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Risk Assessment of Bycatch of Protected Species in Fishing Activities



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Executive Summary

In the EU, all cetaceans are strictly protected under the Habitats Directive, and all seabird species occurring naturally in the wild state are protected under the Birds Directive. In addition, for species listed in Annex II of the Habitats Directive and for birds listed in Annex I of the Birds Directive (as well as for the regularly occurring migratory birds), Natura 2000 sites (protected areas) need to be designated and effectively managed in order to enable those species to reach favourable conservation status. One of the main causes of at-sea mortality for marine birds and mammals is entanglement in fishing gear, commonly referred to as bycatch. The general aim of this contract is to advance the knowledge on bycatch risk for species protected under the EU Birds and Habitats Directives, focusing upon cetaceans and seabirds. Here, we focus upon those species vulnerable to bycatch and occurring regularly in the North-Eastern Atlantic region between southern Scandinavia and the Iberian Peninsula. The results should help identify the most appropriate areas and times of year to focus bycatch monitoring programmes and to implement conservation measures to eliminate or minimise bycatch, as required by the directives and the EU Biodiversity strategy for 2030.

Fishing vessels over 12 metres overall length within the European Union are legally required to carry a vessel monitoring system (VMS), a form of satellite tracking which transmits the vessel's identity, position, course and speed at least every two hours. There are reciprocal agreements with non-EU countries, such as Norway and Faroes as well as Regional Fisheries Management Organisations. When linked to the vessel's log book, these provide important information not only on fishing effort but also the gear used and catches. During transmission, the VMS information is encrypted so that confidentiality is maintained with data transfer certified. Flag states control and protect the data, deciding when and with whom to share it.

Automatic Identification Systems (AIS), another form of vessel tracking, was introduced by the International Maritime Organisation (IMO) to improve maritime safety and avoid ship collisions in the 1990s. AIS is a very high frequency (VHF) radio-based tool which automatically transfers information about the ship to other ships and coastal authorities. More recently, it has been identified as a useful tool to contribute to fisheries research and enforcement efforts since the data are publicly available. In 2014, all fishing vessels above 15 metres overall length within the European Union were required to carry AIS. In addition, an increasing number of fishing vessels (including those of 10-15m length) use AIS voluntarily as an aid to navigation, and as an operational and safety tool.

AIS was initially designed to communicate with vessels in line of sight which therefore limited coverage from land-based receivers. Since 2018, AIS receivers, however, have been placed on low-earth orbit satellites. This has greatly increased coverage and means that AIS signals can be detected from vessels operating beyond the 40nm range of land-based AIS receivers.

Using AIS data provided by Global Fishing Watch, for this contract, maps were prepared of fishing effort for ten gear type groupings (pelagic trawls, pelagic seines, demersal trawls, demersal seines, driftnets, static gillnets, trammel nets, set longlines, drifting longlines, pots & traps) for the Atlantic area from southern Norway to Portugal covering the years 2015 to 2018. A comparison with VMS maps, produced by ICES, was made for the same period for

three different ecoregions (Bay of Biscay & Iberian Peninsula, Celtic Seas, and Greater North Sea), and generally showed good correspondence in terms of relative levels of fishing effort. Any notable discrepancies were highlighted. Some adjustments were made to take account of polyvalent fisheries (i.e. fisheries where vessels may switch from one gear to another which otherwise may not correspond to the gear type registered), in consultation with regional fisheries experts. AIS maps of fishing effort by gear type were then prepared by season, by year (2015-18), and by EU member state.

Twelve seabird species (red-throated diver, Manx shearwater, Cory's shearwater, northern fulmar, northern gannet, European shag, herring gull, lesser black-backed gull, black-legged kittiwake, common guillemot, razorbill, and Atlantic puffin) and twelve cetacean species (harbour porpoise, bottlenose dolphin, common dolphin, striped dolphin, white-beaked dolphin, Atlantic white-sided dolphin, Risso's dolphin, killer whale, long-finned pilot whale, sperm whale, minke whale and fin whale) were selected on the basis of their regular occurrence in a significant portion of the study area. Maps of density distributions of each species were prepared by season using a modelling approach that incorporated environmental variables applying to two oceanographic domains: southern Scandinavia to NW France (northern) and NW France to southern Portugal (southern). These were based upon 1.25 million kilometres of dedicated survey effort for the northern domain, and 0.82 million kilometres for the southern domain, provided by 47 research groups, with surveys undertaken across the period 2005 to 2020.

To create maps of relative risk of bycatch for cetacean and seabird species, standardised AIS effort rasters and animal density rasters were multiplied to create new rasters of relative bycatch risk. Values approaching 1 would indicate that the highest densities of animals correspond with the highest density of fishing pressure, representing the greatest risk; those approaching 0 would indicate that the lowest densities of animals correspond with the lowest density of fishing pressure, representing the greatest risk; those density of fishing pressure, representing the lowest risk. Intermediate scores could represent high densities but low effort or the converse. Overlap for every species-gear type combination was mapped separately for northern and southern domains on a seasonal basis, and with overlays of protected areas. Pelagic trawls and seines were combined, as were set gillnets, trammel nets and drift nets; this was because of uncertainties revealed in the fishing effort data as to whether they had been correctly ascribed across the entire region, due largely to the polyvalent nature of fishing gear registered in some areas. Risk maps were prepared for all twenty-four species (seabirds and cetaceans) along with a map for Balearic shearwater, an endangered species that enters the southern domain from the Mediterranean.

The susceptibility to bycatch for each species and gear type were scored, based upon a review of a little over one hundred bycatch publications, assessments by the ICES fishPi project, annual reports of bycatch to the ICES Working Group on Bycatch of Protected Species, and expert elicitation. Those combinations that scored highest (colour coded red) were included in this report but all were mapped irrespective of the assessment of their susceptibility to bycatch.

1. Introduction

The general aim of this contract is to advance the knowledge on bycatch¹ risk for species protected under the EU Birds² and Habitats³ Directives, focusing upon cetaceans and seabirds. In the EU, all cetaceans are strictly protected under the Habitats Directive, and all seabird species occurring naturally in the wild state are protected under the Birds Directive. In addition, for species listed in Annex II of the Habitats Directive and for birds listed in Annex I of the Birds Directive (as well as for the regularly occurring migratory birds), Natura 2000 sites⁴ (protected areas) need to be designated and effectively managed in order to enable reaching the favourable conservation status of these species. Here, we focus upon those species vulnerable to bycatch and occurring regularly in the North-Eastern Atlantic region between southern Scandinavia and the Iberian Peninsula. The results should help identify the most appropriate areas and times of year to focus bycatch monitoring programmes and to implement conservation measures to eliminate or minimise bycatch, as required by the directives and the EU Biodiversity strategy for 2030⁵.

The specific objective is to provide quantitative and spatial information on bycatch risk for cetaceans and seabirds in the shelf seas of the North-Eastern Atlantic between southern Norway and Portugal. Bycatch risk is assessed as the spatiotemporal overlap between fishing effort using gear types known to cause bycatch and distribution of seabird and cetacean species. In order to achieve this, maps of seasonal fishing effort by gear type and country (flag state) were prepared using publicly available AIS⁶ data as well as maps of density distributions of species modelled from dedicated surveys for twelve regularly occurring seabird species and twelve cetacean species, all known to suffer bycatch. These are averaged across four years (2015-18) for each season. The spatial overlap between fishing effort and species densities is then mapped on a seasonal basis to represent relative risk of bycatch. The information can be used by Member State authorities to improve their bycatch monitoring programmes and the implementation of the necessary measures to prevent bycatch as required by the Birds and Habitats Directives. It can furthermore be used by the Commission in the context of the implementation and enforcement of the EU Birds and Habitats Directives and the implementation of the Biodiversity strategy. It could also be used to inform and plan future risk assessments in other EU regional seas.

¹ Accidental capture of species in fishing gear

 $^{^2}$ Directive 2009/147/EC of the European Parliament and of the Council of 30 November 2009 on the conservation of wild birds, OJ L 20, 26.1.2010, p. 7–25

³ Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora, OJ L 206, 22.7.1992, p. 7–50

⁴ Natura 2000 - Environment - European Commission (europa.eu)

⁵ EUR-Lex - 52020DC0380 - EN - EUR-Lex (europa.eu)

⁶ "automatic identification system" - a system that allows ships to view marine traffic in their area and to be seen by that traffic

2. Methodology

2.1. Mapping Fishing Activity

Publicly available 10th-degree resolution AIS fishing effort data from 2015-18 including date, gridded location (latitude: the southern edge of the grid cell, longitude: the western edge of the grid cell, both in tenths of a degree), vessel Maritime Mobile Service Identity (MMSI) numbers and fishing hours were downloaded from Global Fishing Watch (GFW). The corresponding GFW vessels list including MMSI, callsigns, gear classification and flag state were also downloaded from GFW (in 2018). Detailed information concerning gear type (métier), gear mobility, vessel length, vessel tonnage, hull material and vessel country were collected from the EU Vessel Registry and combined with the GFW fishing effort data using International Radio Call Sign (IRCS) data linked to MMSI numbers from the GFW vessels list.

To preserve the spatial distribution of the fishing effort data and prevent distortion of spatial patterns, initial data processing and rasterization were completed in the same Coordinate Reference System (CRS) of the raw data: WGS84. Data were isolated by year and season, and the following mobile and static gear types, regarded as the most prevalent in cetacean and seabird bycatch, were isolated for analyses: 1) Pelagic Trawl (OTM, PTM); 2) Demersal Trawl (OTB, OTT, PTB); 3) Purse Seine (PS, LA); 4) Demersal Seine (SDN, SPR, SSC); 5) Set Gillnet (GNS, GNC, GTN); 6) Trammel Net (GTR); 7) Set Longline (LLS); 8) Drifting Longline (LLD); 9) Drift Net (GND); and 10) Pots (FPO). Resultant data frames of AIS effort data were rasterized in WGS84 and cropped to the study region. Rasters were subsequently converted to UTM30N and resampled using bilinear interpolation at a 10km x 10km/100km² resolution. Fishing effort was mapped for the entire study region (all EU and non-EU countries included) per gear type and the mean daily fishing effort calculated across the period, 2015-18. To indicate seasonal variation of effort per gear type, effort maps per quarter (Jan-Mar, Apr-Jun, Jul-Sep, and Oct-Dec) were produced, averaged for 2015-18.

To indicate how fishing effort has varied across years between 2015 and 2018, time series of fishing effort were produced by extracting fishing hours per cell from effort rasters and calculating mean fishing hours per km² per day. Fishing effort data were also split by gear type per year and the mean daily fishing effort per km² calculated for the entire study area per year.

2.1.1. Comparisons between VMS and AIS

The Vessel Monitoring System (VMS) is a form of satellite tracking using transmitters on board fishing vessels. The system is a legal requirement for EU member states for all fishing vessels over 12 metres overall length under EC Regulation No. 2244/2003. A basic VMS unit consists of a GPS receiver which plots the position of the vessel coupled with a communications device which reports the position at a minimum of every two hours. To gain a position fix, a GPS receiver must have four GPS satellites within line-of-sight. GPS satellites are Low Earth Orbiting satellites arranged in constellation with the orbits scheduled so that at least six satellites are within line-of-sight from almost anywhere on the Earth's surface. The VMS unit

automatically sends data regarding the vessel's identification, its geographical position, date/time (UTC) of fixing of position, and course and speed on a pre-determined timescale.

Information must be transmitted once every two hours. There are reciprocal agreements with non-EU countries, such as Norway and Faroes as well as Regional Fisheries Management Organisations (RFMOs) such as NEAFC, where the requirement to report position is once every hour. During transmission, the VMS information is encrypted so that confidentiality is maintained with data transfer certified. Flag states control and protect the data, deciding when and with whom to share it.

VMS was developed in the 1990s for vessel monitoring, control and surveillance. The system was to address key concerns facing both fishing vessels and the regulatory authorities, such as national sovereignty issues with boats fishing in another nation's territorial waters, combating illegal fishing, and sustainably monitoring marine resources. Fisheries research in the EU is heavily reliant on effort, catch and fleet capacity data from the fleet register, logbooks, sales notes, and the Vessel Monitoring System (see Council Regulation (EC) No 1224/2009). Whereas VMS data provide detailed information on the vessel tracks at high spatial and temporal resolution, the logbooks include essential information on the gear used, species, and volume of the catches.

Two main software libraries, VMStools and VMSbase, have been developed in the R statistical language to process and analyse VMS and logbook data. Both libraries provide functionalities for cleaning the data, interpolating between consecutive VMS messages, merging VMS and logbook data, clustering the fleet into métier, discriminating between fishing and not fishing activity, and producing high resolution maps of fishing effort (Natale *et al.*, 2015). Various methods are developed to discriminate between fishing and non-fishing (e.g. transiting) activity, generally based upon an analysis of vessel tracks and speed profiles (speeds of between 0.1 and 6 knots, depending upon the type of gear deployed, are usually interpreted as fishing).

Automatic Identification Systems (AIS) were introduced by the International Maritime Organisation (IMO) to improve maritime safety and avoid ship collisions. AIS is a very high frequency (VHF) radio-based tool which automatically transfers information about the ship to other ships and coastal authorities. More recently, it has been identified as a useful tool to contribute to fisheries research and enforcement efforts (Natale *et al.*, 2016; Vespe *et al.*, 2016; Kroodsma *et al.*, 2018; FAO 2019). In 2014, all fishing vessels above 15m overall length within the European Union were required to carry AIS. In addition, an increasing number of fishing vessels (including those of 10-15m length) use AIS voluntarily as an aid to navigation, and as an operational and safety tool.

AIS was initially designed to communicate with vessels in line of sight which therefore limited coverage from land-based receivers. Since 2018, AIS receivers, however, have been placed on low-earth orbit satellites. This has greatly increased coverage and means that AIS signals can be detected from vessels operating beyond the 40nm range of land-based AIS receivers. There remain some technological limitations to AIS, but steps are continually being taken to improve AIS performance, including the recent launch of more and improved satellites. All of

these factors have contributed to increasing the utility of AIS as a fisheries monitoring tool (Natale *et al.,* 2015; Kroodsma *et al.,* 2018; FAO, 2019; Ferra *et al.,* 2020).

A summary of the characteristics, strengths and weaknesses of both VMS and AIS is given in Table 1. VMS is recognised as the gold standard for collection of data on fishing effort. Its strength is that it is compulsory for all vessels above 12 metres length; it can also be linked to electronic logbooks for additional information on catches, etc. Its limitations are that the information is unavailable except to national authorities or regional fisheries management organisations, and, generally, information on the position and speed of the vessel is transmitted only every two hours, although algorithms can be used to assess whether the vessel is likely to be engaged in active fishing. The strengths of AIS are that data are unencrypted and publicly available, and transmission is more or less continuous (every few seconds, whilst every three minutes AIS devices broadcast the vessel's identity, including call sign, name, IMO number, activity, and size). It is the least expensive vessel monitoring system capable of both near shore and high seas monitoring, although there may remain areas where signal reception is poor, and vessels can also turn off their AIS transmitter. Vessels between 12-15m length are not obliged to carry AIS if they operate within national waters or their fishing trips last less than 24 hours, whereas they must carry VMS. On the other hand, some small vessels that do not need to use VMS do have AIS units on board.

Table 1. Measuring fishing effort using GFW AIS data vs VMS data

Feature	Global Fishing Watch	VMS (as used by ICES)			
		ICES rectangles			
Spatial resolution	0.1 x 0.1 decimal degree	0.5 x 1.0 decimal degree			
Temporal resolution	Daily	Quarterly			
Temporal availability	2015-2018	2015-2018			
Accompanying landings data	No	Yes			
No. of gear classes	8	>30			

a) Characteristics of Global Fishing Watch & VMS

b) Comparison of AIS vs VMS

_	Automatic Identification	Vessel Monitoring System
Feature	System (AIS)	(VMS)
Cost per message	€	€€€
Message reception	Not guaranteed	Guaranteed
Signal reliability	Variable	Good
Fleet	Vessels >15m	Vessels >12m
Overall coverage	+++	++
Vessel Identity	Can be falsified	Strictly validated
Access restrictions	Possible	Frequent

Software and analytical capacity is required to translate raw AIS data into usable intelligence. We have used Global Fishing Watch (GFW) data (Kroodsma *et al.*, 2018; FAO, 2019). GFW uses two core algorithms, one to identify vessels and a second model to identify fishing activity.

