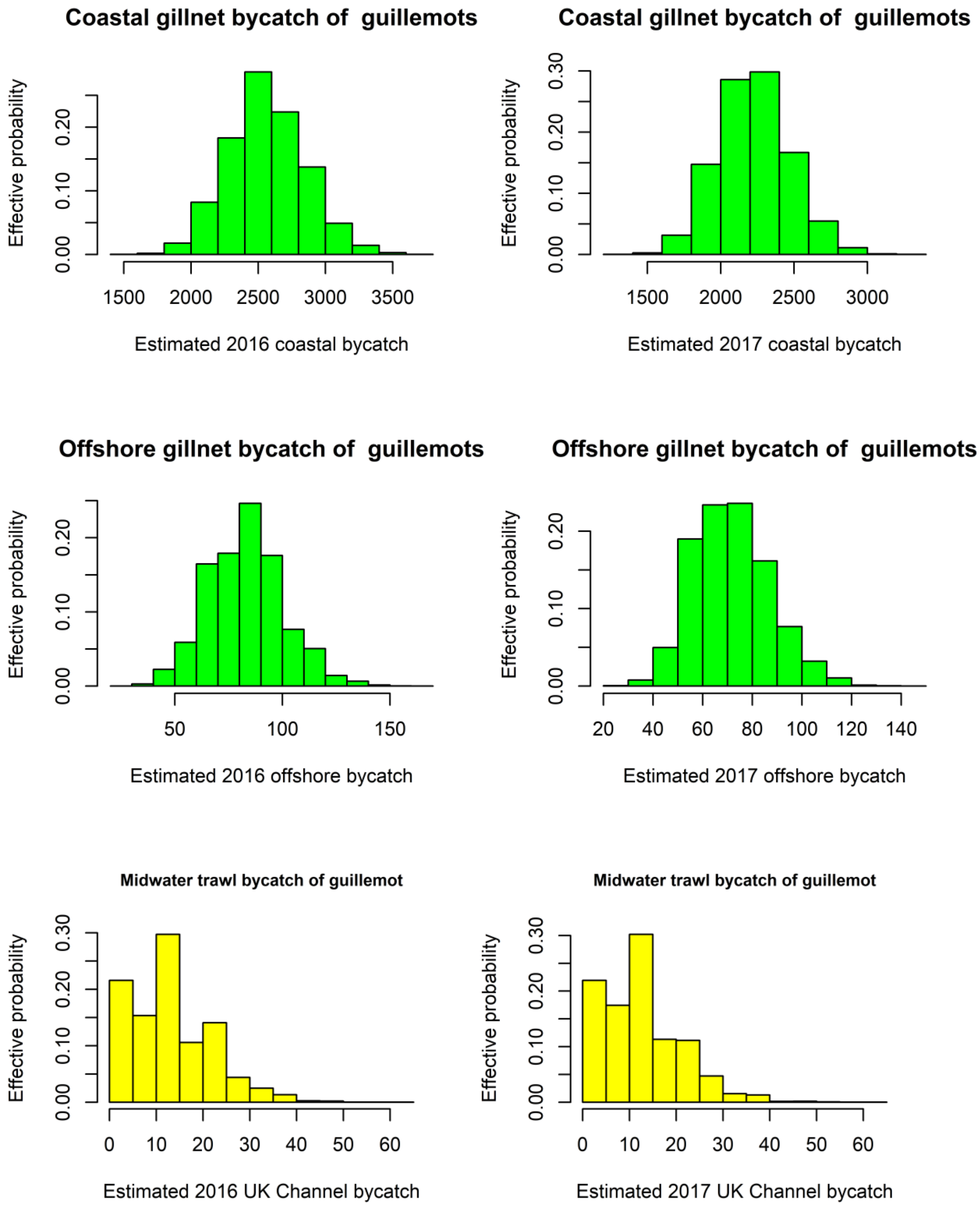
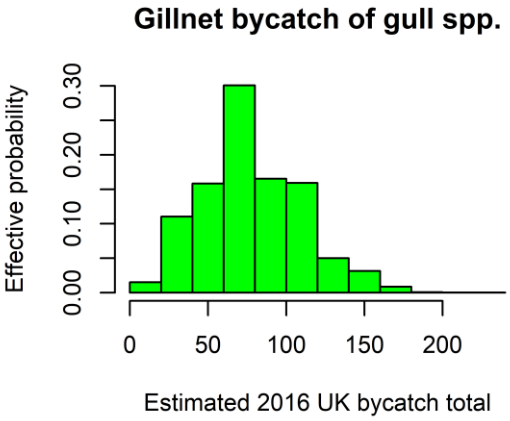
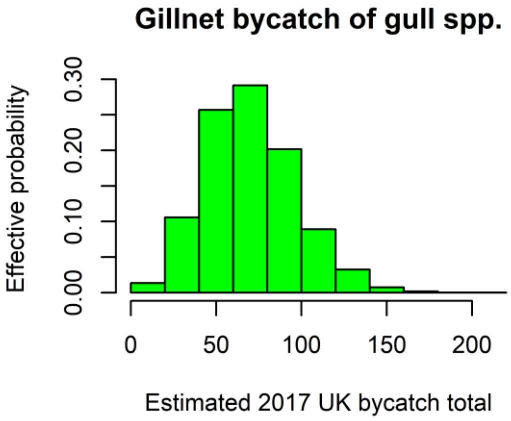


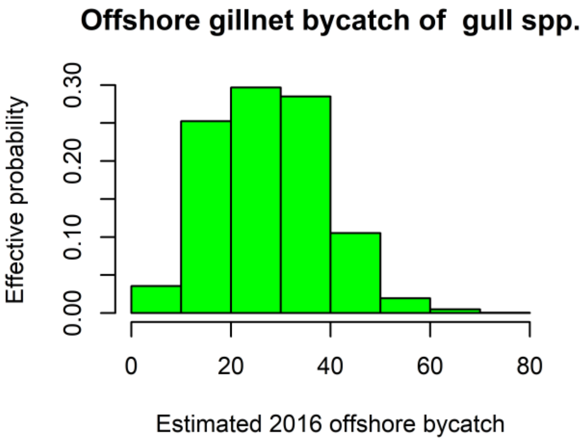
Figure 15: *Probability histograms for guillemot by strata.*

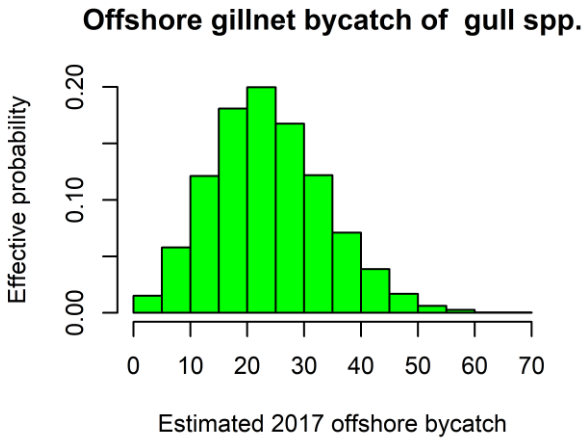
Gull species unidentified (*Laridae*)

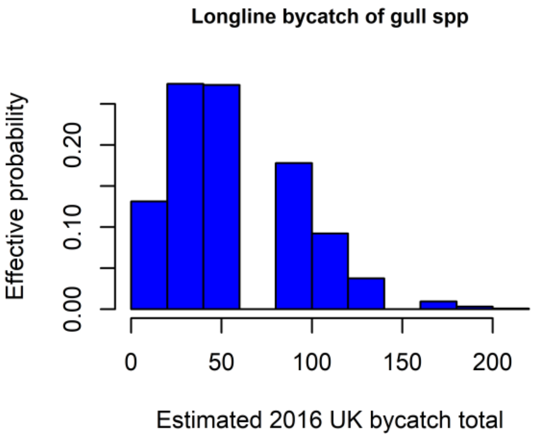
Gulls of indeterminate species were recorded in offshore static net and longline fisheries (in the 4a-6a (northern) stratum only) and number around a hundred per year.

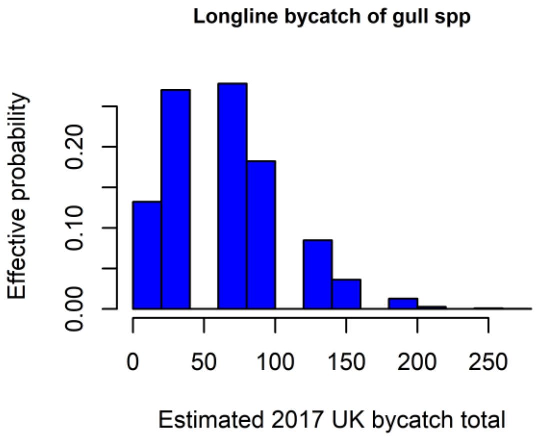












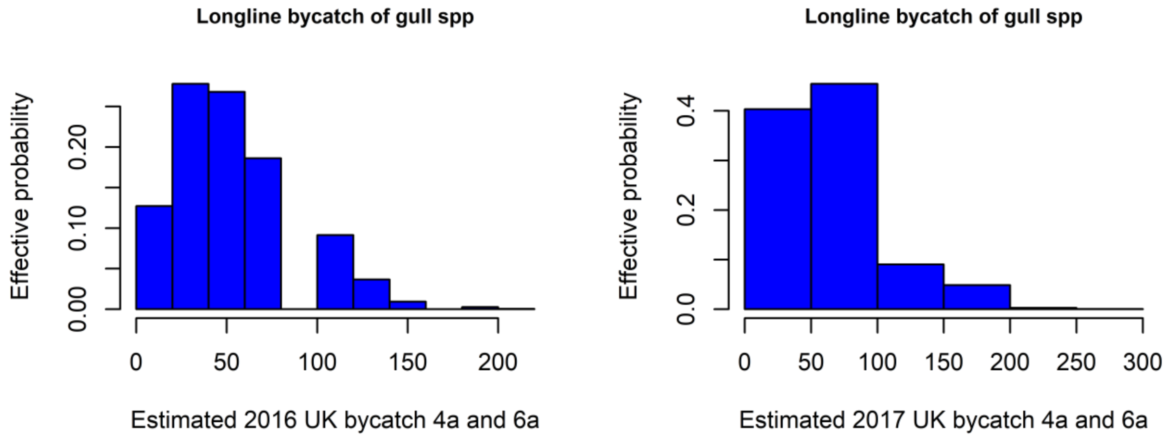
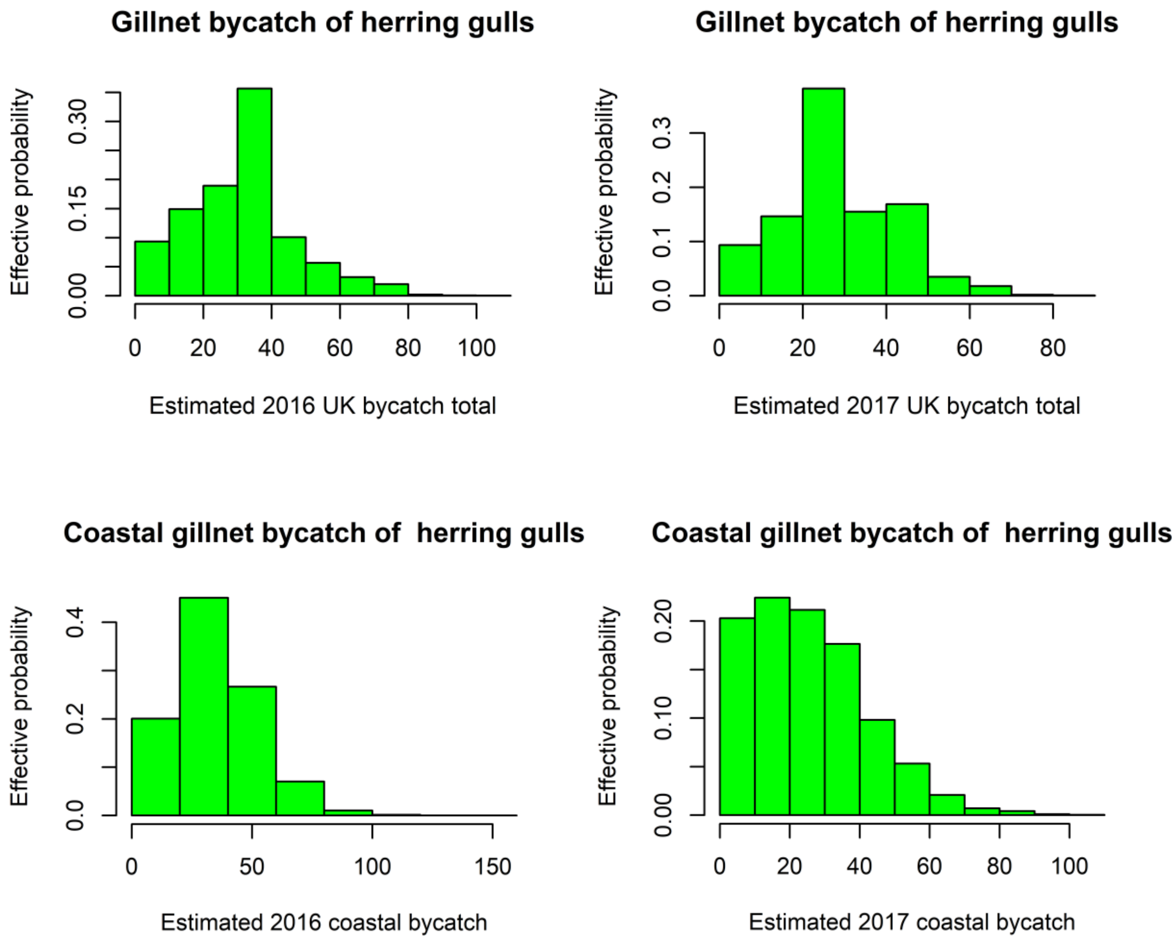