Every vessel is required to have a unique MMSI number and a corresponding unique callsign. Using the MMSI and callsigns in the GFW vessels list, each MMSI in the fishing effort data can be checked against the EU vessel register to identify the gear type associated with that vessel. However, some fleets are polyvalent carrying more than one gear type and yet assigned to only one of these in the register. We have therefore sought advice from regional fisheries experts as well as consulting fisheries literature, to better establish which gear types are used and when, and have attempted to address this wherever possible when assigning fishing effort to a specific gear type. Nevertheless, there may be occasions when a vessel has switched between bottom trawling to midwater trawling or the converse, which we have not identified. GFW also uses a model to identify vessel characteristics, including vessel size and gear type, based on vessel movements to identify those vessels not matched to official registries, although this is more relevant to vessels in some other parts of the world. For those, the model uses a convolutional neural network trained to distinguish vessel type, vessel size, tonnage and/or engine power from the movements of known vessels in the matched database. For a vessel to be assigned a specific gear type, both a registry and the neural network vessel classifier had to agree (Kroodsma et al., 2018, 2019). It should be noted that vessels can be misclassified to gear type even within the EU register (Kroodsma et al., 2019).

A second model using another convolutional neural network is applied to identify whether a vessel is fishing or engaged in transiting or other non-fishing activity. Datasets were used to train the model taking account of vessel speeds and tracks for different specific gear types. For this classification, only times with likely gear in water or hauling gear were considered fishing operations. Searching was classified as "not fishing" even though searching by some fishing gears is sometimes included in measures of fishing hours (e.g. purse seines, trolling) (Kroodsma et al., 2019). To translate the placing or hauling of fishing gear, as measured by the neural net, into hours of fishing operations, each position is assigned half the time to the previous and next AIS position. Time between positions is calculated up to 24 hours between positions; after that, no time is assigned. If the position is classified as fishing, then all the time associated with that position is considered "fishing" (Kroodsma et al., 2019). It should be noted, however, that whereas by using fishing hours, fishing operations can be mapped in high detail, comparing fishing hours across gear types can be problematic because vessels will spend a different portion of the day with their gear in the water. A purse seine, for example, will either be setting or hauling for a small fraction of their time at sea, while a drifting longline will be setting or hauling for the majority of a given day while fishing. Thus, the time period over which a marine mammal or bird species may be vulnerable to bycatch varies between gears. Similarly, the amount of gear will likely vary according to vessel size which is not accounted for in the measurement of fishing effort here.

GFW-1	GFW-2	GFW-3	EU codes*
Drifting longlines			LLD
Pole and line			LHM, LHP
Trollers			LTL
Fixed gear	Pots & traps		FPO
	Set longlines		LLS
	Set gillnets		GNS, GTN, GTR, GNC
Trawlers		Pelagic trawls	PTM, OTM
		Demersal trawls	PTB, OTB, OTT
Dredge fishing			DRB, DRH, HRD
Seiners	Purse seines		PS, LA
	Other seines	Demersal seines	SDN, SPR, SSC
Driftnets			GND

Table 2. Gear type classifications used by GFW and corresponding EU gear codes

*Where GFW does not differentiate a gear type, the gear codes assigned to the vessel in the EU Register were used.

Gear types are classified by name in the GFW AIS datasets using only a small number of general categories, and so in order to identify these according to EU gear codes, the EU Vessel Register was consulted to determine which primary gear code was allocated to a particular vessel. Table 2 summarises which EU gear codes have been allocated to which GFW gear name.

To compare effort recorded using AIS (publicly available) and VMS (restricted access), variation in effort per gear type for the two systems were visually compared with published maps produced by the ICES Working Group on Spatial Fisheries Data (WGSFD) by ecoregion for the same period 2015-2018.

Under each fishing gear group, the data were further split per EU member state (i.e. showing fishing effort of vessels flying a flag of certain EU country). For the four fishing gears that pose the greatest bycatch risk (Demersal Trawl, Pelagic Trawl, Set Gillnets and Trammel Nets), fishing effort was mapped across 2015-2018, seasonally and annually. For the remaining six fishing gears which pose a lower bycatch risk (Drifting Longlines, Set Longlines, Drift Nets, Pelagic Seine, Demersal Seine and Pots), fishing effort was mapped across 2015-2018 only. Fishing effort per EU member state is presented as mean fishing hours/km²/day.

2.2. Species Distribution Maps

2.2.1. Data Collation

Wherever possible, analyses in the current project focused on survey data collated for the NERC/DEFRA funded Marine Ecosystems Research Programme (MERP). These data are

described in Waggitt et al. (2020) and, at the time of publication, amounted to 2.63 million km surveyed from 50 sources. New permissions were sought to include restricted access (i.e. not open-access and/or government funded) datasets used in Waggitt et al. (2020) in the current project, and analyses associated with this new project only included those where permission was granted. Additional survey data were also sought, including recent surveys (2015-2020) from existing sources and new sources, particularly in the Portuguese and southern Spanish EEZ where previous coverage was limited. Improved cleaning and processing approaches have also increased the amount of survey data from original data suppliers suitable for analyses. As before, only survey data collected in less than Beaufort Scale 4 was considered for analysis, as detectability would be compromised in rougher weather. However, unlike before, only survey data collected since 2004 was included, ensuring that density distribution maps were representative of recent decades. A summary of survey data (sources and km travelled) for the new analyses within this project are provided in Table 3. Please see Section 2.2.8 for an explanation of northern and southern domains. In total, 1.25 million km was available for the northern domain, and 0.82 million km for the southern domain.

Table 3. Sources of Cetacean & Seabird Survey Data used in the Analysis

Source	Таха	North (Km)	South (Km)
Aarhus University	Cetaceans	1760	0
Bottlenose Dolphin Research Institute	Cetaceans	0	4939
Bundesamt für Naturschutz	Cetaceans	9707	0
Bureau Waardenburg/Delta Project Management	Seabirds and Cetaceans	70875	0
Crown Estate	Seabirds and Cetaceans	135314	5222
Coordinadora para o Estudo dos Mamíferos Mariños	Cetaceans	13814	21585
CETUS Project	Cetaceans	949	371895
CGFS Surveys	Seabirds and Cetaceans	4461	3938
CODA Surveys	Seabirds and Cetaceans	5451	3537
Cetacean Research and Rescue Unit	Cetaceans	19050	0
DUNKRISK Surveys	Seabirds and Cetaceans	8045	14
ECOCADIZ Surveys	Seabirds and Cetaceans	0	4687
EVHOE Surveys	Seabirds and Cetaceans	7855	7855
FTZ, University of Kiel	Seabirds and Cetaceans	30439	0
Hebridean Whale and Dolphin Trust	Cetaceans	45487	0
IBERAS Surveys	Seabirds and Cetaceans	0	927
IBTS Surveys	Seabirds and Cetaceans	3856	1707
International Fund for Animal Welfare/MCR	Cetaceans	11109	6730
Institute for Marine Resources and Ecosystem Studies	Cetaceans	33147	0
Research Institute for Nature and Forest	Seabirds and Cetaceans	23825	112
Irish Whale and Dolphin Group	Cetaceans	57492	24996
Joint Nature and Conservation Committee	Seabirds and Cetaceans	46251	1540
KOSMOS Surveys	Cetaceans	9331	3681
Marine Science Scotland	Seabirds and Cetaceans	9143	0
Manx Whale and Dolphin Trust	Cetaceans	6306	0
Natural England	Seabirds and Cetaceans	5097	3727
Royal Netherlands Institute for Sea Research	Seabirds and Cetaceans	2	0
National Parks and Wildlife Service	Cetaceans	2634	892
OBSERVE Surveys	Seabirds and Cetaceans	41103	18656
Ornis Consult	Seabirds and Cetaceans	0	0
ORCA	Cetaceans	90908	47321
PELACUS Surveys	Seabirds and Cetaceans	7599	10601
PELGAS Surveys	Seabirds and Cetaceans	38774	38774
PELTIC Surveys	Seabirds and Cetaceans	2634	2634
Royal Belgium Institute of Natural Sciences	Seabirds and Cetaceans	19637	0
Royal Society for the Protection of Birds	Seabirds	883	0
SAMM Surveys	Seabirds and Cetaceans	50508	47696
PELAGIS/SCANS3 Surveys	Seabirds and Cetaceans	9833	9833
SCANS1 Surveys	Cetaceans	0	0
SCANS2 Surveys	Cetaceans	26686	9448
SIAR Surveys	Cetaceans	0	0
NatureScot	Cetaceans	2691	0
Sociedade Portuguesa para o Estudo das Aves	Seabirds and Cetaceans	274	53672
Sea Watch Foundation	Cetaceans	38664	26142
University of Veterinary Medicine Hannover, Foundation	Cetaceans	84807	0
University College Cork	Seabirds and Cetaceans	0	0
UK Oil and Gas	Seabirds and Cetaceans	1809	0
University of Aberdeen	Cetaceans	12192	0
Vogelwarte Helgoland	Seabirds and Cetaceans	24256	0
Whale and Dolphin Conservation	Cetaceans	6950	946
Wildfowl and Wetlands Trust	Seabirds and Cetaceans	227807	86629

2.2.2. Data Standardisation

The collation in Table 3 contained survey data collected using a wide range of methods including aerial/vessel platforms, line/ESAS/strip transects, and visual/digital observations. Survey data are also collected across different weather conditions, most notably differences in sea state. The primary difference amongst methods and weather conditions is the area covered, and quantifying variations in the area covered amongst survey data helps to standardise measurements of distribution and densities. To estimate the area covered for a particular survey, the effective strip width (esw) and g(0) were calculated across different platforms and sea states using detection function models (Buckland et al., 2001). Further details on methods and rationale are provided in Waggitt et al (2020). For all of the 24 species included in Waggitt et al. (2020), detection functions were sourced from those calculated in these previous analyses. For additional species not included in Waggitt et al. (2020), (Balearic shearwater, Cory's shearwater, and red-throated diver), new detection functions were either sourced from comparable species in these previous analyses or produced from data where permissions were obtained. Because of the similarities in appearance and behaviour, existing detection functions in Waggitt et al. (2020) for Manx shearwater and large gulls (herring gull and lesser black-backed gull) were applied to Balearic shearwaters and great black-backed gulls, respectively. For Cory's shearwaters and red-throated divers, the approaches used to produce new detection functions in this project were identical to those in Waggitt et al. (2020). Sightings of black-throated diver, great northern diver and unidentified divers were included in the production of detection functions for red-throated diver, increasing sample sizes and allowing better estimation of variations in detectability amongst platforms and seastate. Unfortunately, in the datasets available for analyses, suitable sightings of Cory's shearwaters (distances and behaviour, i.e. water or in flight) were completely absent in aerial line-transect surveys and extremely scarce in vessel line-transect surveys. This created issues because comparable species were absent from previous analyses. It was decided to omit aerial line-transect surveys from analyses because this species has a primarily Iberian distribution and aerial line-transects occurred exclusively around the UK coastline. However, despite the extremely low-sample size, the esw estimated for flying and sitting Cory's shearwaters vessel line-transect surveys seemed reasonable (~200m and 160m, respectively) and broadly agreed with the esw estimated for this species and survey method recently (Astarloa et al. 2021). Therefore, it was decided to retain these estimations, but seek additional data permissions in future analyses. The new detection functions for red-throated diver and Cory's shearwater are summarised in Table 4.

Table 4. Summary of esw calculations for red throated diver and Cory's shearwater: sample size (n), response type (hr = hazard rate, hn = half normal: Res), slope estimate for platform height (PL), slope estimate for sea state (SS), probability of detection up to the maximum esw (Pr), standard error in the probability of detection up to the maximum esw (Se) and coefficient of variation in probability of detection up to the maximum esw (CV).

Species	Survey	Behaviour	n	Res	PL	SS	Pr	Se	cv
Red-throated Diver	Aerial-Line (1000m)	Flight	38	Hr	0.00	0.00	0.49	0.05	0.09
		Water	9760	Hr	-0.03	0.00	0.27	0.00	0.01
	Vessel-Line (1000m)	Flight	819	Hr	-0.04	0.00	0.29	0.01	0.03
		Water	22	Hr	0.00	0.00	0.14	0.05	0.37
	ESAS (300m)	Water	1503	Hr	0.00	0.00	1.00	0.00	0.00
Cory's Shearwater	Vessel-Line (1000m)	Flight	2	Hr	0.00	0.00	0.20	0.00	0.01
		Water	2	Hn	0.00	0.00	0.16	0.12	0.77
	ESAS (300m)	Water	430	Hn	-0.77	-2.48	0.94	0.03	0.03

2.2.3. Environmental Variables

To produce density distribution maps at regional and monthly-scales, environmental variables needed to discriminate among consistently different habitats (e.g. shallow versus deep, warm versus cool) and seasons (e.g. coolest versus warmest months). Sea temperatures (°C) were sourced from oceanographic models available from the Marine Environmental Monitoring Systems (http://marine.copernicus.eu), and provided at monthly and ~7km resolution values. Values of seabed depth (m) were sourced from the EMODnet archive and provided at approximately 1km resolution (http://www.emodnet-bathymetry.eu). To correspond with the cells used in the analysis, values of environmental variables are resampled at 10km resolution. A full description of the environmental variables and rationale for their inclusion are provided in Waggitt et al. (2020). Several additions were also made to this suite of environmental variables. First, to improve predictions in shelf-seas, average stratification intensity (absolute range in temperature between the 0 and 150m depth) was included to discriminate between mixed water columns in areas of stronger tidal currents and shallow bathymetry, and more stratified water columns in areas of weaker tidal currents and/or deeper depths. Average stratification intensity has been shown to strongly explain the distribution of animals in shelf-seas (Scott et al., 2010). Second, front intensity was included as an interaction with regional temperature rather than in isolation. Animals could increase their use of frontal-regions during warmest months, where the differences between adjacent water-masses intensify due to reduced wind and solar-warming (Scales et al., 2014).

2.2.4. Data Processing

Waggitt *et al.* (2020) focused on the North-East Atlantic between northern Iberia and southern Norway. The expansion of the study region into southern Iberia, including the entire Spanish Atlantic and Portuguese EEZ, necessitated changes because no single oceanographic model covered the entire area, and it was deemed inappropriate to combine environmental variables from different oceanographic models. To overcome this challenge, the study region was divided into two model domains: a northern domain spanning from just north of Shetland to Brittany in France, and a southern domain spanning from Brittany to the north-west African coastline. The model domains are illustrated by the survey data maps provided in the

Supplementary Material. The northern domain used FOAM AMM7 outputs whereas the southern domain used IBI MFC outputs. Due to differences in oceanographic model outputs processed at the time of analyses, values of temperature from FOAM AMM7 outputs represented average values in the upper 150m of the water column, whereas those from IBI MFC outputs represented values at the sea surface. Therefore, tidal fronts in the latter were represented by horizontal gradients in average sea surface temperature across months whilst those from the former were identified by similar gradients in the average stratification intensity across months. As only sea surface temperature was provided in IBI MFC outputs, stratification was not included in the southern domain. However, variation in on-shelf stratification would be negligible in the southern domain due to the narrow shelf width. There were also differences in the time-coverage of each model; IBI MFC outputs represented averages between 1993 and 2020, whereas FOAM AMM7 represented averages between 1985 and 2018.

For each domain, spatial and temporal variations in species presence (0 = absent, 1 = present), animal density (individuals per km²), the surface area covered (km²), and environmental characteristics were quantified in a 10km resolution orthogonal grid. On occasions where transects span several cells, transects were split into several sections, with each section occupying a single cell. These measurements are provided for each combination of platform, day, and cell. Each model domain included survey and environmental data slightly beyond their boundaries to improve detection of seasonal movements and distribution (see Supplementary Material). Therefore, some data contributed to both northern and southern domains. However, there was no overlap in prediction areas.