Figure 16: *Probability histograms for gull spp. by strata.*

Herring gull (*Larus argentatus*)

Herring gulls were recorded bycaught in coastal and offshore static net fisheries. Estimated bycatch mortality is in the order of several tens of birds a year.



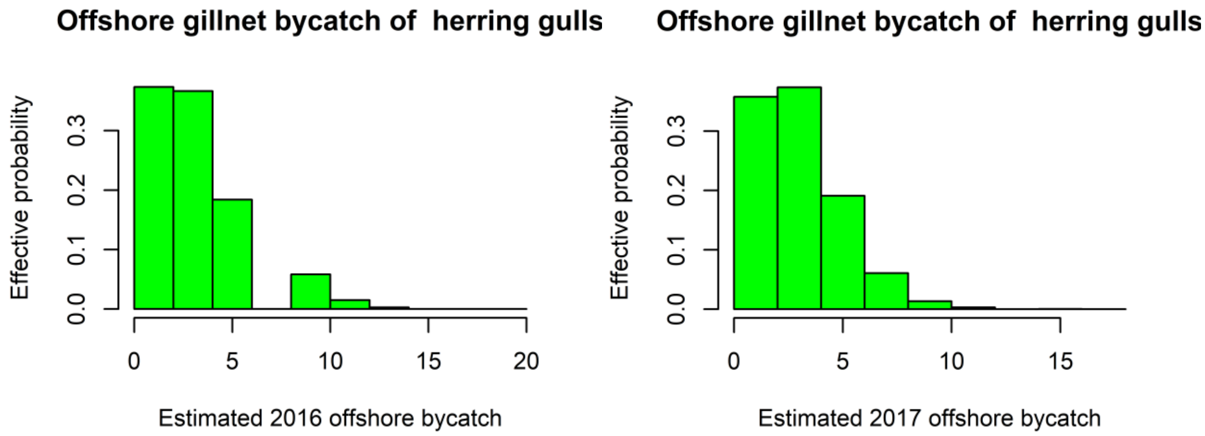


Figure 17: *Probability histograms for herring gull by strata.*

Kittiwake (*Rissa tridactyla*)

Kittiwake bycatch was only recorded in 4a and 6a (northern) longline fisheries. Estimated bycatch amounts to a few tens of birds per year.

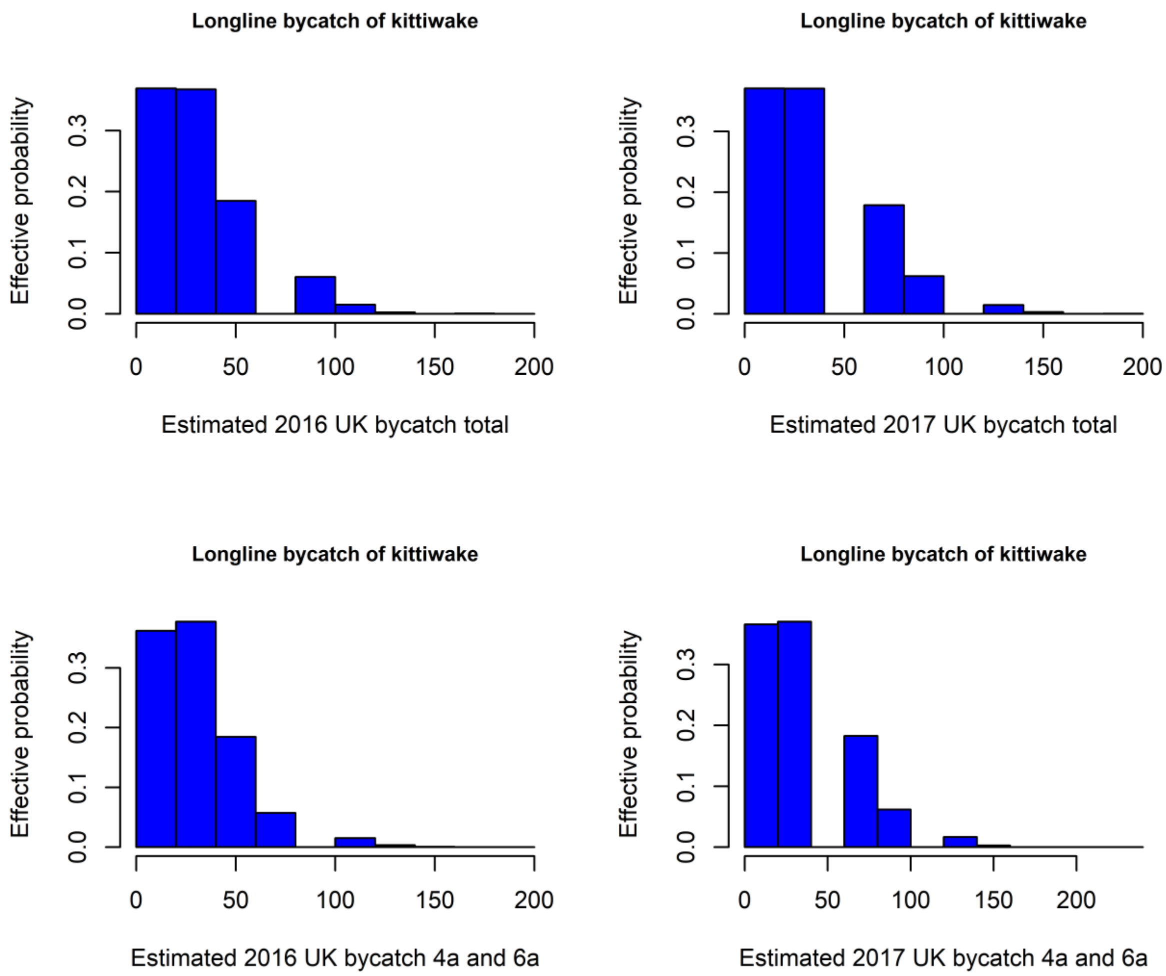
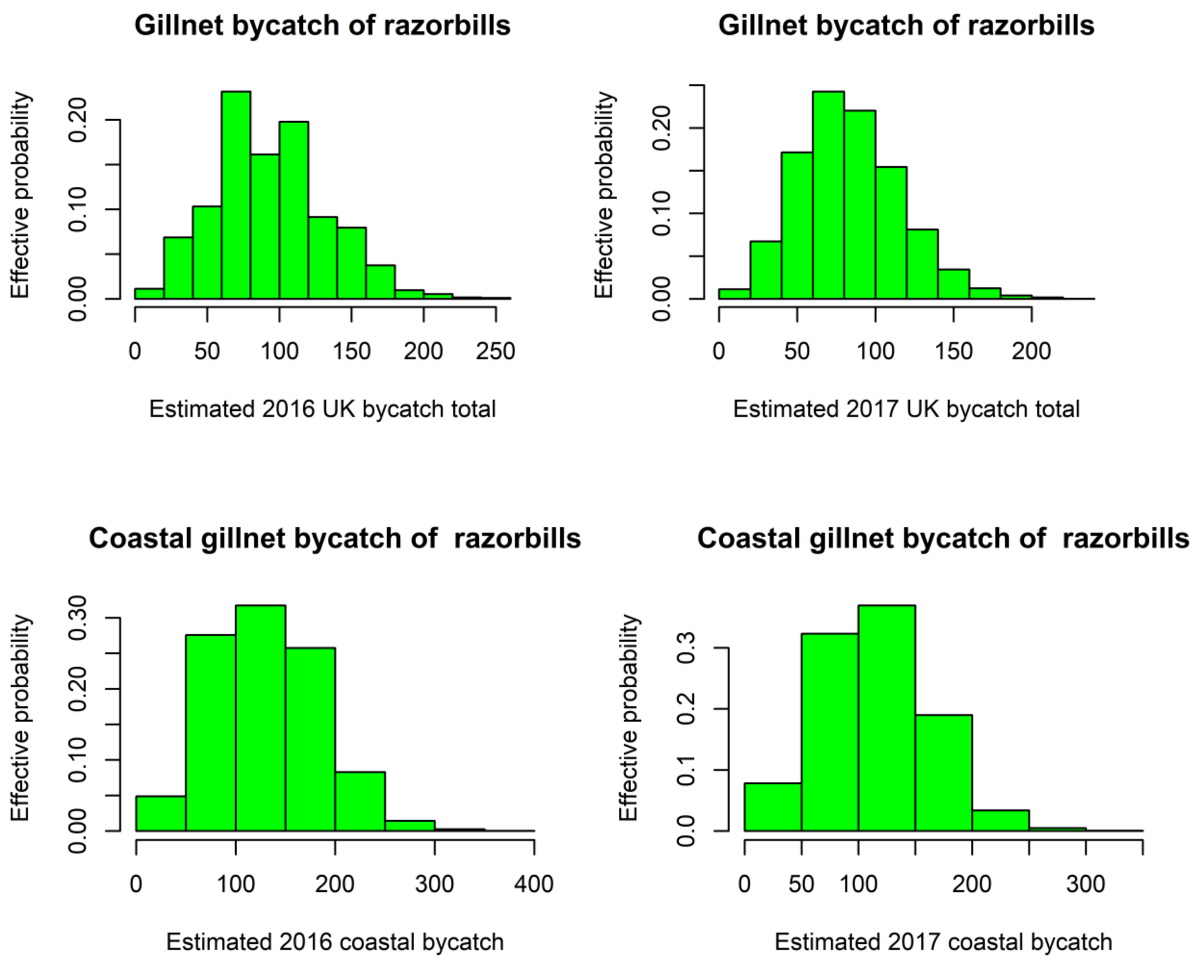


Figure 18: *Probability histograms for kittiwake by strata.*

Razorbill (*Alca torda*)

Razorbills were recorded from coastal static net fisheries and English Channel midwater trawl fisheries. The majority of mortality can be attributed to net fisheries. Estimated mortality in static net and midwater trawls is approximately 100-200 birds per annum.



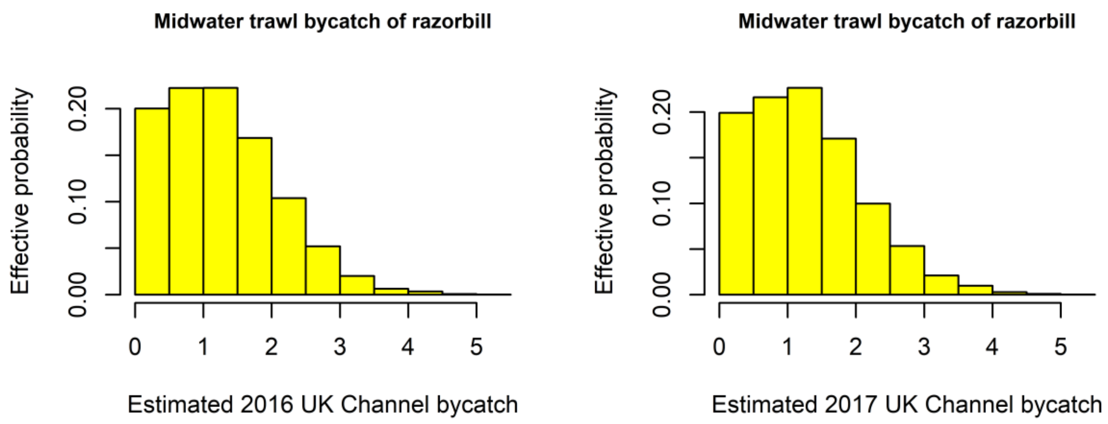


Figure 19: *Probability histograms for razorbill by strata.*

Shag (*Phalacrocorax aristotelis*)

Shags were only recorded bycaught in coastal static net fisheries. Estimated bycatch mortality amounts to fewer than one hundred birds per year.