2.2.5 Model Setup

The model setup mirrored the generalized estimating equation-generalized linear model (GEE-GLM) hurdle approach described in Waggitt et al (2020) which quantified ecological associations between species presence/density and environmental variables, before using these associations to predict animal densities. However, there were a few amendments to these approaches in the current study. First, in Waggitt et al. (2020), the log of area covered (km²) was included as a statistical offset to account for differences in the area covered amongst samples in the presence model. This relationship assumed that the probability of encountering animals increased proportionally with increasing area before reaching a threshold. However, presumably, this relationship cannot be assumed. In this study, the relationship between probability of encounters and area covered was instead estimated through the inclusion of the latter as an additional explanatory variable. In Waggitt et al. (2020), using squareroot transformed densities and omitting the statistical offset accounted for variations in effort in the density model, whilst overcoming issues with overdispersion. However, like the use of the offset in the presence model, using densities assumes that the overall relationship between number of animals and area covered is linear. The distribution of animals is usually ephemeral, and increasing the area covered could increase the likelihood of encountering a large group, which then dramatically raises the recorded density. Therefore, to better account for any complicated relationships between densities and area covered, the latter was included as an additional explanatory variable in the density model. For both the binomial and negative binomial models, both area covered and the log of area covered were considered. Second, in Waggitt et al. (2020), the GEE component of GEE-GLM and detection functions were assumed to account for most differences in encounter rates

and densities linked to variation in survey method. However, some differences in animal behaviour and consequences on observations may not be completely accounted for. For example, detections of scavenging seabirds (great skua, northern gannet, northern fulmar, Laridae) or small Delphinidae may be higher from vessels due to animal attraction. Those of deep-diving cetaceans could also be higher in vessels because slower speeds mean they spend more time in an area. To better account for the differences, platform-type (vessel, plane) was included as a categorical explanatory variable in presence and density models.

2.2.6 Model Selection

Model selection generally followed approaches in Waggitt *et al.* (2020). However, following the inclusion of area covered and platform as an explanatory variable, forwards-model selection was performed for the density model as well as the presence-absence model. Suitable restrictions were included with additional explanatory variables: because negative associations with front intensity and distance travelled seem implausible, only positive relationships were retained. Tables 5-8 summarises the updated forwards-model selection.

Presence Model
Stage 1
Platform
Area Covered
log(Area Covered)
Platform + Area Covered
Platform + log(Area Covered)
Stage 2
Colony Index
Breeding Season
Colony Index + Breeding Season
Stage 3
Depth ²
Annual Temperature Variance
Depth ² + Annual Temperature Variance
Stage 4
Annual Temperature ²
Annual Temperature ² + Regional Temperature * Annual Temperature
Annual Temperature ² + Regional Temperature * Depth
Annual Temperature ² + Regional Temperature * Annual Temperature Variance
Density Model
Stage 1
Platform
Area Covered
log(Area Covered)
Stage 2
Seabed Roughness * Regional Temperature
Front Intensity * Regional Temperature
Seabed Roughness + Front Intensity *Regional Temperature

Table 5. Summary of the forwards-model selection used for the presence and density model for seabirds in the southern domain. 2 = Quadratic Term; * = Interactive Term.

Table 6. Summary of the forwards-model selection used for the presence and density model for cetaceans in the southern domain. 2 = Quadratic Term; * = Interactive Term.

Presence Model
Stage 1
Platform
Area Covered
log(Area Covered)
Platform + Area Covered
Platform + log(Area Covered)
Stage 2
Depth ²
Annual Temperature Variance
Depth ² + Annual Temperature Variance
Stage 3
Annual Temperature ²
Annual Temperature ² + Regional Temperature
Annual Temperature ² + Regional Temperature * Annual Temperature
Annual Temperature ² + Regional Temperature * Depth
Annual Temperature ² + Regional Temperature * Annual Temperature Variance
Density Model
Stage 1
Platform
Area Covered
log(Area Covered)
Platform + Area Covered
Platform + log(Area Covered)
Stage 2
Seabed Roughness * Regional Temperature
Front Intensity * Regional Temperature
Seabed Roughness + Front Intensity *Regional Temperature

Table 7.	Summary	of the	forwards-n	nodel	selection	used for	or the	presence	and	density	model	for
seabirds	in the nor	thern do	omain. 2 = (Quadra	atic Term;	* = Inte	eractiv	e Term.				

Presence Model
Stage 1
Platform
log(Area Covered)
Distform + Aroa Covered
Platform + log(Area Covered)
Stage 2
Stage 2
Prooding Season
Colony Index + Prooding Season
Colony index + breeding season
Sidge S
Appual Stratification
Annual Stratification
Annual Temperature Variance
Ponth ² + Annual Temperature Variance
Depth ² + Annual Stratification
Depth ² + Annual Temperature Variance + Annual Stratification
Annual Tomporaturo ²
Annual Temperature ² + Regional Temperature
Annual Temperature ² + Regional Temperature * Appual Temperature
Annual Temperature ² + Regional Temperature * Donth
Annual Temperature ² + Regional Temperature * Appual Temperature Variance
Annual Temperature ² + Regional Temperature * Annual Stratification
Density Model
Distorm
log(Area Covered)
Detform L Area Covered
Platform $\pm \log(Arca Covered)$
Stage 2
Front Intensity * Regional Temperature
Coshed Boughness L Front Intensity * Regional Temperature
Seased Roughness + Front Intensity Regional remperature

Table 8. Summary of the forwards-model selection used for the presence and density model for cetaceans in the northern domain. 2 = Quadratic Term; * = Interactive Term.

Presence Model
Stage 1
Platform
Area Covered
log(Area Covered)
Platform + Area Covered
Platform + log(Area Covered)
Stage 2
Depth ²
Annual Stratification
Annual Temperature Variance
Annual Temperature Variance + Annual Stratification
Depth ² + Annual Temperature Variance
Depth ² + Annual Stratification
Depth ² + Annual Temperature Variance + Annual Stratification
Stage 3
Annual Temperature ²
Annual Temperature ² + Regional Temperature
Annual Temperature ² + Regional Temperature * Annual Temperature
Annual Temperature ² + Regional Temperature * Depth
Annual Temperature ² + Regional Temperature * Annual Temperature Variance
Annual Temperature ² + Regional Temperature * Annual Stratification
Density Model
Stage 1
Platform
Area Covered
log(Area Covered)
Platform + Area Covered
Platform + log(Area Covered)
Stage 2
Seabed Roughness * Regional Temperature
Front Intensity * Regional Temperature
Seabed Roughness + Front Intensity *Regional Temperature

2.2.7. Predictions

As in Waggitt *et al.* (2020), densities (animals per km²) were predicted at monthly and 10km resolution using the appropriate model, before being averaged across months to provide quarterly densities for the current project. In most cases, distributions of species were produced in both domains, the exceptions being those with primarily northern or southern distributions; Balearic shearwaters and Cory's shearwaters were constrained to the southern domain whereas Atlantic white-sided dolphin, killer whale, and white-beaked dolphin were only predicted in the northern domain. In predictions, platform-type was defined as 'vessel' because this represented the commonest platform in both northern and southern domains. If population estimates of species were being sought, then the tendency for animals to be attracted/repelled from ships and be misrepresented by vessel surveys, or perform deep-dives and be missed by aerial surveys, would have been considered when selecting whether to use 'vessel' or 'plane' in SDM predictions. However, because project outputs were based on relative densities alone, the choice of platform in model predictions is negligible.

Model performance was evaluated qualitatively using current knowledge of species distributions, and quantitatively using area under the curve (AUC) and normalised root-mean-squared-error (NRMSE). AUC describes the ability of models to predict presences and absences in the original observations. NRMSE is the mean difference between predicted and observed values, which are standardised by dividing this difference by the range in the latter. Both produce indices with values between 0 and 1. AUC values approaching 1 and NRMSE approaching 0 represent better performance. Model performance is summarised in Table 9 below. Model performance was generally high (AUC > 0.80, NRMSE <0.20) for both cetaceans and seabirds in the northern domain, and seabirds in the southern domain. By contrast, performance was sometimes low for cetaceans in the southern domain (AUC <0.80), particularly for widespread and/or scarce species. This may relate to lower sample sizes and dynamic populations, with inconsistencies in seasonal distribution across the study period. However, general distributions and seasonality appeared sensible in most cases.

Таха	Species	Norther	n Domain	Southerr	Southern Domain		
		AUC	NRMSE	AUC	NRMSE		
Cetacean	Bottlenose Dolphin	0.92	0.07	0.69	0.07		
	Common Dolphin	0.87	0.06	0.73	0.05		
	Fin Whale	0.97	0.10	0.92	0.11		
	Harbour Porpoise	0.81	0.03	0.90	0.08		
	Killer Whale	0.88	0.17	n/a	n/a		
	Minke Whale	0.85	0.10	0.73	0.05		
	Pilot Whale	0.95	0.04	0.92	0.11		
	Rissos Dolphin	0.86	0.08	0.90	0.08		
	Sperm Whale	0.98	0.21	0.69	0.07		
	Striped Dolphin	0.98	0.09	0.73	0.05		
	White-Beaked Dolphin	0.84	0.06	n/a	n/a		
	Atlantic White-Sided Dolphin	0.95	0.13	n/a	n/a		
Seabird	Atlantic Puffin	0.88	0.08	0.88	0.18		
	Balearic Shearwater	n/a	n/a	0.90	0.09		
	Black Legged Kittiwake	0.82	0.04	0.89	0.05		
	Common Guillemot	0.81	0.04	0.88	0.08		
	Corys Shearwater	n/a	n/a	0.92	0.04		
	European Shag	0.96	0.17	0.94	0.19		
	European Storm Petrel	0.92	0.16	0.84	0.11		
	Great Black Backed Gull	0.81	0.04	0.85	0.06		
	Great Skua	0.86	0.11	0.81	0.10		
	Herring Gull	0.84	0.04	0.84	0.09		
	Lesser Black Backed Gull	0.85	0.05	0.80	0.07		
	Manx Shearwater	0.94	0.03	0.75	0.10		
	Northern Fulmar	0.81	0.04	0.83	0.08		
	Northern Gannet	0.76	0.05	0.79	0.06		
	Razorbill	0.87	0.02	0.89	0.12		
	Red throated Diver	0.91	0.05	n/a	n/a		
	Yellow Legged Gull	n/a	n/a	0.92	0.07		

Table 9. Quantitative evaluation of presence-absence and density GEE-GLM predictions using area under the curve (AUC) and normalised root mean squared error (NRMSE), respectively.

2.2.8. List of Species

Seasonal and overall density distribution maps were produced for the following species:

Birds

Red-throated Diver *Gavia stellata* Manx Shearwater *Puffinus puffinus* Cory's Shearwater *Calonectris borealis* Northern Fulmar *Fulmarus glacialis* Northern Gannet *Morus bassanus* European Shag *Phalacrocorax aristotelis* Herring Gull *Larus argentatus* Lesser Black-backed Gull *Larus fuscus* Black-legged Kittiwake *Rissa tridactyla* Common Guillemot *Uria aalge* Razorbill *Alca torda* Atlantic Puffin *Fratercula arctica*

Cetaceans

Harbour Porpoise Phocoena phocoena Bottlenose Dolphin Tursiops truncatus Common Dolphin Delphius delphis Striped Dolphin Stenella coeruleoalba White-beaked Dolphin Lagenorhynchus albirostris Atlantic White-sided Dolphin Lagenorhynchus acutus Risso's Dolphin Grampus griseus Killer Whale Orcinus orca Long-finned Pilot Whale Globicephala melas Sperm Whale Physeter macrocephalus Minke Whale Balaenoptera acutorostrata Fin Whale Balaenoptera physalus

All cetacean species are listed in Annex IV of the Habitats Directive and two cetacean species (harbour porpoise and bottlenose dolphin) are listed in Annex II of the Habitats Directive thus requiring designation of special areas of conservation (SACs). All of the marine bird species listed are ones requiring classification of special protection areas (SPAs) under the Birds Directive.

2.3. Bycatch Risk Mapping

Bycatch risk assessment was made for each of the species listed, based on the overlap of distribution/abundance data and fishing activity, expressed as relative risk and presented in maps.

Prior to risk analyses, AIS effort rasters and cetacean density rasters were standardised (0-1) by extracting raster values, dividing by the highest value and rasterizing. Due to the high volume of NA values present in AIS effort data, NA values have been converted to 0 to allow data to be displayed correctly.

To create maps of relative risk of bycatch for cetacean and seabird species, standardised AIS effort rasters and animal density rasters were multiplied to create new rasters of relative bycatch risk. Values approaching 1 would indicate that the highest densities of animals correspond with the highest density of fishing pressure, representing the greatest risk; those approaching 0 would indicate that the lowest densities of animals correspond with the lowest density of fishing pressure, representing the lowest density of fishing pressure, representing the lowest risk. Intermediate values could indicate either (1) higher values of animal densities overlapping with lower values of fishing density (2) lower values of animal densities overlapping with higher values of fishing density and (3) moderate values of animal densities overlapping with moderate values of fishing density. In all these instances, the level of risk should be assessed on a species by species basis. It needs noting that values are relative within model domains. Therefore, a high or low value in the northern domain may not necessarily represent a high or low value in the southern domain, respectively. This approach is necessary as direct comparisons of densities between domains are inappropriate due to different environmental values and model parameters.

Maps of relative risk by month were created for each cetacean and seabird species per gear type (métier) for the whole study region, averaged over the period 2015-18. From these maps, areas of high risk are identified to allow for interpretation of bycatch risk for specific gear type and species combinations throughout northwest European shelf seas from southern Norway to Portugal. Bycatch risk for each gear type per cetacean and seabird species are assessed based upon a consideration of the overlap between the species and fishing effort as well as species known vulnerabilities to particular gears as established from the bycatch literature as well as analyses undertaken by ICES WGBYC (2019).

All analysis of effort data, cetacean density data, and risk mapping has been performed in R v.4.0.0 using the following packages: dplyr (Wickam and Francois, 2015), ggplot2 (Wickham and Chang, 2015), raster (Hijmans, 2013), RColorBrewer (Neuwirth, 2014), rgdal (Bivand *et al.*, 2015), sf (Pebesma, 2018) and sp (Pebesma and Bivand, 2005). Those data are provided for EU waters in the eastern North Atlantic from southern Norway to southern Portugal, i.e. including marine waters of Portugal, Spain, France, Ireland, Belgium, the Netherlands, Germany and Denmark, but excluding the UK. However, for the marine area of abovementioned EU Member States, the fishing activity data are presented regardless of the flag state.

2.4. Bycatch Risk Mapping in marine Natura 2000 sites

Where cetacean or seabird species require protection in Natura 2000 sites, the risk of bycatch needs to be assessed with reference to the boundaries of the protected areas (Natura 2000 sites). Two cetacean species (bottlenose dolphin and harbour porpoise) are listed in Annex II of the Habitats Directive whilst several marine bird species are listed in Annex I of the Birds

Directive and together with regularly occurring migratory species not listed in Annex I, require Special Protection Areas (SPAs).

The maps that indicate bycatch risk in terms of overlap between species densities and fishing effort are overlain with the boundaries of relevant Natura 2000 sites designated for protection of those species (excluding sites with non-significant presence of species), using the most recent Natura 2000 database⁷ as provided by the European Commission.

3. Results

3.1. Fishing Effort

3.1.1. VMS vs AIS Comparison

As detailed in section 2.1.1 of the methods, AIS has its limitations for use in describing fishing effort. It is therefore important to evaluate potential biases within the region of interest. We have therefore mapped AIS fishing effort by gear type and compared these with maps using VMS produced by ICES in its latest ecoregion reviews derived from analyses by its Working Group on Spatial Fisheries Data, covering the same years, 2015-2018. These are compared for three ecoregions: Bay of Biscay & Iberian Peninsula; Celtic & Irish Seas; and Greater North Sea (ICES, 2019a, b, 2020). Only gear type categories plotted in those maps and for which cetaceans and seabirds are at risk of bycatch, are considered. These include: Bottom Otter Trawls (OT, OTB, OTT, OTS, PT, PTB, TB, TBN, TBS, TMS), Demersal Seines (SB, SDN, SND, SPR, SSC, SV, SX), Pelagic Trawls & Seines (OTM, PS, PTM, TM), and Static Gears (FG, FNC, FPN, FPO, FYK, GEN, GN, GNC, GND, GNF, GNS, GTN, GTR, LA, LHM, LHP, LL, LLD, LLS, LN, LNB, LTL, LX).