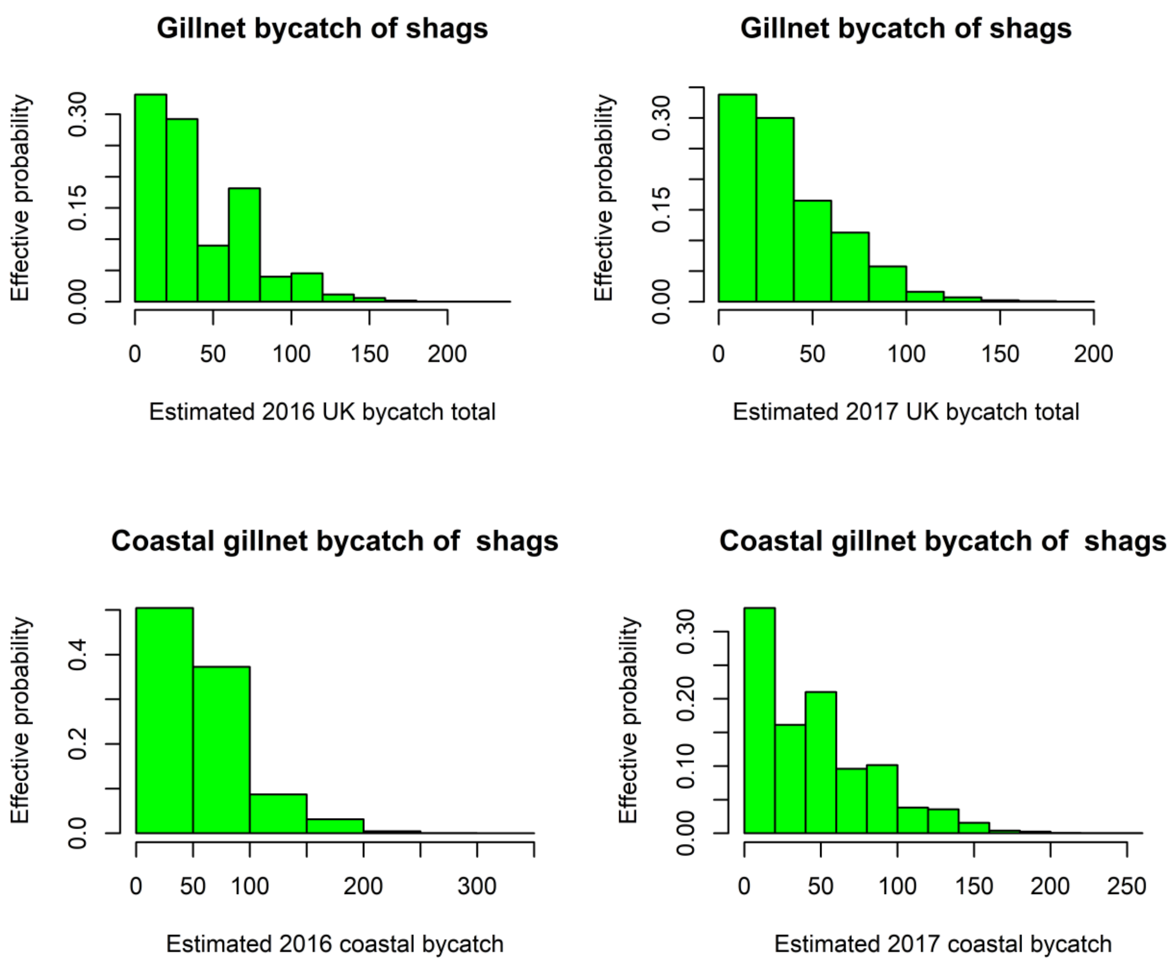


Figure 20: *Probability histograms for shag by strata.*

Bycatch estimates by MSFD area

Although the main output from this work are stratified estimates produced by combining ICES Divisions with similar observed bycatch rates into distinct strata and displayed as probability histograms, there was also a contractual and policy requirement to present estimates by MSFD region and within/outside the UK EEZ. In general, most fisheries management efforts, including fishing effort data collection and fisheries sampling programmes use the ICES delineations and fisheries databases are normally structured accordingly. It is often difficult to reconcile different spatial management systems, and in this case the ICES and MSFD areas do not align, as shown in Figure 19.

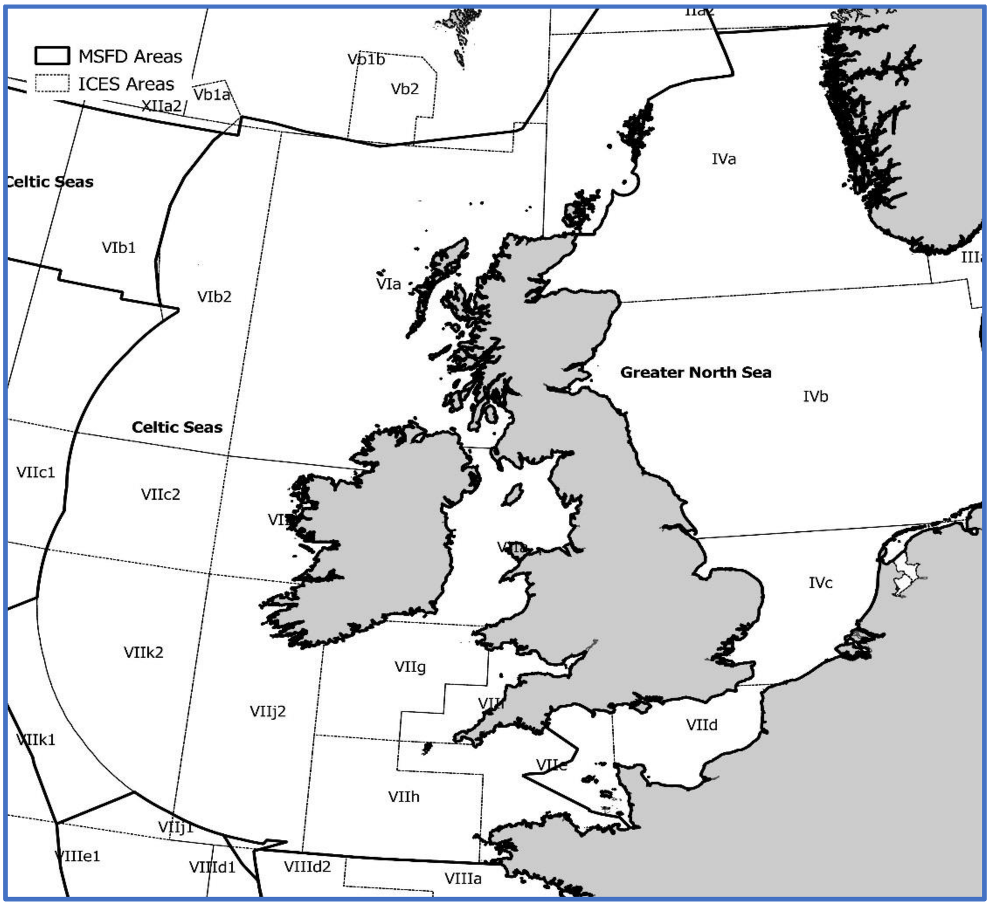


Figure 21: *Plot showing ICES and MSFD areas.*

Because of this mismatch, fishing effort data is not readily available by MSFD region, but it can be estimated fairly accurately. To do this we have apportioned the fishing effort data for all three gear types into Celtic Seas ("CS") or Greater North Sea ("GNS") strata, by pro-rating reported fishing effort by ICES rectangle according to the proportional area of each rectangle that lies within each MSFD region. Thus, for those rectangles that straddle the GNS and CS boundary, we have divided the recorded fishing effort in proportion to the sea area present within each region.

A similar problem relates to disaggregating the fishing effort data and subsequent mortality estimates into UK and non-UK waters, inside and outside EEZs. This is further complicated by the fact that all observed coastal static net effort, northern (4a-6a) longline effort, the majority of English Channel midwater trawl effort and a large portion of offshore static net effort were within the UK or Irish EEZs, so that estimating bycatch rates outside EEZs, or outside of the UK EEZ would lack statistical power. Further detailed disaggregation and pro-rating of existing fishing effort data and further analysis of BMP bycatch data would be required to produce estimates specifically for the UK EEZ portions of each of the MSFD regions. This would be a very time-consuming exercise and would be of limited utility as so few observations to date have been made outside the UK EEZ. For now, we simply tabulate below the percentage of observed hauls by gear type within and outside the UK EEZ (Table 5 below).

Table 5: Observation effort by gear type in relation to the UK EEZ.

Gear	Observed Hauls	Hauls Inside UK EEZ	Hauls Outside UK EEZ	% Inside UK EEZ
Longline	103	80	23	77.7
Trawl	2239	1934	305	86.37
Net	18916	17082	1834	90.30

Although the bycatch data are not necessarily well balanced between the Greater North Sea and Celtic Seas regions for all the fishery strata we have used, our estimates still provide an approximate measure of how bycatch may be distributed between the two relevant MSFD regions. The results of this exercise are tabulated in Annex 2a and b for 2016 and 2017 respectively but should be interpreted with caution especially where sampling is limited in either MSFD region.

Discussion

The analysis undertaken here is the first attempt to describe the nature (i.e. which fisheries and areas are involved) and scale of seabird bycatch based from at sea observations for some sectors of the UK fishing fleet. The results provide a broad-scale overview and should not be taken as a definitive or overly accurate estimate of recent seabird bycatch levels. This work is intended to initiate a discussion about which areas and fisheries might require more focused sampling to improve future mortality estimates by reducing uncertainty, to highlight what other analyses of the existing data might be undertaken to help improve current understanding of seabird bycatch and to provide an initial basis to begin exploring and prioritising possible management measures to help reduce mortality from fisheries bycatch.

The data used in this analysis originate solely from sampling of UK registered fishing vessels and thus only provide insights into potential bycatch levels within UK fisheries operating in UK and adjacent waters. There is known to be significant non-UK effort in the same areas by the same/similar gear types but neither bycatch rate data or fleet effort data from those fisheries were available to include in this analysis, and we caution against applying observed bycatch rates from UK fisheries to those non-UK fisheries in the absence of detailed information about the operational characteristics of those fleets. For example, the UK offshore longline fleet has been developing and, based on both observer data and industry communications, fairly routinely using seabird bycatch mitigation measures (tori lines, offal disposal routines) for a number of years which are likely to reduce bycatch rates. It is currently unknown if other nations' vessels working in the same fisheries are using similar (or any) measures to address bycatch. Consequently, the mortality estimates presented here should be viewed as one component of total mortality from the areas and gear types under consideration.

As alluded to through the report the mortality estimates produced here are very likely to be associated with substantial biases for a number of reasons. Biases can occur due to sampling designs, data collection protocols and data analytical issues and we discuss those here.

The accuracy of the estimates is highly dependent on how representative the sampling has been within each of the fishery strata. True random sampling of fisheries activity is very rarely achieved because it relies on 100% access to the fleet, 100% of the time. In reality, where there is no robust legal requirement for all vessels to carry observers whenever they are requested, there will always be either particular vessels or particular periods where access for observers, for whatever reason, is not guaranteed. Consequently, it is vitally important to try to minimise (but probably never remove) any biases associated with non-representative sampling. For this reason, it is vital that a good relationship is maintained with the fishing industry to try and maximise access to vessels, but also to ensure that industry's significant collective knowledge about such issues is utilised properly. Trust in how data are collected, handled, presented and interpreted is crucial in this regard.