Figures 1-3 show the comparisons for the three ecoregions respectively. In the Bay of Biscay and Iberian Peninsula (Figure 1), VMS bottom otter trawl fishing effort is concentrated in the shelf waters of the Bay of Biscay, particularly in the northern sector near the French coast, and around the coast of north-west Spain and Portugal. The same areas show up in the AIS map, with highest effort in the north-east of the Bay, a small area in the south-east, off Galicia and along the coast of Portugal particularly on the south coast. It should be noted that the areas of higher fishing effort are highlighted by being in yellow, orange and red in order to meet the main objective of identifying areas of greatest fishing effort but effort is nevertheless on a continuous scale. VMS and AIS demersal seine fishing effort are both concentrated in the coastal north-east sector of the Bay of Biscay.

Pelagic trawl and seine fishing effort occurs widely in the Bay of Biscay but concentrated particularly around the coast and offshore along the shelf edge. Those same areas are highlighted in both VMS and AIS maps, although relatively high effort off north-west Spain shows up more strongly in the VMS map. Coastal fishing effort is high all along the west coast of Galicia and on the west and particularly south coasts of Portugal in the AIS map but is absent from most of the coast of Portugal in the VMS map. In the AIS map this is attributed

⁷ database version March 2021, end 2020 data

to seining effort. In both VMS and AIS maps, static gear is deployed particularly along the French coast in the north-east sector of the Bay of Biscay as well as all around the coast of the Iberian Peninsula, with highest effort in central west Portugal. Low level deployment of static gear (attributed to drifting longlines) is indicated in the AIS map which is scarcely present in the VMS map.

In the Celtic and Irish Seas (Figure 2), both VMS and AIS show bottom otter trawl effort to be concentrated in the western English Channel and South-west Approaches to the Channel, around the south-west of Ireland, along the shelf edge west of Ireland and the Hebrides, and north of Shetland. Hot spots of fishing effort occur also in the Minch and Sea of Hebrides west of Scotland, the Firth of Clyde, Dublin Bay, east of the Isle of Man, and off south-west Wales. All of these are revealed by both VMS and AIS. Demersal seine fishing activity is greatest off the south coast of Ireland, in the English Channel south of Devon, and around Shetland. Again, the distribution of effort is very similar between VMS and AIS.

In both VMS and AIS maps, pelagic trawl & seine fishing effort occurs mainly off the south coast of Ireland, along the shelf edge west of Ireland north to the west of the Outer Hebrides and the Northern Isles of Scotland. There are also individual hotspots in the Minch west of Scotland, in Dublin Bay and between eastern Ireland and the Isle of Man, and in the St George's Channel between south-east Ireland and south-west Wales. The Irish trawl fleet is polyvalent with vessels registered as demersal trawlers but at particular seasons (e.g. the winter herring season) switching gears to pelagic trawls (Gerritsen and Kelly, 2019). For static gear, fishing effort is greatest in the western English Channel, along the shelf edge of the Celtic Sea from west of NW France northwards west of Ireland and Scotland towards the Northern Isles of Scotland. There are smaller hotspots off south-west Scotland and in the Sea of Hebrides. Those same areas are all highlighted by both VMS and AIS.

In the Greater North Sea (Figure 3), the main areas of fishing effort are in the Skagerrak and eastern sector of the Kattegat, offshore west of SW Norway, east of Shetland and Orkney, in the Outer Moray Firth, Firth of Forth and off the Northumbrian coast, offshore in the central North Sea, in the German Bight, and the eastern and western English Channel. Most of these are revealed by both VMS and AIS, but fishing effort offshore in the northern and central North Sea show up more strongly in the VMS map compared with the AIS one. It is possible that in those offshore areas, AIS signal reception is poorer (see Vespe *et al.*, 2016). Nevertheless, the overall pattern is rather similar. Most demersal seining occurs in the eastern English Channel and off the coast of northern Denmark in the Skagerrak, but with some fishing effort also in the northern North Sea between SW Norway and the Northern Isles of Scotland, in the central North Sea west of Denmark and north of Germany and the Netherlands, and around the Dogger Bank. These are revealed in both the VMS and AIS maps but offshore tend to be stronger in the VMS data.

Pelagic trawl and seine activity is concentrated in four main areas: the Skagerrak; northwestern North Sea between the Northern Isles & north-east Scotland and south-west Norway; offshore in the central North Sea; and in the English Channel, particularly off the north coast of the Netherlands and France. Both VMS and AIS show the same distribution of effort although AIS shows relatively more effort between Belgium and south-east England whereas VMS shows higher effort offshore in the central North Sea where weak AIS signal reception may again be under-representing fishing effort there. Finally, VMS and AIS show similar patterns of usage of static gear with highest effort in the western and eastern English Channel, in the German Bight and off west Denmark, east of Shetland, and off the Yorkshire coast in eastern England. Some vessels may have been miss-assigned to particular gear types where AIS shows pelagic trawl & seine activity along the coast of SW Norway, and static gear usage in the Skagerrak off the south-west coast of Sweden whereas these do not show in the VMS maps.

In conclusion, for the most part, the distribution of fishing effort, and particularly hotspots, were similar between VMS and AIS maps. No attempt was made to compare total fishing effort between VMS and AIS as the main aim was to identify relative hotspots of effort within each gear type.



a) Bottom Otter Trawl





b) Demersal Seine



Figure 1 (cont.). Bay of Biscay & Iberian Peninsula AIS vs VMS Comparisons (VMS map reproduced from ICES, 2019a)

c) Pelagic Trawl & Seine





d) Static Gear



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a) Bottom Otter Trawl



a) Demersal Seine







c) Pelagic Trawl & Seine



d) Static Gear







a) Bottom Otter Trawl



a) Demersal Seine





c) Pelagic Trawl & Seine



d) Static Gear



3.1.2. Fishing Effort by Year

In order to establish whether there is much inter-year variation in fishing effort, plots were produced for each gear type under consideration for each of the years 2015 to 2018. These are presented in Figures 4-13. There are some small variations in effort between years but for all gear types, the main areas of fishing effort remain the same. The following are the main differences observed between years by gear type.

Pelagic trawls (Fig. 4)

In the northern part of the Greater North Sea, fishing effort shifted slightly northwards from east of the Moray Firth to east of the Northern Isles by 2018. Elsewhere in the North Sea and Channel, and in the Celtic Seas, there was very little change. In the Bay of Biscay, some variation in effort between years is indicated along the north coast of Spain.

Pelagic seines (Fig. 5)

These include purse seines, and effort is largely in the Bay of Biscay and around the Iberian Peninsula. There is also pelagic seining in the northern North Sea, with some indication of an increase in effort. Otherwise, there is very little variation in effort between years.

Demersal trawls (Fig. 6)

For all three ecoregions, the same main areas of demersal trawling effort are highlighted between years, with no areas showing any marked change in effort. However, some changes in fishing effort have taken place over this period. For example, trawling deeper than 800 m in the Celtic seas on the continental slope and offshore banks has been banned since December 2016. This deep-water trawl fishery mainly targeted roundnose grenadier, black scabbardfish, and blue ling.

Demersal seines (Fig. 7)

In the eastern sector of the Central North Sea, fishing effort was higher in 2016 compared with the other three years. The same may have been the case in the English Channel and off the coast of south-east Ireland. However, differences are small.

Driftnets (Fig. 8)

There is limited drift netting in the region, occurring mainly south and south-west of Ireland. Fishing effort off southern Ireland has been reduced in 2017 and 2018 compared with 2015 and 2016.

Static Gillnets (Fig. 9)

There is very little change across years indicated in any of the three ecoregions. There was possibly more fishing effort north of Shetland in 2015.

Trammel Nets (Fig. 10)

The main areas identified as using trammel nets show very little variation between years. However, use of trammel nets rather than other set gillnets is difficult to distinguish, particularly amongst Spanish and Portuguese polyvalent vessels where switching between nets is linked to the species of prey targeted. In Spain, when targeting hake, "Volanta" gear is used whereas when targeting anglerfish, "Rasco" gear is used. Although both are gillnets, the technical characteristics of them are quite different due to the target species. Bycatch risk is likely to be greater with "Volanta" gear as the total height of the net is 10 metres whereas in "Rasco" gear, it is 3.5 metres (E. Mugerza, *pers. comm.*). The artisanal fleet tends to use more trammel nets than other gillnets.

Set Longlines (Fig. 11)

The same main areas of fishing are indicated in each of the four years, with possibly greater effort along the shelf edge west of Ireland in 2015 compared with later years.

Drifting Longlines (Fig. 12)

Most drifting longline effort is west of the Iberian Peninsula and in the northern Bay of Biscay. Effort appears to have increased in northern Bay of Biscay extending northwards to the western Approaches to the English Channel. West of Portugal, it has also varied between years, with greater effort indicated in 2016 and 2018.

Pots (Fig. 13)

Most fishing effort using pots and traps are small vessels under 15m length and the majority probably do not carry AIS. Vessels engaged in potting only show up strongly around the British Isles and north-west France, with some also in the German Wadden See and south-west coast of Sweden. Effort is greatest in west Scotland, Wales, South-west England and off the coast of Normandy and Brittany. There is no indication of variation in effort between years.



Figure 4. Annual Variation in Fishing Effort using Pelagic Trawls, 2015-2018 (MFH = mean fishing hours/km²/day)



2016


Figure 5. Annual Variation in Fishing Effort using Pelagic Seines, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 6. Annual Variation in Fishing Effort using Demersal Trawls, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 7. Annual Variation in Fishing Effort using Demersal Seines, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 8. Annual Variation in Fishing Effort using Driftnets, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 9. Annual Variation in Fishing Effort using Static Gillnets, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 10. Annual Variation in Fishing Effort using Trammel Nets, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 11. Annual Variation in Fishing Effort using Set Longlines, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 12. Annual Variation in Fishing Effort using Drifting Longlines, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 13. Annual Variation in Fishing Effort using Pots, 2015-2018 (MFH = mean fishing hours/km²/day)

3.1.3. Fishing Effort by Season

Whereas there is very little variation in fishing effort between the years 2015-2018 for most gear types, one might expect larger differences on a seasonal basis since the more migratory pelagic fish (and cephalopod) species are targeted at different times of year. The distribution of fishing effort by gear type is illustrated in Figures 14-23, and summarised below:

Pelagic trawls (Fig. 14)

In the Bay of Biscay, pelagic trawlers target sardine and anchovy, mainly in summer and autumn whereas in winter, hake and sea bass are mainly caught.

In the Celtic Seas, pelagic trawling targeting blue whiting occurs far offshore beyond the shelf edge around the Porcupine Bank west of Ireland mainly between January and March. Closer to the shelf edge, there is pelagic trawling for albacore tuna in the Bay of Biscay and southwest of Ireland during the summer as the fish move northwards, whilst horse mackerel are taken over the shelf west of Ireland in spring. Mackerel are taken along the shelf edge from SW Ireland to NW Scotland and also around Shetland and east of Orkney during their spring southward migration. Herring are caught mainly north of Scotland, in the Celtic Sea and south of Ireland between October and January, and in the northern Irish Sea around the Isle of Man between July and December. Sprat fisheries occur in coastal waters of Ireland and in the south Minch between October and March. Boarfish are taken south of Ireland between September and March.

In the northern North Sea, herring, mackerel, horse mackerel and Norway pout are the main target species, along with blue whiting in deeper areas north of the British Isles. Further south in the central North Sea, some herring, mackerel and horse mackerel are taken along with sandeel in some areas, whilst sprat are taken primarily in the Skagerrak, southern North Sea and Channel, mainly between August and February. There is an important herring fishery in the Skagerrak, with catches highest between September and February.

Pelagic seines (Fig. 15)

Off the Iberian Peninsula, Portuguese purse seiners operating primarily between 20 and 100 metres depths target mainly sardine, chub mackerel, anchovy, horse mackerel, and blue jack mackerel. Further north in the Bay of Biscay, purse seiners target mackerel, anchovy, horse mackerel, and sardine, following some of these northward along the shelf edge. Mackerel are taken between February and March; sardine and anchovy are taken between March and June. In spring, horse mackerel are taken over the shelf west of Ireland. In summer, albacore tunas are caught near the shelf edge off SW Ireland when mackerel are also taken further north west of Ireland. In the northern North Sea, off northern Scotland, purse seiners target mackerel between October and March.

Demersal trawls (Fig. 16)

Most demersal fisheries involve otter trawls. In the Bay of Biscay and around the Iberian Peninsula, much of this is coastal over the shelf (at depths <500m) and therefore undertaken in a narrow strip around Atlantic Spain and Portugal, but where the shelf widens as in the northern part of the Bay of Biscay, it extends farther offshore. Target species are hake throughout the region, sea bass, and other species such as anglerfishes, megrims, Norway

lobster, horse mackerel, mackerel, pollack, and red mullet, with blue whiting taken in deeper waters (200-800m depth) beyond the shelf. Demersal trawling occurs in the region throughout the year although with different seasonal peaks in catches for different species. Hake are taken in the north of the Bay of Biscay mainly in January to April, in the Celtic Sea in June and July, and along the continental slope off the south-west and west coasts of Ireland extending up to Scotland, between August and December. In these latter regions, demersal otter trawling operates on most of the continental shelf and slope, targeting anglerfish along the shelf slope, taking *Nephrops* in the Irish Sea, around the Aran Islands and offshore over the Porcupine Bank west of Ireland and in the Scottish Hebrides, flatfish and rays in the south-western Celtic Sea, and gadoids (e.g. cod, haddock, whiting and pollack) in the south-eastern Celtic Sea including western English Channel and Irish Sea. Those fisheries occur year-round.

In the Greater North Sea, otter trawls are used intensively in most parts of the region, including the Skagerrak and the English Channel, catching gadoids, other groundfish, plaice, and *Nephrops*. In the northern North Sea and the Skagerrak, haddock, cod, whiting, anglerfish, megrim, and plaice are targeted, although *Nephrops* and some flatfish species are also taken. In the deeper waters of the northern North Sea, some vessels target saithe. In the southern North Sea and the eastern English Channel, the otter trawl fleet catches a wide variety of fish (including cod, plaice, sole, haddock, and whiting) and shellfish species (including cephalopods) and, in muddy areas, *Nephrops*. The demersal trawling fishing effort in the region occurs year-round.

Demersal seines (Fig. 17)

In the Bay of Biscay, demersal seines operate year-round over the shelf close to the coast in the north-eastern sector, catching gadoids such as hake and pollack.

In the Celtic Seas, most demersal seining occurs off southern Ireland, in the Sea of Hebrides and around the Northern Isles of Scotland, targeting gadoids (particularly whiting but also haddock), flatfish and other benthic species, with hake also taken off the south-west of Ireland. Fishing effort occurs year-round.

Bottom seine fisheries operate mainly in the Skagerrak, central North Sea, and in the eastern English Channel, with limited effort in the northern North Sea. Cod, haddock, whiting and plaice are mostly taken. In the Skagerrak and along the southern coastal margin of the North Sea, fishing effort is greatest between April and September, whereas in the eastern English Channel it is more or less the same year-round.

Driftnets (Fig. 18)

Large-scale drift netting has been banned but some small-scale gillnetting recorded as drift netting shows around the coasts of Ireland, particularly in the south, with no seasonal pattern. The possibility exists that these have been miss-assigned, and should be treated as gillnetting (i.e. EU code GNS rather than GND). In the past, there has been widespread salmon drift netting around the south and west coasts of Ireland.

Static Gillnets (Fig. 19)

Three fleets of gillnetters operate around the coast of the Iberian Peninsula. A fleet called *Beta* uses a mesh size of 60 mm, while the *Volanta* fleet uses a mesh size of 90 mm; both

target hake. The *Rasco* fleet uses a mesh size of 280 mm for targeting deeper water anglerfish and monkfish. A large number of vessels (Spanish and Portuguese) are <15m length, and indeed many are <12m, so fishing effort using AIS (or even VMS) will be under-recorded. Vessels are polyvalent and may switch from one gear to another (see next section on *Trammel Nets*). These operate year-round, and may also take cephalopods, shellfish and crustaceans.

In the Bay of Biscay, the main gillnet fishery involving Spanish and French vessels targets hake along the continental slope at depths of 150-600 metres. In shallower waters, target species include sole and sea bass. Fishing effort in this region is greatest between January and March. Some low-level fishing effort assigned to gillnetting is indicated offshore in the Bay of Biscay during July to September. It is not known whether this is correct or miss-assigned to this gear type.