Historically, typical annual sampling coverage under the BMP has been <1% of total static net effort, 1-2% of longline effort and roughly 5% of midwater trawl effort so it is likely that sampling under the BMP will not have covered some specific metiers where seabird bycatch occurs at relatively higher rates than in the metiers we report on here. However, it is unlikely that those metiers have a wide geographical distribution and/or are large scale in terms of total effort. More probably, there are specific fisheries operating at small spatial scales that we have not sampled, where seabirds are caught at relatively higher (or lower) rates than observed in our general sampling efforts. Conversely, our sampling may create a biased impression of a higher overall rate than is actually the case, for example if we have over-sampled specific areas or even individual boats from which bycatch rates are systematically higher than they are in the wider fleet within that strata. This is more likely to occur when sampling levels (i.e. % of total effort or % of total vessels) are limited, and therefore less likely where we have achieved relatively high levels of sampling against the same measures. All the estimates presented above must therefore be considered in light of how much sampling has been achieved against total effort levels (see Tables 1 and 4) and how many seabirds were observed bycaught (see Table 2). The level of sampling compared to the total fleet effort influences not only the accuracy of the point estimates (if sampling is unrepresentative or biased due to small or unrepresentative samples), but also the level of precision calculated from the bootstrap resampling technique. Consequently, a potentially false impression of higher precision may be associated with strata where there has been more limited sampling in relation to total effort, i.e. static nets and longlines.

On deck sampling protocols are also an extremely important factor in improving accuracy and precision. Protocols that are not optimised for assessing protected species (including seabirds) bycatch can lead to unreliable data because observers may not notice or record such incidences because they are preoccupied with other tasks, positioned where they cannot see the hauling operation, or simply because there is no facility within the data recording system to note a protected species bycatch event. For this reason, we have not included data in this analysis from other fisheries data collection programmes. Even within the BMP, where data collection procedures are designed to estimate protected species bycatch there are potentially some areas worth closer examination to ensure the accuracy of the data. For example, as alluded to earlier, on large midwater trawlers the catch is often pumped from the cod-end into holding tanks and opportunities to see bycatches of fairly small organisms, such as birds, might be restricted. For that reason, we have excluded that dataset from this analysis, but nonetheless it is worth noting here that we have monitored several hundred hauls from such vessels without recording any seabird bycatch. Sampling under the BMP was initially heavily focussed on cetaceans, though observers were instructed to record incidences of any protected species, but this raises the possibility that non-cetacean bycatches were under-reported in the earlier years of the programme.

From an analytical perspective it might have been more helpful to stratify the observer and fishing effort data to a finer resolution. Better stratification is almost certainly possible with further statistical analysis of the existing data but was beyond the scope of this work. However, the more finely we stratify the data the more likely we are to lose observations in some strata. This means we would be unable to produce mortality estimates for those strata and would then risk obscuring the general broad-scale picture that this analysis was designed to provide. More detailed stratification should increase precision in individual strata mortality estimates, but particularly where sample sizes are low, may also introduce more biases (inaccuracy) overall.

Given the approach used here of generating multi-annual bycatch rates and applying them to a single year's fishing effort data it is important to emphasise that changes in the mortality estimates between years for which we have provided estimates (2016 and 2017) are solely driven by changes in fishing effort levels rather than changes in the underlying bycatch rates.

Despite all the caveats associated with the estimates and probability distributions, we have still managed to provide preliminary mortality estimates for a range of species in a number of fishery strata and by MSFD region, which clearly provide useful initial insights into patterns of seabird bycatch by UK vessels and some justifiable numbers to begin assessing potential population level impacts.

The estimates and associated uncertainties also provide a structure to prioritise the development, direction and planning of future monitoring efforts to further improve knowledge of seabird bycatch, particularly when these estimates are viewed in light of the results emanating from planned population impact assessments. For example, the scale of the fishery, available bycatch mortality estimates and associated precision levels, and the potential for population level impacts should all be considered simultaneously when designing future sampling plans, within budgetary constraints and existing policy priorities, to help ensure that fisheries related mortality does not pose a conservation threat to seabird populations in the long term.

References

R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

ICES, 2016. Report of the Working Group on Bycatch of Protected Species (WGBYC). ICES CM 2016/ACOM: 27.

Acknowledgements

This work was funded by Defra and administered by JNCC. We are grateful for some very helpful comments on previous versions by Matt Parsons (JNCC) and Mark Tasker (independent reviewer), and by several members of the Technical Advisory Group (comprising representatives of Cefas, the UK's Country Nature Conservation Bodies, Defra, Marine Scotland, Marine Scotland Science, RSPB, Seafish, University of St Andrews). We would also like to thank Liz Clarke (MSS) for pointing out an egregious error in the estimation of the confidence limits in an earlier version and to Len Thomas (St Andrews) for helping to fix it.

We also acknowledge the hard work of our observer team over the past 25 years, without which our understanding of protected species bycatch in UK fisheries would be extremely limited. Finally, we want to recognise the significant input and support of industry representatives and vessel owners, and particularly the skippers and crews of the hundreds of fishing vessels who have made our observers welcome on board and have shared their considerable knowledge of the specifics of their fishing activity and their insights into seabird bycatch.

Annex 1 – Tabulated point estimates and confidence limits by strata.

Species	Point estimate	95% Lower Confidence Limit	95% Upper Confidence Limit	Point estimate	95% Lower Confidence Limit	95% Upper Confidence Limit
	All static nets 2016			All static nets 2017		
Cormorant	311	195	444	271	176	385
Fulmar	86	23	171	74	20	149
Gannet	117	55	195	102	47	169
Great northern diver	8	0	23	7	0	20
Guillemot	2081	1683	2510	1803	1458	2174
Gull spp.	78	23	148	68	20	128
Herring gull	31	8	62	27	7	54
Razorbill	93	31	179	81	27	155
Shag	40	0	117	34	0	101
	Static nets coastal boats 2016			Static nets coastal boats 2017		
Cormorant	367	227	531	319	197	460
Fulmar	0	0	0	0	0	0
Gannet	22	0	54	19	0	47
Great northern diver	11	0	32	9	0	28
Guillemot	2563	2025	3151	2226	1765	2713
Gull spp.	0	0	0	0	0	0
Herring gull	33	0	76	28	0	66
Razorbill	130	32	249	113	38	216
Shag	54	0	152	47	0	131
	Static nets offshore boats 2016			Static nets offshore boats 2017		
Cormorant	17	3	39	14	2	34
Fulmar	31	8	61	27	7	53
Gannet	36	14	64	31	12	55
Great northern diver	0	0	0	0	0	0
Guillemot	83	50	119	72	45	103
Gull spp.	28	8	50	24	7	45
Herring gull	3	0	8	2	0	7
Razorbill	0	0	0	0	0	0
Shag	0	0	0	0	0	0
	Channel midwater trawls 2016			Channel midwater trawls 2017		
Cormorant	1	0	2	1	0	2
Guillemot	13	2	32	13	2	31
Razorbill	1	0	3	1	0	3
	All offshore longlines 2016			All offshore longlines 2017		
Fulmar	4770	2400	8127	5266	2613	8949
Gannet	220	27	464	241	30	510
Great black-backed gull	55	0	164	61	0	180
Gull spp.	55	0	136	60	0	150
Kittiwake	27	0	82	30	0	90
	Longlines northern area (4a,6a) 2016			Longlines northern area (4a,6a) 2017		
Fulmar	4452	2205	7638	5358	2672	9149
Gannet	130	0	315	159	0	377
Great black-backed gull	53	0	157	64	0	189
Gull spp.	52	0	131	63	0	157
Kittiwake	27	0	79	32	0	94
	Longlines southern area (7bcj) 2016			Longlines southern area (7bcj) 2017		
Fulmar	150	0	357	133	0	319
Gannet	91	0	268	80	0	239
Great black-backed gull	0	0	0	0	0	0
Gull spp.	0	0	0	0	0	0
Kittiwake	0	0	0	0	0	0