Further north, the main gillnet fishery targets hake along the continental slope west of Ireland, particularly in June and July, although this species is also taken widely over the shelf south of Ireland. In the shallower Celtic Sea, target species include anglerfish, flatfish, and gadoids. A large number of inshore gillnetters (<12m) are also active in this ecoregion, targeting a range of species. Between January and March, the primary target of inshore gillnetters operating south of Ireland and in the southern Irish Sea is cod. Fisheries closer inshore around the Irish coast seasonally target anglerfish, flatfish, pollack, and dogfish. There is currently little gillnetting west of Scotland. Gillnetters from the UK, France, Germany and Spain once operated in deep waters west of Ireland and Scotland, targeting hake, monkfish, and deep-water sharks. This fishery stopped or seriously reduced from 2006, following EU regulation of deep-water gillnetting at depths below 600m.

In the Greater North Sea, gillnet fisheries primarily operate in the shallower areas of the southern North Sea, eastern English Channel, and Skagerrak. Small and medium-sized boats target flatfish and demersal fish, depending on the gear used. Gillnet fisheries conducted in deeper areas also target anglerfish. Gillnet fisheries with smaller mesh sizes usually target sole, for example in the eastern English Channel. Off the North Sea coast of Denmark, a variety of benthic species may be taken. Cod, plaice and sole are mainly taken, but other species include turbot, hake, and lumpfish. In the Skagerrak, cod and plaice are the prime species but also taken are sole, pollack, hake and monkfish. Gillnet fisheries operate year-round, although sole is taken mainly between April and September.

Trammel nets (Fig. 20)

Trammel nets differ from other gill nets in having three layers of netting: a slack middle net with a smaller mesh size, and two outer nets with larger mesh sizes. Whereas gill nets capture mainly around the gill, trammel nets capture by entangling the whole or part of the body. Without access to logbooks, it is difficult to determine from the EU register, whether vessels are using gillnets or trammel nets. As with conventional gill nets, many vessels are less than 15 metres length, and so are not required to carry AIS, and of those a high proportion may be less than 12 metres and so not obliged to carry VMS either. Around the Iberian Peninsula there is the further complication of artisanal vessels being polyvalent using gill nets (GNS) and trammel nets (GTR) when targeting angler fish, but may use gill nets when targeting hake. In the Basque Country, sole are caught by vessels in coastal waters during spring and summer but move further offshore in early autumn. About 40% of coastal netters in the Basque

Country were estimated to use trammel nets taking hake, sole and horse mackerel (Stergiou *et al.*, 2006). Further west in the Cantabrian Sea, both gill nets and trammel nets are important in the artisanal inshore fleet numbering around 4,000 small vessels. The larger vessels, for the most part, use gillnets.

In the Celtic and Greater North Sea ecoregions, the AIS maps have not recorded trammel netting in several areas where it may be used. For example, in the Skagerrak and along the North Sea coast of Denmark, trammel nets operate between April and June catching sole, between April and December catching plaice, and throughout the year catching cod. Monkfish are caught between April and September, and hake between July and December. The majority of those vessels are less than 8m length (Savina, 2018).

Set Longlines (Fig. 21)

Around the Iberian Peninsula and in the Bay of Biscay, set longliners operate along the continental slope, targeting hake. Similarly, in the Celtic Sea and west of Ireland, hake are targeted, although pollack and saithe are also taken. Further north, a demersal longline fishery mainly targets ling, blue ling and other deep-water species along the continental slope west of the Outer Hebrides. In the northern North Sea, along the shelf edge and around the Northern Isles of Scotland, longlines target saithe, cod, haddock, ling, and tusk. Fishing effort appears to be greatest between July and September, although south and south-west of Ireland it is greatest between April and June, probably reflecting the season migration of hake.

Drifting Longlines (Fig. 22)

Drifting longlines are used well beyond the continental shelf at depths of 800-1450 metres targeting deep water species such as black scabbard fish, mainly between October and March.

Pots (Fig. 23)

A very large number of inshore vessels operate pot fisheries. Most of these are vessels <15m length, and a high proportion will not be equipped with AIS, and so the maps presented will not give a true picture of the extent of usage. Pot fisheries target crustaceans such as lobster and crabs, operating year-round when weather permits.







Figure 15. Seasonal Variation in Fishing Effort using Pelagic Seines, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 16. Seasonal Variation in Fishing Effort using Demersal Trawls, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 17. Seasonal Variation in Fishing Effort using Demersal Seines, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 18. Seasonal Variation in Fishing Effort using Driftnets, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 19. Seasonal Variation in Fishing Effort using Static Gillnets, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 20. Seasonal Variation in Fishing Effort using Trammel Nets, 2015-2018 (MFH = mean fishing hours/km²/day)



Figure 21. Seasonal Variation in Fishing Effort using Set Longlines, 2015-2018 (MFH = mean fishing hours/km²/day)







Figure 23. Seasonal Variation in Fishing Effort using Pots, 2015-2018 (MFH = mean fishing hours/km²/day)

3.1.4. Fishing Effort by Member State

Figures 24-34 present maps of fishing effort by main gear type for each member state operating in the region. Given the limitations of some gears being misclassified in the EU vessel register, fleets that are polyvalent which may be registered for one gear type whilst using another, the fact that vessels less than 15m length may not be carrying AIS, and that it can switched off, the following is a summary of the number of vessels known in each fleet by member state, as drawn from ICES ecoregion fisheries reviews (ICES 2019a, b; 2020), Gerritsen and Kelly (2019) for the Celtic Sea and Fernandes *et al.* (2019) for the Bay of Biscay as a validation procedure so that biases in the data are better understood. Discrepancies with ICES information based upon VMS and/or electronic logbooks are highlighted.

Sweden (Fig. 24)

- >400 vessels in Greater North Sea with demersal trawls & seines catching mainly *Nephrops*, northern shrimp, cod, witch, flounder, and saithe in Skagerrak & Kattegat.
- c. 300 of those vessels are in passive gear fleet, 94 of which target *Nephrops* (30 of 10-18m length, 64 <10m).
- 15 vessels are in pelagic fleet, targeting sprat, herring, and sandeel.

Conclusions: As to be expected, set net and pot fisheries from the smaller vessels are not well represented.

Denmark (Fig. 25)

- 1,400 vessels, of which 600 vessels in Greater North Sea demersal fisheries use bottom trawls & seines targeting cod, plaice, saithe, northern shrimp and *Nephrops*; most of the fleet are small vessels (<12m).
- c. 30 large vessels (>40m) & c. 200 smaller (12-40m) are pelagic/industrial trawlers targeting herring, mackerel, and sandeel, sprat, and Norway pout.
- 8 vessels in Celtic Seas, targeting blue whiting with pelagic trawls.

Conclusions: Fisheries are generally well represented although small vessels (<15m length) are likely to be under-represented.

Germany (Fig. 26)

- >200 vessels in Greater North Sea.
- c. 180 vessels (12-24m) of these are beam trawlers targeting brown shrimp in southern North Sea.
- 6 large (>40m) demersal trawlers target saithe in northern North Sea and further north.
- Several mid-sized bottom otter trawlers and beam trawlers (24-40m) target saithe, cod, sole, and plaice in German waters.
- <10 vessels (mainly >40m) are pelagic/industrial trawlers targeting herring, but also catching horse mackerel, mackerel, sprat, and sandeel.
- c. 10 vessels in Celtic Seas, targeting mainly anglerfish and hake with gillnets and longline.

• c. 3 large pelagic freezer-trawlers target mackerel along shelf edge.

Conclusions: Longlining effort from German vessels is not showing; note that beam trawling has not been mapped as it does not pose a bycatch risk.

The Netherlands (Fig. 27)

- c. 500 vessels in Greater North Sea
- 275 vessels of these are beam-trawlers (of which 190 are <24m and 85 are >24m) in southern and central N Sea, targeting sole and plaice, as well as other flatfish species. Most of smaller beam trawlers ("Eurocutters") seasonally target shrimp or flatfish.
- 7 vessels (>60m) of these are pelagic freezer-trawlers targeting mainly herring, mackerel, and horse mackerel.
- c. 10-15 large pelagic freezer-trawlers in the Celtic Seas, west of Scotland and Ireland, mainly targeting horse mackerel and mackerel.

Conclusions: Fisheries are generally well represented, except for small vessels (<15m length).

Belgium (Fig. 28)

- c. 70 vessels in Greater North Sea, primarily beam trawlers both above and below 24m in length, with few <12m, catching mainly sole and plaice, but also lemon sole, turbot, anglerfish, rays, cod, shrimp, and scallops.
- c. 33 vessels in Celtic Seas (of which c. 21 are in Irish Sea). Majority (89%) are >24m, while remainder are 18-24m. Beam trawls and otter trawls used for rays, plaice, sole, and anglerfish (but no targeted fisheries for sole in Irish Sea since 2016).
- 156 vessels, all beam trawlers, in south-eastern Bay of Biscay, targeting sole (June-Sep) but also taking monkfish.

Conclusions: Fisheries are generally well represented; note that beam trawls, forming a significant part of the Belgian fleet, have not been mapped.

Ireland (Fig. 29)

- c. 1,500 <10m and 500 ≥10m vessels in Celtic Seas.
- Small vessels (<10m) inshore, targeting shellfish with pots or demersal fish with nets.
- Vessels ≥ 10 m target wide variety of species using several types of gear: vessels of 12–25m length target *Nephrops* using trawls around Ireland and on Porcupine Bank. Both inshore and offshore mixed demersal fisheries use trawls and seine nets to target gadoids and benthic species. Vessels using gillnets target hake offshore and pollack, monkfish, and cod inshore.
- 10 beam trawlers target benthic species (e.g. megrim, anglerfish, flatfish, and rays). There are dredge fisheries for razor clams and scallops in inshore and offshore areas.
- 17 large (≥30m) pelagic trawls around Ireland target mackerel, horse mackerel, blue whiting, boarfish, and sprat. Pelagic trawling for albacore tuna may also occur offshore.
- c. 8 large vessels (>40m) in Bay of Biscay target small pelagic fish, mainly boarfish, horse mackerel, and mackerel.

- c. 40 vessels (paired mid-water pelagic trawls) in Bay of Biscay target albacore tuna in summer.
- c. 15 vessels (gillnets) in Bay of Biscay target hake.
- Up to 8 vessels (demersal otter trawls) in Bay of Biscay.

Conclusions: Fisheries involving both demersal trawls & seines are generally well represented, although there may be misclassification as vessels registered as demersal trawlers also undertake pelagic trawling. On the other hand, some fishing activity ascribed to pelagic trawling along the south coast of Ireland is probably demersal trawling. It would therefore be best to consider pelagic and demersal trawling together. There is, however, pelagic trawling for herring in the south-east of Ireland, and in the Irish Sea within Dublin Bay. Areas showing in blue for demersal seines (and possibly other gear types) do not correspond with VMS maps from Gerritsen & Kelly's (2019) Irish Fisheries Atlas so may not represent actual fishing effort. Gillnetting indicated as high effort off the south coast of Ireland is not apparent in Gerritsen & Kelly (2019) so may be a misclassified gear type in those instances. Much more longlining effort shows in the AIS maps compared with the Irish Fisheries Atlas where it is confined to a few areas along the coasts of Clare, Galway, Mayo and Donegal. The Irish Fisheries Atlas shows potting occurring around coastal areas of several parts of Ireland, particularly in the south-west and north-west (where it also occurs offshore) but also in the south-east (and probably elsewhere) whereas AIS data are lacking for this gear type here. Almost certainly this is due to the fact that pot fisheries are largely prosecuted by small vessels that are not equipped with AIS. Drift netting is not depicted in the Irish Fisheries Atlas whereas it is showing over wide coastal areas in the south and west of Ireland. In the EU vessel register, they may be misclassified demersal trawls (H. Gerritsen, pers. comm.).

France (Fig. 30)

- >600 vessels in the Greater North Sea. Demersal fisheries operate mainly in the eastern English Channel and southern North Sea, catching a variety of finfish and shellfish species. Most are gill- and trammel netters (10–18m) targeting sole, demersal trawlers (12–24m) catching a great diversity of fish and cephalopod species, and dredgers catching scallops. Smaller boats operate different gears throughout the year and target different species assemblages.
- 6 large demersal trawlers (>40 m) target saithe in northern North Sea and to the west of Scotland.
- 3 vessels are active in the pelagic fishery catching herring, mackerel, and horsemackerel in the Celtic Sea along the shelf edge between south-west Ireland and northwest France
- c. 350 vessels (18-35m) in the Celtic Sea (over the shelf between southern Ireland and north-west France and in the western English Channel) are mostly bottom trawlers targeting gadoids, *Nephrops* or anglerfish, megrim, and rays, with <10 vessels using Danish seine.
- c. 10 bottom trawlers target saithe and deep-sea fish (but <800m depth) off W Scotland.
- A few smaller vessels use longlines or nets to target hake west of Scotland
- 2 large pelagic trawlers target herring and mackerel, one of which also takes blue whiting beyond the shelf edge.

c. 1,500 vessels (>1,100 are <12m) operate in Bay of Biscay, of which 1,000 are in the northern part and 500 the southern part, 71% within 12nm of the coast. c. 20 vessels operate occasionally off the north coast of Spain. Main gears used by coastal vessels are nets, lines (longlines and handlines), pots, scoop nets, dredges, and bottom trawls. Offshore fishery is mostly carried out by bottom trawlers, netters, and a few longliners. Main species caught are hake, anglerfish, sole, sea bass, *Nephrops*, sardines, cuttlefish, albacore, squids, pollack, and anchovy. Some bottom trawlers have VHVO (Very High Vertical Opening) to their trawls.

Conclusions: Most fisheries are well-represented. However, the gill- and trammel-netting fleet includes many small vessels which do not carry AIS and so are under-represented. There are small amounts of demersal seining effort showing in Gerritsen & Kelly (2019) off south and south-west Ireland that are not revealed in the AIS map.

Spain (Fig. 31)

- In the Celtic Seas, 67 vessels (>24m) operate mainly offshore around Porcupine and Great Sole banks, and, to lesser degree, west of Scotland, targeting demersal species.
 44 of those are set longlines targeting hake along the shelf edge; 21 are bottom otter trawls targeting megrim, anglerfish, and hake; 2 are set gillnets targeting hake.
- c. 4,500 vessels in Bay of Biscay and Iberian waters, operating mainly in northern Spanish waters, comprising artisanal vessels, trawlers, purse-seiners, demersal longliners, and gillnetters. Fleets operating in Iberian waters comprise trawlers, trollers, pelagic longliners, and purse-seiners.
- c. 4,000 of those vessels are operating in the artisanal fishery (of 7m average length) using artisanal gears including dredges, trammel nets, gillnets, pots, bottom longline, handline, purse-seine, and beam trawl, targeting mackerel, clams, and octopus; 75 vessels (29m av. length) use bottom- and pair trawl to target horse mackerel, mackerel, blue whiting, and hake; 250 are purse-seiners (22m av. length) targeting mackerel, anchovy, horse mackerel, and sardine; 55 are demersal longliners (16m av. length) targeting hake as well as European conger; 65 are gillnetters (18m av. length) catching mainly hake and anglerfish.
- c. 57 vessels operate mainly in the Bay of Biscay: 15 vessels are trawlers targeting hake, anglerfish, and megrim; 42 vessels use passive gears (mainly bottom longlines and some gillnets) targeting hake.
- c. 700 vessels operate mainly in Gulf of Cadiz, of which c. 500 vessels (9m av. length) are using artisanal gears including dredges, trammel nets, gillnets, bottom longline, and handline, targeting blackspot seabream, striped venus, octopus, and cuttlefish; 130 trawlers (19m av. length) target shellfish and cephalopods; and 80 purse-seiners (17m av. length).
- c. 10 vessels (25m av. length) operate in the trawl fishery. These are bottom otter trawls with some pair trawling also occurring. Within the Bay of Biscay, the fleet uses trawl nets with a very high vertical opening to primarily target hake.
- Trolling fleet targets albacore tuna.