Annex 2a: Point estimates and confidence limits by MSFD sub-region for 2016.

Prorated estimates 2016	**Greater North Sea**			**Celtic Seas**		
All static nets	**Point estimate**	**Lower 95 % confidence limit**	**Upper 95% confidence limit**	**Point estimate**	**Lower 95 % confidence limit**	**Upper 95% confidence limit**
Cormorant	126	46	229	157	92	233
Fulmar	0	0	0	60	16	119
Gannet	23	0	57	70	27	125
Great northern diver	12	0	34	0	0	0
Guillemot	1270	916	1649	844	634	1078
Gull spp.	0	0	0	54	16	103
Herring gull	0	0	0	22	5	43
Razorbill	138	46	263	0	0	0
Shag	0	0	0	27	0	81
Coastal static nets	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Cormorant	106	30	196	188	104	285
Fulmar	0	0	0	0	0	0
Gannet	15	0	45	7	0	21
Great northern diver	15	0	45	0	0	0
Guillemot	1445	1011	1946	983	717	1267
Gull spp.	0	0	0	0	0	0
Herring gull	0	0	0	21	0	49
Razorbill	180	45	332	0	0	0
Shag	0	0	0	35	0	97
Offshore static nets	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Cormorant	6	0	16	6	0	16
Fulmar	0	0	0	34	9	69
Gannet	1	0	4	37	13	69
Great northern diver	0	0	0	0	0	0
Guillemot	22	10	36	47	22	75
Gull spp.	0	0	0	31	9	60
Herring gull	0	0	0	3	0	9
Razorbill	0	0	0	0	0	0
Shag	0	0	0	0	0	0
Channel midwater trawl	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Cormorant	2	0	5	0	0	0
Guillemot	5	0	11	3	0	9
Razorbill	0	0	0	0	0	1
Longline All	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Fulmar	541	68	1239	4300	1947	7648
Gannet	45	0	135	171	0	423
Great black-backed gull	0	0	0	56	0	169

Gull spp.	0	0	0	56	0	141
Kittiwake	0	0	0	27	0	85
Longline North (4a,6a)	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Fulmar	540	68	1239	4021	1807	7282
Gannet	45	0	135	82	0	219
Great black-backed gull	0	0	0	55	0	164
Gull spp.	0	0	0	55	0	137
Kittiwake	0	0	0	27	0	82
Longline South (7bcj)	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Fulmar	0	0	0	150	0	357
Gannet	0	0	0	91	0	268
Great black-backed gull	0	0	0	0	0	0
Gull spp.	0	0	0	0	0	0
Kittiwake	0	0	0	0	0	0

Annex 2b: Point estimates and confidence limits by MSFD sub-region for 2017.

All static nets	**Point estimate**	**Lower 95 % confidence limit**	**Upper 95% confidence limit**	**Point estimate**	**Lower 95 % confidence limit**	**Upper 95% confidence limit**
Cormorant	109	40	200	135	79	201
Fulmar	0	0	0	51	14	103
Gannet	20	0	50	61	23	107
Great northern diver	10	0	30	0	0	0
Guillemot	1108	799	1457	728	547	930
Gull spp.	0	0	0	47	14	89
Herring gull	0	0	0	19	5	37
Razorbill	120	40	230	0	0	0
Shag	0	0	0	23	0	65
Coastal static nets	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Cormorant	92	26	171	161	89	245
Fulmar	0	0	0	0	0	0
Gannet	13	0	39	6	0	18
Great northern diver	13	0	39	0	0	0
Guillemot	1265	868	1711	839	614	1092
Gull spp.	0	0	0	0	0	0
Herring gull	0	0	0	18	0	42
Razorbill	158	53	289	0	0	0
Shag	0	0	0	30	0	89
Offshore static nets	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Cormorant	5	0	14	5	0	14
Fulmar	0	0	0	30	8	60
Gannet	1	0	4	33	11	60
Great northern diver	0	0	0	0	0	0
Guillemot	19	9	31	41	22	63
Gull spp.	0	0	0	27	8	49
Herring gull	0	0	0	3	0	8
Razorbill	0	0	0	0	0	0
Shag	0	0	0	0	0	0

Channel midwater trawl	point GNS	LCL GNS	UCL GNS	point CS	LCL CS	UCL CS
Cormorant	1	0	4	0	0	1
Guillemot	4	0	10	5	0	12
Razorbill	0	0	0	1	0	1
Longline All	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Fulmar	948	118	2168	4239	1943	7632
Gannet	79	0	236	168	0	394
Great black-backed gull	0	0	0	55	0	169
Gull spp.	0	0	0	56	0	141
Kittiwake	0	0	0	28	0	84
Longline North (4a,6a)	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Fulmar	941	118	2168	4217	1885	7627
Gannet	79	0	236	86	0	232
Great black-backed gull	0	0	0	57	0	174
Gull spp.	0	0	0	58	0	145
Kittiwake	0	0	0	28	0	87
Longline South (7bcj)	**point GNS**	**LCL GNS**	**UCL GNS**	**point CS**	**LCL CS**	**UCL CS**
Fulmar	0	0	0	133	0	319
Gannet	0	0	0	80	0	239
Great black-backed gull	0	0	0	0	0	0
Gull spp.	0	0	0	0	0	0
Kittiwake	0	0	0	0	0	0