Conclusions: Most fisheries are well-represented. One important exception is the Spanish demersal trawlers which in the GFW AIS database are labelled as unspecified trawlers (see

Fig. 31g) and may be under representing fishing effort in the Bay of Biscay and Celtic Sea. We have reported this to Global Fishing Watch as it may be an issue within their AIS synthesised dataset, as these do show up better in earlier AIS maps, corresponding well with VMS (see Fernandes et al., 2019). We have therefore also included a map (Fig. 31h) showing the distribution of trawling effort in the Bay of Biscay from Fernandes et al. (2019). Otherwise, as applies in general, small vessels using gillnets and trammel nets will be under-represented as most do not carry AIS (or VMS). Trolling is another fishing activity used by some Spanish vessels in the Bay of Biscay to capture albacore tuna but which are not identified in the AIS dataset. Trolling involves a line with natural or artificial baited hooks trailed by a vessel near the surface. Handlines (LHP) and pole-lines (LHM) are further gears that are used in the Bay of Biscay but which the AIS data set did not represent in a realistic manner. A pole and line consists of a hooked line attached to a pole. Handlines have up to 30 hooks. Each hook has a fragment of wool, normally red coloured, acting as bait Mechanised pole lines mainly target mackerel in March and April although they may also target albacore and bluefin tuna mainly between July and October, some of which operate as purse seiners (mixed gear vessels), taking mackerel from March-April and anchovy from April-May, and horse mackerel and sardine in autumn.

Portugal (Fig. 32)

- In Portuguese waters, 80 bottom otter trawlers (mainly 18-40m length, with only 8 <12m), of which 25 target crustaceans (deep-water rose shrimp and Norway lobster) and blue whiting in deep (200-800m) waters, while 55 catch finfish in waters <500 m depth.
- c. 150 purse-seiners (9-27m length) operate mainly at depths of 20-100m, catching sardine, chub mackerel, anchovy, horse mackerel, and blue jack mackerel.
- c. 2,000 vessels (<12m length) operate within 30 miles of the coast, and licensed for several gears, namely gillnet (80mm mesh size), trammel net (100mm mesh size), hand- and longlines, pots and dredges, small purse-seines, and other gears. This smallscale fleet catches, among others, hake, anglerfish, octopus, pout, horse mackerel, and clams.
- 15 deep-water longliners (av. 20m length) operates offshore at the slope at depths of 800-1,450m, targeting black scabbard fish.

Conclusions: Fisheries are generally well represented although if there is any demersal trawl activity outside coastal waters it is not showing in the AIS maps. Small vessels using gillnets are trammel nets are almost certainly under represented since most do not carry AIS (or VMS).



Figure 24. Swedish Fishing Effort, 2015-2018



c) Demersal Trawls







d) Demersal Seines



f) Set Gillnets





Figure 25. Danish Fishing Effort, 2015-2018













d) Demersal Seines



f) Set Gillnets





Figure 26. German Fishing Effort, 2015-2018



c) Set Gillnets





Figure 27. Dutch Fishing Effort, 2015-2018

b) Pelagic Seines

c) Demersal Trawls





e) Set Gillnets





Figure 28. Belgian Fishing Effort, 2015-2018



c) Set Gillnets





Figure 29. Irish Fishing Effort, 2015-2018

c) Demersal Trawls









d) Demersal Seines



f) Set Gillnets



Figure 29 (cont.). Irish Fishing Effort, 2015-2018

g) Set Longlines





Figure 30. French Fishing Effort, 2015-2018

c) Demersal Trawls













f) Drifting Longlines




Figure 30 (cont.). French Fishing Effort, 2015-2018



i) Trammel Nets







Figure 31. Spanish Fishing Effort, 2015-2018

c) Set Longlines



e) Trammel Nets & Set Gillnets





d) Drifting Longlines



f) Pots



Figure 31g. Spanish Trawling (unspecified, demersal + pelagic) Effort, 2015-2018



Figure 31h. Spanish Demersal Trawl Fishing Effort in 2017 (from Fernandes et al., 2019)



[Shows trawl fishing intensity of Spanish vessels larger than 15 m in the Bay of Biscay comparing analysis of VMS and AIS data processed by GFW (cells with <25 hours of effort have been considered empty)].



c) Set Longlines



e) Trammel Nets





b) Demersal Trawls

d) Drifting Longlines



f) Set Gillnets



3.2. Species Distributions

The seasonal distributions of twelve seabird species regularly occurring in the region plus Balearic shearwater are shown in Figures 33-45, and for twelve cetacean species in Figures 46-57. When viewing each map, careful attention should be paid to differences in scale for densities between species.

3.2.1. Seabirds

Amongst seabirds, several show strong seasonal changes in distribution related to the breeding cycle, tending to disperse over a wider region offshore between September and March. Shearwaters migrate southwards out of the region during this period; kittiwakes, lesser black-backed gulls and puffins tends to move offshore beyond the continental shelf although segments of the population may remain within shelf seas. Red-throated divers that breed inland on freshwater lakes in summer move to coastal regions, particularly the southern North Sea, in winter, with populations coming from the British Isles and Scandinavia. Further east in the Baltic, wintering red-throated divers come largely from Russia. European shag remains in inshore waters year-round although there can be seasonal movements around the coast. Herring gulls and great black-backed gulls are very coastal in summer but are more widely dispersed at sea during winter. Guillemots and razorbills are also more coastal in summer when they are breeding, and in winter populations from further north may move into regions, extending south to coastal waters of the Iberian Peninsula. Most gannets migrate south for the winter after the summer breeding season.

3.2.2. Cetaceans

Most cetacean species do not show major changes in distribution between seasons. Minke whales, a predominantly shelf species, tend to move offshore beyond the shelf between September and March, and some may migrate southwards although the species can be seen in the same shelf seas year-round. Sperm whales occupy deep waters beyond the shelf edge, particularly in the Bay of Biscay. Fin whales also favour deep waters but are more likely to come onto the continental slope and deeper areas within the shelf. Long-finned pilot whales range up and down the shelf edge and beyond. Some species have predominantly northerly distributions occurring in greatest numbers north of our study region. These include killer whale and Atlantic white-sided dolphin; the former has its main population in the northern North Atlantic, Barents and Norwegian Seas, although animals from Iceland seasonally move into northern British waters feeding upon mackerel and herring in winter and taking seals predominantly in summer. Atlantic white-sided dolphins travel along the shelf edge, occasionally entering deep fjords in Norway, the Faroes and Shetland. They are uncommon south of the British Isles, being replaced largely by striped dolphins that are more of a warm temperate to subtropical species rarely straying far from deep waters. The most common delphinid species along the continental shelf slope and into shelf seas is the common dolphin. Its distribution is centred upon temperate seas. There is some evidence that the species moves northwards in summer and more onto the shelf around the British Isles, then going more offshore and further south in winter. White-beaked dolphin which is endemic to the North Atlantic occurs largely over the continental shelf in central and northern North Sea but also the more northern parts of the Celtic Seas. Risso's dolphins are widely distributed mainly in deep waters along the shelf slope but are more likely to enter shelf seas in summer and autumn. The bottlenose dolphin forms two main ecotypes, one which ranges along the shelf

edge, and the other which forms small, often discrete, coastal populations within bays and estuaries. Finally, the harbour porpoise is primarily a shelf species with important populations in the North Sea and Channel, but occurring also in the Celtic Seas and in smaller numbers in the Bay of Biscay and around the Iberian Peninsula where a genetically distinct population exists.

Habitat and foraging preferences, typical prey and foraging method of prey capture are summarised for each seabird species in Table 10a, and for cetacean species in Table 10b.

Table 10. List of Marine Bird & Cetacean Species and their Foraging Ecology

a) Marine Birds

Species	Habitat	Foraging habitat depths	Typical Prey	Foraging method
Red-throated Diver	Coastal shelf seas	10-50m	Herring, sprat, mackerel, sand eels, flatfish, gobies, sticklebacks, perches, ruffe	Demersal/benthic surface diver (usually <3m, max. 21m)
Manx Shearwater	Pelagic & shelf seas	50-500m	Herring, sprat, sardine, anchovy, sandeel, cephalopods	Pursuit diving (usually <10m, max 55m)
Cory's Shearwater	Mainly shelf slope	50-500m	Sauries, boarfish, trumpet fish, sardine, chub mackerel, blue jack mackerel, horse mackerel, flying fish, myctophids, squids	Pursuit diving (usually <5m)
Northern Fulmar	Pelagic & shelf seas	30-500m	Squid, octopus, crustaceans, lantern fish, Norway pout, blue whiting, whiting, silvery pout, herring, fish offal	Surface feeder, discards (usually <1m, max. 3m)
Northern Gannet	Mainly shelf seas	30-200m	Mackerel, herring, garfish, sprat, sandeel, gurnard, sardine, anchovy, saithe, pollack, whiting, cod, haddock, poor cod, fish offal	Pursuit diving (usually c. 5m, max 25m)
European Shag	Coastal shelf seas	10-50m	Sandeel, saithe, poor cod, cod, pollack, gobies, sea scorpion, rockling, eelpout, goldsinny	Demersal/benthic surface diver (usually <35m, max. 43m)
Herring Gull	Coastal shelf seas	10-100m	Molluscs, crustaceans, echinoderms, many fish species, birds & eggs	Surface snatching, discards (<1m)
Lesser Black-backed Gull	Pelagic & shelf seas	30-100m	Molluscs, crustaceans, echinoderms, gadoid fish, herring, birds & eggs	Surface snatching, discards (<1m)
Black-legged Kittiwake	Pelagic & shelf seas	50-200m	Sandeel, crustaceans, squid, herring, cod, lantern fish, fish offal	Surface dipping (<1m)
Common Guillemot	Mainly shelf seas	30-150m	Sandeel, herring, sprat, flatfish, smelts	Pursuit diving (usually <50m, max.180m)
Razorbill	Mainly shelf seas	30-100m	Sandeel, herring, sprat, hake, butterfish, crustaceans	Pursuit diving (usually <15m, max. 50m)
Atlantic Puffin	Pelagic & shelf seas	30-300m	Sandeel, sprat, herring, rockling, hake, smelts, butterfish, crustaceans, cephalopods	Pursuit diving (usually <30m, max.100m)

b) Cetaceans

Species	Habitat	Foraging habitat preferences	Typical Prey	Foraging method
Harbour Porpoise	Mainly shelf seas	20-100m	Whiting, sandeel, sprat, herring, cod, gobies, pouts	Mainly benthic & demersal
Bottlenose Dolphin	Coastal & shelf edge	5-200m	Sea bass, salmon, whiting, cod, herring, sandeel, sprat, saithe, haddock, pouts, hake, scad, mullets	Meso- & bentho-pelagic
Common Dolphin	Mainly shelf slope, also shelf seas	50-200m	Mackerel, pouts, sardine, anchovy, whiting, scad, sprat, sandeel, blue whiting	Pelagic, pursuit diving
Risso's Dolphin	Mainly shelf slope, also shelf seas	50-1500m	Octopus, cuttlefish, various small squids	Manly benthic & demersal, suction feeding
Striped Dolphin	Pelagic deep waters	200-2000m	Sprat, blue whiting, whiting, silvery pout, pouts, hake, scad, anchovy, bogue, garfish, haddock, saithe, myctophids, gobies, squids	Meso- & bentho-pelagic
White-sided Dolphin	Mainly shelf slope	100-300m	Herring, mackerel, silvery pout, blue whiting, scad, argentine, myctophids, squids	Pelagic, pursuit diving
White-beaked Dolphin	Mainly shelf seas	50-100m	Cod, whiting, herring, mackerel, hake, scad, sprat, pouts, sandeel, haddock, sole, gobies, octopus	Meso- & bentho-pelagic
Killer Whale	Pelagic deep waters	100-1000m	Mackerel, herring, salmon, cod, halibut, other marine mammals	Pelagic, pursuit diving
Long-finned Pilot Whale	Pelagic deep waters	200-3000m	Mainly squids; also mackerel, cod, whiting, pollack, scad, sea bass, hake, sole, pouts, eels	Meso- & bentho-pelagic
Sperm Whale	Deep canyons	500-3000m	Mainly squids; also saithe, monkfish, halibut, other fish, and crustaceans	Meso- & bentho- pelagic, suction feeding
Minke Whale	Mainly shelf seas	50-200m	Sandeel, sprat, herring, cod, haddock, saithe, whiting, mackerel, pouts, gobies	Meso- & bentho- pelagic, lunge-feeding
Fin Whale	Mainly shelf slope	100-2000m	Mainly euphausiids, also copepods; herring, mackerel, sandeel, blue whiting, sauids	Pelagic, gulping



Figure 33. Seasonal Distributions of Red-throated Diver (number of individuals per km²)

Note: the species is uncommon in southern Europe



Figure 34. Seasonal Distributions of Manx Shearwater (number of individuals per km²)



Figure 34 (cont.). Seasonal Distributions of Manx Shearwater (number of individuals per km²)

b) South



Figure 35. Seasonal Distributions of Balearic Shearwater (number of individuals per km²)

Note: the species is uncommon in northern Europe



Figure 36. Seasonal Distributions of Cory's Shearwater (number of individuals per km²)

Note: the species is uncommon in northern Europe



Figure 37. Seasonal Distributions of Northern Fulmar (number of individuals per km²)



Figure 37 (cont). Seasonal Distributions of Northern Fulmar (number of individuals per km²)



Figure 38. Seasonal Distributions of Northern Gannet (number of individuals per km²)



Figure 38 (cont.). Seasonal Distributions of Northern Gannet (number of individuals per km²)



Figure 39. Seasonal Distributions of European Shag (number of individuals per km²)



Figure 39 (cont.). Seasonal Distributions of European Shag (number of individuals per km²)



Figure 40. Seasonal Distributions of Herring Gull (number of individuals per km²)

a) North



Figure 40 (cont.). Seasonal Distributions of Herring Gull (number of individuals per km²)



Figure 41 (cont.). Seasonal Distributions of Lesser Black-backed Gull (number of individuals per km²)

a) North



Figure 41. Seasonal Distributions of Lesser Black-backed Gull (number of individuals per km²)



Figure 42. Seasonal Distributions of Black-legged Kittiwake (number of individuals per km²)



Figure 42 (cont.). Seasonal Distributions of Black-legged Kittiwake (number of individuals per km²)

b) South



Figure 43. Seasonal Distributions of Common Guillemot (number of individuals per km²)



Figure 43 (cont.). Seasonal Distributions of Common Guillemot (number of individuals per km²)



Figure 44. Seasonal Distributions of Razorbill (number of individuals per km²)

a) North



Figure 44 (cont.). Seasonal Distributions of Razorbill (number of individuals per km²)



Figure 45. Seasonal Distributions of Atlantic Puffin (number of individuals per km²)



Figure 45 (cont.). Seasonal Distributions of Atlantic Puffin (number of individuals per km²)



Figure 46. Seasonal Distributions of Harbour Porpoise (number of individuals per km²)

a) North



Figure 46 (cont.). Seasonal Distributions of Harbour Porpoise (number of individuals per km²)

b) South



Figure 47. Seasonal Distributions of Bottlenose Dolphin (number of individuals per km²)

a) North



Figure 47 (cont.). Seasonal Distributions of Bottlenose Dolphin (number of individuals per km²)



Figure 48. Seasonal Distributions of Common Dolphin (number of individuals per km²)




b) South



Figure 49. Seasonal Distributions of Striped Dolphin (number of individuals per km²)

a) North



Figure 49 (cont.) Seasonal Distributions of Striped Dolphin (number of individuals per km²)

a) South



Figure 50. Seasonal Distributions of White-beaked Dolphin (number of individuals per km²)

Note: the species occurs only rarely in the south



Figure 51. Seasonal Distributions of Atlantic White-sided Dolphin (number of individuals per km²)

Note: the species occurs only rarely in the south



Figure 52. Seasonal Distributions of Risso's Dolphin (number of individuals per km²)

a) North



Figure 52 (cont.). Seasonal Distributions of Risso's Dolphin (number of individuals per km²)



Figure 53. Seasonal Distributions of Killer Whale (number of individuals per km²)

Note: the species occurs only rarely in the south (except for an isolated population in the Strait of Gibraltar)



Figure 54. Seasonal Distributions of Long-finned Pilot Whale (number of individuals per km²)



Figure 54 (cont.). Seasonal Distributions of Long-finned Pilot Whale (number of individuals per km²)



Figure 55. Seasonal Distributions of Sperm Whale (number of individuals per km²)

a) North



Figure 55 (cont.). Seasonal Distributions of Sperm Whale (number of individuals per km²)



Figure 56. Seasonal Distributions of Minke Whale (number of individuals per km²)



Figure 56 (cont.). Seasonal Distributions of Minke Whale (number of individuals per km²)



Figure 57. Seasonal Distributions of Fin Whale (number of individuals per km²)



Figure 57 (cont.). Seasonal Distributions of Fin Whale (number of individuals per km²)

4. Bycatch Risk Mapping

The risk of a marine bird or mammal becoming bycaught in fishing gear is related to its foraging ecology and behaviour that may make it more susceptible to entanglement by particular gears and the spatiotemporal overlap with that gear type. Besides the challenges imposed by low and patchy sampling effort through dedicated observer schemes and remote electronic monitoring (REM), the bycatch rates derived from analyses are influenced by the population sizes of a particular species. Those species that are common and widespread such as common guillemot and northern fulmar amongst birds and common dolphin and harbour porpoise amongst cetaceans, are the ones that inevitably show the highest bycatch rates. This makes it difficult to make a robust assessment of the bycatch risk of a species to a specific gear type. ICES have attempted to do this through the fishPi project (2016, 2019), combining both susceptibility and vulnerability (spatiotemporal overlap) by region for functional groups of birds and mammals that suffer bycatch.

Since we are addressing spatiotemporal overlap through mapping relative densities of fishing effort with bird and mammal species density distributions, we need to examine susceptibility independent of vulnerability. This was undertaken by a literature review of a little over one hundred publications relating to marine bird and cetacean bycatch (focusing upon the North Atlantic and Mediterranean regions), reference to the ICES fishPi project, and expert elicitation taking account of the biology, behaviour, and ecology of each species. All of the publications consulted are listed in the reference section at the end of the report. The main references relating to bycatch that underlie the risk assessments are given, along with the associated gear type, by species in Table 11. This includes a systematic review of bycatch data in the reports of the ICES Working Group on Bycatch of Protected Species from the last ten years (ICES WGBYC, 2011-20), with the gear type for which at least one bycatch event was recorded for each marine bird and cetacean species being considered here. From the combined approaches, risk assessments were made and are presented in Table 12. A scoring system was used similar to the one adopted by fishPi, and colour coded, with red being the relatively high risk gear type interactions, amber the moderate, and green the relatively low risk ones.

All species-gear-type combinations were mapped by season to establish spatiotemporal overlap. This generated several hundred maps. Within this report, only the ones showing evidence of high susceptibility of bycatch (colour coded red in Table 12) are shown. Although not one of the seabird species that was selected for risk assessment, a risk map for the endangered Balearic shearwater was also generated within the study area of the project. Figures 57-74 depict a selection of risk maps for birds, and Figures 75-106 for cetaceans.

Gill nets (particularly trammel nets) cause bycatch across all species and therefore pose a special threat. Driftnets are well known to cause high mortality of dolphins and auks, leading to a general ban on their large-scale usage, although drifting nets are still deployed on a small scale. Pelagic and bottom trawls can also cause bycatch for a variety of species. Since they are often used away from the coastal zone, their impacts may be underestimated. Longlines also affect several species of marine birds and cetaceans, with fulmars and shearwaters being particularly affected amongst birds, and some of the deep diving species (Risso's dolphin, long-finned pilot whale, and sperm whale) most vulnerable amongst cetaceans. The lines

associated with pots and traps cause bycatch to members of the cormorant family (including shag considered here), divers (including red-throated diver considered here), grebes, mergansers and some diving ducks, as well as large whales (for example, minke whale and humpback whale).

4.1. Bycatch Risk Map Summaries

A set of risk maps for every species-gear type combination for marine birds and cetaceans is provided separately. Here, we have selected only those cases where the overlap is believed to pose a relatively high risk of bycatch. Each map includes an overlay of the boundaries of Natura 2000 sites under the Habitats Directive for relevant species of cetaceans, and the sites under the Birds Directive for birds, respectively.

Because of ambiguities over some of the gear type coding, as discussed earlier, the following gear type combinations (equivalent to the codes listed) were used for the risk maps:

Pelagic trawls & seines: PTM, OTM, PS Demersal trawls: PTB, OTB, OTT Demersal seines: SDN, SPR, SSC SV Gillnets: GNS, GTR, GND, GNC, GTN, GEN, GN Set Longlines: LLS Drifting Longlines: LLD

Pots & Traps (FPO) were not included in the risk maps because they are used predominantly by small vessels, most of which do not carry AIS, and it is clear from the map of FPO fishing effort that this gear type is widely under-recorded. On the other hand, only a limited number of species are thought to be at risk: baleen whales, shags and cormorants that can become entangled in the lines connecting pots and traps.

Areas identified as of relatively high risk for species for specific gear types (see Table 11) include the following:

4.1.1. Seabirds

Red-throated Diver

• Gillnets in the eastern English Channel/Strait of Dover (between January and June) (Fig. 58).

Manx Shearwater

- Set longlines along the shelf edge west of Scotland and Ireland between April and September but risk is relatively low (Fig. 59).
- Set longlines along the shelf edge in the northern Bay of Biscay, off the coast of NW Spain and the Bay of Setúbal, in west Portugal between April and September (Fig. 60).
- Drifting longlines offshore in the Celtic Deep west of the English Channel during July to September (Fig. 61)

 Drifting longlines offshore off NW Spain and west Portugal between April and June, and along the shelf edge in northern Bay of Biscay between July and September (Fig. 62)

Balearic Shearwater

- Set longlines along the shelf edge in the Bay of Biscay and around the Iberian Peninsula (slight peak off NW Spain between April and September) (Fig. 63).
- Drifting longlines along the shelf edge in the Bay of Biscay and around the Iberian Peninsula (peak off west Portugal between April and September) (Fig. 64).

Cory's Shearwater

- Set longlines off the coast of west Portugal (particularly between April and September) (Fig. 65).
- Drifting longlines offshore west of Portugal (particularly between July and September) (Fig. 66).

Northern Fulmar

- Gillnets north and west of Shetland, for northern fulmar (between January and June) (Fig. 67).
- Set longlines along the shelf edge west and north of Scotland and west and south-west of Ireland (year-round) (Fig. 68).
- Set longlines along shelf edge of northern Bay of Biscay (year-round) (Fig. 69).

Northern Gannet

- Pelagic trawls and seines in the north-western Irish Sea, around Ireland, in Hebrides and north-east Scotland (year-round, but particularly between July and March) (Fig. 70).
- Pelagic trawls and seines at several locations around the coast of the Iberian Peninsula (year-round, but particularly between April and December) (Fig. 71).
- Gillnets in the English Channel (year-round) and Celtic Sea (July to September) (Fig. 72).
- Gillnets at several locations around the Biscay coast and Iberian Peninsula (yearround) (Fig. 73).

European Shag

• gillnets at several locations off the coasts of west Spain and Portugal (year-round, but particularly October to December) (Fig. 74)

Common Guillemot

- gillnets in the English Channel and Celtic Sea (particularly between April and June) (Fig. 75)
- gillnets in the eastern edge of the Bay of Biscay (between October and March) (Fig. 76)

Razorbill

- gillnets in the western and eastern parts of the English Channel (between April and June), and western and eastern English Channel (between October and December) (Fig. 77)
- gillnets in the eastern edge of the Bay of Biscay and off the west coast of the Iberian Peninsula (between October and March) (Fig. 78)

Atlantic Puffin

• Gillnets in the eastern edge of the Bay of Biscay (between October and March) and off the west coast of the Iberian Peninsula (year-round) (Fig. 79).

4.1.2. Cetaceans

Harbour Porpoise

- Gillnets in the eastern part of the English Channel (year-round), the western English Channel (between July and September), and the Skagerrak and the German Bight (particularly between April and June) (Fig. 80).
- Gillnets in the north-east of the Bay of Biscay and off the coast of central and northern Portugal (year-round) (Fig. 81).

Bottlenose Dolphin

- Gillnets in the Celtic Sea in the south-west and south of Ireland (year-round), and over the Porcupine Bank (between October and December) (Fig. 82).
- Gillnets along the eastern margin of the Bay of Biscay and around the west and northwest coasts of the Iberian Peninsula, for bottlenose dolphin (year-round) (Fig. 83).

Common Dolphin

- Pelagic trawls and seines in north-eastern Irish Sea (July to September), southwest of Ireland (July to September), and the Celtic shelf south of Ireland (October to December) (Fig. 84).
- Pelagic trawls and seines around the Iberian Peninsula and the northern end of the Bay of Biscay (year-round, but particularly between April and September) (Fig. 85).
- Demersal trawls in the Celtic Sea and western English Channel (year-round) (Fig. 86).
- Demersal trawls in the north-eastern margin of the Bay of Biscay (April to December) and around the west coasts of the Iberian Peninsula (year-round), for common dolphin (Fig. 87).
- Demersal seines in the Celtic Deep (July to September) and central English Channel (October to March) (Fig. 88).
- Demersal seines in the north-eastern margin of the Bay of Biscay (year-round) (Fig. 89).
- Gillnets in the Celtic Sea (year-round but particularly April to December) and western English Channel (July to December) (Fig. 90).
- Gillnets on the eastern margin of the Bay of Biscay and the west coast of the Iberian Peninsula (year-round) (Fig. 91).

Striped Dolphin

- Pelagic trawls and seines in south-eastern Bay of Biscay (April to June) and the deeper parts of central Biscay (July to September) (Fig. 92).
- Demersal trawls off the south coast of Portugal (January to June) (Fig. 93).
- Gillnets off the coast of Galicia (July to September) and the south-east corner of the Bay of Biscay (October to December) (Fig. 94).

White-beaked Dolphin

- Pelagic trawls and seines in the north-western North Sea (July to December) and in various locations north and west of Scotland (January to June) (Fig. 95).
- Gillnets north of the Shetland Isles between April and June (Fig. 96).

Atlantic White-sided Dolphin

- Pelagic trawls and seines west of Ireland (January to March) and northwest of Scotland (April to June) (Fig. 97).
- Gillnets along the shelf edge north of the Shetland Isles between April and June and beyond the shelf off SW Ireland between July and September (Fig. 98).

Risso's Dolphin

- Demersal trawls in the Celtic Sea and western English Channel and north-western Irish Sea and Hebrides (year-round) (Fig. 99).
- Demersal trawls in the northern part of the Bay of Biscay and around the west coasts of the Iberian Peninsula (year-round) (Fig. 100).
- Gillnets in the western English Channel (year-round), Celtic Sea and south-west Ireland (April to September) (Fig. 101).
- Gillnets in the eastern part of the Bay of Biscay and around the west coasts of the Iberian Peninsula (year-round) (Fig.102).
- Set longlines along the shelf edge west of Scotland (mainly between October and June) and south-west of Ireland (year-round) (Fig. 103).
- Set longlines along the shelf edge of northern Bay of Biscay and around the west coast of the Iberian Peninsula (year-round) (Fig. 104).
- Drifting longlines in the Celtic Sea (July to September) (Fig. 105).
- Drifting longlines at various locations along the west coast of the Iberian Peninsula (April to September), and along the shelf edge of northern Bay of Biscay (July to September) (Fig. 106).

Long-finned Pilot Whale

- Gillnets on the Porcupine Bank west of Ireland (October to December) and along the shelf edge in the Celtic Sea west of Brittany (January to March) (Fig. 107).
- Gillnets off the west coast of the Iberian Peninsula but particularly off Galicia (yearround) and in the Cap Breton Canyon in south-east Bay of Biscay (October to March) (Fig. 108).
- Set Longlines along the shelf edge south of Ireland (year-round) (Fig. 109).
- Set Longlines along the shelf edge in northern Bay of Biscay year-round and off NW Spain mainly between January and June (Fig. 110).

- Drifting Longlines along the shelf edge west of NW France between July and December (Fig. 111).
- Drifting longlines along the shelf edge in the Bay of Biscay, off NW Spain and the west coast of the Iberian Peninsula between July and December (Fig. 112).

Sperm Whale

- Gillnets off the coast of the Iberian Peninsula, but mainly in north-west Spain (July to September) (Fig. 113).
- Set longlines along the shelf edge between south-west Ireland and north-west France (October to March), and west of the Scottish Hebrides (January to June) (Fig. 114).
- Set longlines along the shelf edge in eastern margin of the Bay of Biscay (year-round but particularly July to December), as well as north-west Spain and south-west Portugal (year-round) (Fig. 115).
- Drifting longlines along the shelf edge west of north-west France (July to September) (Fig. 116).
- Drifting longlines along the shelf edge in northern Bay of Biscay (July to September), and west coast of the Iberian Peninsula, particularly off north-west Spain (July to December) (Fig. 117).

Across taxa, greatest overlap tends to occur in the same general areas: for offshore species that favour the shelf edge, there is overlap with several species with respect to longlining. This applies particularly to birds such as northern fulmar and some of the shearwaters, but also Risso's dolphin and sperm whale may be vulnerable in areas where bycatch probably goes unrecorded. The narrow coastal shelf around the Iberian Peninsula and along the northeastern margin of the Bay of Biscay makes fishing activities there pose a particular bycatch risk to several cetacean species, but particularly common dolphin. Further north over the wider shelf, harbour porpoise appears to be at greatest risk from gillnetting along the southern margin of the North Sea and at both eastern and western ends of the English Channel, although areas within the German Bight and Skagerrak also pose a risk of gillnet bycatch. Red-throated divers are also at greatest risk of bycatch from gillnets in the shallow waters of the southwestern North Sea, particularly in late winter and spring. The same is likely to apply to other diver species seasonally inhabiting this region as well as sea duck, mergansers and grebes, that forage in a similar way. An important caveat that applies particularly when considering bycatch risk from gillnetting is the limitation of AIS (and to a lesser extent, VMS) in capturing effort from the very many small vessels operating gillnets of one form or another in coastal areas, thus fishing effort from these will be under-estimated.

Table 11. Literature Sources for Bycatch Risk of Marine Bird & Cetacean Species(in addition to fishPi, 2016, 2019 which applied to functional groups of species)

a) Marine Birds

Species	References
Red-throated Diver	Piatt & Nettleship (1987: GNS, GND), Žydelis (2009: GNS), Warden (2010: GNS), Zydelis <i>et al.</i> (2013: GNS), ICES WKBYCS (2013: GTR), ICES WGBYC (2011, 2013, 2019: GN, GNS)
Manx Shearwater	Perrins & Brooke (1976: LLS, Nets), Žydelis <i>et al.</i> (2013: LLS, GNS), ICES WKBYCS (2013: PS), J.M. Arcos (<i>pers. comm.</i> : LLS)
Cory's Shearwater	BirdLife International (2009: LLS, GND, PTM, OTM), García-Barcelona <i>et al.</i> (2009: LLS), Oliveira et al. (2015: LLS, LLD, PS), ICES WKBYCS (2013: PS) ICES WGBYUC (2016: LL, GN)
Northern Fulmar	Dunn & Steele (2001: LLS), Fangel <i>et al.</i> (2011: GNS), Fangel et al. (2015: LLS, GNS), ICES WGBYC (2016, 2018-20: LL), ICES (2019-20: GN), ICES (2019: LLS, LLD), Northridge <i>et al.</i> (2020: GNS, LLS)
Northern Gannet	McCarthy <i>et al.</i> (2011: GNS, PTM, OTM), Henriques <i>et al.</i> (2013: PTM, OTM, OTB), ICES WKBYCS (2013: OTB, PTM, OTM, LLS, GNS, GTR, PS), Oliveira <i>et al.</i> (2015: GNS, LLS, OTB, PS), ICES WGBYC (2016, 2018-20: GN), ICES WGBYC (2016: Bottom Trawls, Seines), ICES WGBYC (2020: Bottom Trawls, Pair Trawls, Rods & Lines), Northridge <i>et al.</i> (2020: GNS, LLS)
European Shag	Bell (2012: FPO), ICES WKBYCS (2013: FPO), ICES WGBYC (2016-20: GN), ICES WGBYC (2018, 2020: Bottom Trawls), Northridge <i>et al.</i> (2020: GNS)
Herring Gull	Oliveira <i>et al.</i> (2015: GNS), ICES WGBYC (2019: Bottom Trawls, LL), ICES WGBYC (2019-20: PS), Northridge <i>et al.</i> (2020: GNS)
Lesser Black-backed Gull	ICES WKBYCS (2013), Oliveira <i>et al.</i> (2015: LLS, LLD, PS), ICES WGBYC (2016: GN), ICES WGBYC (2019: LL)
Black-legged Kittiwake	Northridge et al. (2020: LLS)
Common Guillemot	Christensen & Lear (1977: GND), Brun (1979: GND, LLS), Evans & Nettleship (1985: GNS, GND), Piatt & Nettleship (1987: GNS, GND), Strann <i>et al.</i> (1991: GNS), Tasker <i>et al.</i> (2000: GNS), Žydelis (2009: GNS), ICES WGBYC (2011, 2013-14, 2016-20: GN, GNS), Oliveira <i>et al.</i> (2015: GNS), Northridge <i>et al.</i> (2020: GNS, PTM, OTM)
Razorbill	Evans & Nettleship (1985: GNS, GND), Tasker <i>et al.</i> (2000: GNS), Žydelis (2009: GNS), ICES WGBYC (2013, 2019: GN, GNS), Northridge <i>et al.</i> (2020: GNS, PTM, OTM),
Atlantic Puffin	Brun (1979: GND, LLD), Evans & Nettleship (1985: GNS, GND), Strann <i>et al.</i> (1991), Tasker <i>et al.</i> (2000: GNS), ICES WGBYC (2013, 2017-20: GN)

b) Cetaceans

Species	References
Harbour Porpoise	Tregenza <i>et al.</i> (1997b: GNS), Vinther (1999: GNS), Northridge & Hammond (1999: GNS, GTR), CES (2002b: GND), Vinther & Larsen (2004: GNS), ICES WGBYC (2011, 2013-20: GN, GNS, GTR, GTN), ICES WGBYC (2011, 2017: LL), ICES WGBYC (2011, 2013, 2016-20: Bottom Trawls, PTB), ICES WGBYC (2012: Polyvalent), ICES WGBYC (2012-14: PS), ICES WGBYC (2013: PTM, OTM, OTB, SDN, SSC, TBB, LLS, LLD), ICES WGBYC (2011, 2013-14: PTM), ICES WGBYC (2016, 2019: Seines), ICES WGBYC (2016-19: Pelagic Trawls), ACCOBAMS (2017: GTN), ICES WGBYC (2019: Pelagic Trawls), ICES WGBYC (2019-20: Bottom Trawls)
Bottlenose Dolphin	CEC (2002a, b: PTM), Chavez-Rosales <i>et al.</i> (2017: OTB, TBB), ACCOBAMS (2017: GN, GNS, GTR, GTN, GND, PS, TBB, LLD, LX), ICES WGBYC (2011: PTM, OTM), ICES WGBYC (2012: Polyvalent), ICES WGBYC (2013: PTM, Bottom Trawls, OTB, PS), ICES WGBYC (2014: PTM, GTR, GTN), ICES WGBYC (2015, 2017: GN) ICES WGBYC (2015, 2019: Pelagic Trawls), ICES WGBYC (2018-20: Bottom Trawls), ICES WGBYC (2019: LL)
Common Dolphin	Tregenza <i>et al.</i> (1997a: GNS), Tregenza & Collet (1998: PTM, OTM), Morizur <i>et al.</i> (1999: PTM), CEC (2002b: GND), Rogan & Mackey (2007), Fernandez- Contreras <i>et al.</i> (2010), Goetz <i>et al.</i> (2015), Marçalo <i>et al.</i> (2015: PS), Chavez- Rosales <i>et al.</i> (2017: OTB, TBB), ICES WGBYC (2011, 2013-20: GN, GNS, GTR, GTN), ACCOBAMS (2017: GN, GND, LLD, PS)
Striped Dolphin	Morizur et al. (1999: PTM), CEC (2002b: GND), Marcalo et al. (2010), ICES WGBYC (2011: GNS, GTR), López et al. (2012: LLD), ICES WGBYC (2014: OTM, OTB, SPR), ICES WGBYC (2015: GN, Seines, Bottom Trawls), ACCOBAMS (2017: GN, GND, LLD, LX), ICES WGBYC (2015, 2018-19: Pelagic Trawls), ICES WGBYC (2019: Bottom Trawls)
White-beaked Dolphin	CEC (2002b: PTM), ICES WGBYC (2015, 2020: GN), ICES WGBYC (2017: Pelagic Trawls)
Atlantic White-sided Dolphin	Morizur <i>et al.</i> (1999: PTM), CEC (2002a, b: PTM), ICES WGBYC (Pelagic & Bottom Trawls), ICES WGBYC (2013: GNS), Chavez-Rosales <i>et al.</i> (2017: OTB, TBB), ICES WGBYC (2015: GN), ICES WGBYC (2013, 2017-19: Bottom Trawls)
Risso's Dolphin	Chavez-Rosales <i>et al.</i> (2017: OTB, TBB), ACCOBAMS (2008: GND, GTR, LLD, LL, LX), ICES WGBYC (2011, 2020: LL), Macías López <i>et al.</i> (2012: LLD), ICES WGBYC (2013, 2017-19: Bottom Trawls), ICES WGBYC (2014: GNS)
Killer Whale	ACCOBAMS (2017: FIX)
Long-finned Pilot Whale	Di Natale (1995: GND), CEC (2002a, b: PTM), ACCOBAMS (2008: GND, LLD, LX, LHP), López <i>et al.</i> (2012: LLD), Macías López <i>et al.</i> (2012: LLD), ICES WGBYC (2011, 2013, 2018: Bottom Trawls), Vázquez <i>et al.</i> (2014: LLD), ICES WGBYC (2014: OTM), ICES WGBYC (2018: GN), Chavez- Rosales <i>et al.</i> (2017: OTB, TBB), ICES WGBYC (2017, 2019: LL)
Sperm Whale	ACCOBAMS (2008: GND, GTR, LLD)
Minke Whale	Lien (1994: FPO), ACCOBAMS (2008: GN, GND), Northridge <i>et al.</i> (2010: FPO, GNS), ICES WGBYC (2013: GNS), Ryan <i>et al.</i> (2016: FPO), ICES (2019: FPO)
Fin Whale	Lien (1994: FPO), ACCOBAMS (2008: LLD, GND), Northridge <i>et al.</i> (2010: FPO)

Table 12. Bycatch Risk of Marine Bird & Cetacean Species

a) Marine Birds

Species	Pelagic Trawls (PTM, OTM)	Bottom Trawls (PTB, OTB, OTT)	Purse Seines (PS, LA)	Bottom Seines (SDN, SPR, SSC)	Gill Nets (GNS, GTR, GNC, GTN)	Drift Nets (GND)	Long lines (LLS, LLD)	Pots & Traps (FPO)
Red-throated Diver	1	1	1	1	3	2	1	2
Manx Shearwater	2	1	2	1	2	1	3	1
Cory's Shearwater	2	1	2	1	2	2	3	1
Northern Fulmar	1	1	1	1	3	1	3	1
Northern Gannet	3	2	2	2	3	2	2	2
European Shag	1	1	1	1	3	2	2	3
Herring Gull	1	1	1	1	1	2	2	1
Lesser Black-backed Gull	1	1	1	1	1	2	2	1
Black-legged Kittiwake	1	1	1	1	1	1	2	1
Common Guillemot	2	1	1	1	3	3	2	1
Razorbill	2	1	1	1	3	3	2	1
Atlantic Puffin	2	1	1	1	3	3	2	1

b) Cetaceans

Species	Pelagic Trawls (PTM, OTM)	Bottom Trawls (PTB, OTB, OTT)	Purse Seines (PS, LA)	Bottom Seines (SDN, SPR, SSC)	Gill Nets (GNS, GTR, GNC, GTN)	Drift Nets (GND)	Long lines (LLS, LLD)	Pots & Traps (FPO)
Harbour Porpoise	2	2	2	2	3	3	2	1
Bottlenose Dolphin	2	2	2	2	3	3	2	1
Common Dolphin	3	3	3	2	3	3	2	1
Striped Dolphin	3	3	3	2	3	3	2	1
White-beaked Dolphin	2	2	2	2	3	3	1	1
White-sided Dolphin	3	2	2	2	3	3	1	1
Risso's Dolphin	1	3	2	2	3	2	3	1
Killer Whale	1	1	1	1	1	1	1	2
Long-finned Pilot Whale	2	2	2	2	2	3	3	2
Sperm Whale	2	2	2	2	2	3	3	2
Minke Whale	1	1	1	1	2	2	2	2
Fin Whale	1	1	1	1	2	2	2	2

Notes: 1 = low evidence of risk; 2 = moderate evidence of risk; 3 = high evidence of risk



Figure 58. Risk Maps of Selected Seabird Species: Red-throated Diver vs Gillnets



Figure 59. Risk Maps of Selected Seabird Species: Manx Shearwater vs Set Longlines



Figure 60. Risk Maps of Selected Seabird Species: Manx Shearwater vs Set Longlines



Figure 61. Risk Maps of Selected Seabird Species: Manx Shearwater vs Drifting Longlines



Figure 62. Risk Maps of Selected Seabird Species: Manx Shearwater vs Drifting Longlines



Figure 63. Risk Maps of Selected Seabird Species: Balearic Shearwater vs Set Longlines



Figure 64. Risk Maps of Selected Seabird Species: Balearic Shearwater vs Drifting Longlines



Figure 65. Risk Maps of Selected Seabird Species: Cory's Shearwater vs Set Longlines



Figure 66. Risk Maps of Selected Seabird Species: Cory's Shearwater vs Drifting Longlines



Figure 67. Risk Maps of Selected Seabird Species: Northern Fulmar vs Gillnets



Figure 68. Risk Maps of Selected Seabird Species: Northern Fulmar vs Set Longlines


Figure 69. Risk Maps of Selected Seabird Species: Northern Fulmar vs Set Longlines



Figure 70. Risk Maps of Selected Seabird Species: Northern Gannet vs Pelagic Trawls & Seines



Figure 71. Risk Maps of Selected Seabird Species: Northern Gannet vs Pelagic Trawls & Seines



Figure 72. Risk Maps of Selected Seabird Species: Northern Gannet vs Gill Nets



Figure 73. Risk Maps of Selected Seabird Species: Northern Gannet vs Gill Nets



Figure 74. Risk Maps of Selected Seabird Species: European Shag vs Gillnets



Figure 75. Risk Maps of Selected Seabird Species: Common Guillemot vs Gill Nets



Figure 76. Risk Maps of Selected Seabird Species: Common Guillemot vs Gill Nets



Figure 77. Risk Maps of Selected Seabird Species: Razorbill vs Gill Nets



Figure 78. Risk Maps of Selected Seabird Species: Razorbill vs Gill Nets



Figure 79. Risk Maps of Selected Seabird Species: Atlantic Puffin vs Gill Nets



Figure 80. Risk Maps of Selected Cetacean Species: Harbour Porpoise vs Gill Nets



Figure 81. Risk Maps of Selected Cetacean Species: Harbour Porpoise vs Gill Nets



Figure 82. Risk Maps of Selected Cetacean Species: Bottlenose Dolphin vs Gill Nets



Figure 83. Risk Maps of Selected Cetacean Species: Bottlenose Dolphin vs Gill Nets



Figure 84. Risk Maps of Selected Cetacean Species: Common Dolphin vs Pelagic Trawls & Seines



Figure 85. Risk Maps of Selected Cetacean Species: Common Dolphin vs Pelagic Trawls & Seines



Figure 86. Risk Maps of Selected Cetacean Species: Common Dolphin vs Demersal Trawls



Figure 87. Risk Maps of Selected Cetacean Species: Common Dolphin vs Demersal Trawls



Figure 88. Risk Maps of Selected Cetacean Species: Common Dolphin vs Demersal Seines



Figure 89. Risk Maps of Selected Cetacean Species: Common Dolphin vs Demersal Seines



Figure 90. Risk Maps of Selected Cetacean Species: Common Dolphin vs Gillnets



Figure 91. Risk Maps of Selected Cetacean Species: Common Dolphin vs Gillnets



Figure 92. Risk Maps of Selected Cetacean Species: Striped Dolphin vs Pelagic Trawls & Seines



Figure 93. Risk Maps of Selected Cetacean Species: Striped Dolphin vs Demersal Trawls



Figure 94. Risk Maps of Selected Cetacean Species: Striped Dolphin vs Gillnets



Figure 95. Risk Maps of Selected Cetacean Species: White-beaked Dolphin vs Pelagic Trawls & Seines



Figure 96. Risk Maps of Selected Cetacean Species: White-beaked Dolphin vs Gillnets



Figure 97. Risk Maps of Selected Cetacean Species: Atlantic White-sided Dolphin vs Pelagic Trawls & Seines



Figure 98. Risk Maps of Selected Cetacean Species: Atlantic White-sided Dolphin vs Gillnets



Figure 99. Risk Maps of Selected Cetacean Species: Risso's Dolphin vs Demersal Trawls



Figure 100. Risk Maps of Selected Cetacean Species: Risso's Dolphin vs Demersal Trawls



Figure 101. Risk Maps of Selected Cetacean Species: Risso's Dolphin vs Gillnets



Figure 102. Risk Maps of Selected Cetacean Species: Risso's Dolphin vs Gillnets



Figure 103. Risk Maps of Selected Cetacean Species: Risso's Dolphin vs Set Longlines



Figure 104. Risk Maps of Selected Cetacean Species: Risso's Dolphin vs Set Longlines


Figure 105. Risk Maps of Selected Cetacean Species: Risso's Dolphin vs Drifting Longlines



Figure 106. Risk Maps of Selected Cetacean Species: Risso's Dolphin vs Drifting Longlines



Figure 107. Risk Maps of Selected Cetacean Species: Long-finned Pilot Whale vs Gillnets



Figure 108. Risk Maps of Selected Cetacean Species: Long-finned Pilot Whale vs Gillnets



Figure 109. Risk Maps of Selected Cetacean Species: Long-finned Pilot Whale vs Set Longlines



Figure 110. Risk Maps of Selected Cetacean Species: Long-finned Pilot Whale vs Set Longlines



Figure 111. Risk Maps of Selected Cetacean Species: Long-finned Pilot Whale vs Drifting Longlines



Figure 112. Risk Maps of Selected Cetacean Species: Long-finned Pilot Whale vs Drifting Longlines



Figure 113. Risk Maps of Selected Cetacean Species: Sperm Whale vs Gillnets



Figure 114. Risk Maps of Selected Cetacean Species: Sperm Whale vs Set Longlines



Figure 115. Risk Maps of Selected Cetacean Species: Sperm Whale vs Set Longlines



Figure 116. Risk Maps of Selected Cetacean Species: Sperm Whale vs Drifting Longlines



Figure 117. Risk Maps of Selected Cetacean Species: Sperm Whale vs Drifting Longlines

5. Discussion and Conclusions

A risk mapping exercise such as this requires a number of factors to be taken into account when interpreting results. First, the GFW AIS fishing effort dataset has several limitations compared with VMS combined with logbook data (Kroodsma *et al.*, 2018, 2019; Fernandes *et al.*, 2019): vessels may have been assigned to the wrong gear type code; this can happen because of the smaller number of gear names used by GFW or because the EU Vessel Register has assigned these incorrectly. Vessels that are polyvalent may have been registered as using a single gear type but at times be using another, and without reference to log books this may have not been accounted for. This may happen between pelagic and demersal trawls; trawls and seines; and normal gillnets, trammel nets and driftnets. Ideally, one would like to analyse effort for each of these separately but it is probably safer to consider them in broader groupings.

AIS clearly under-represents fishing fleet activity employing small vessels (<15m) where it is not mandatory. This limitation is not confined to AIS but will also apply to VMS where only vessels of 12m length or above are required to be equipped with a transmitting unit. The extent of this potential bias is difficult to evaluate. Some small vessels (even down to 8 or 9 metres length) do carry AIS, whilst many such vessels are engaged in pot fisheries and therefore likely to be relevant solely for those species (e.g. divers & cormorants, minke & humpback whales) that are susceptible to entanglement in the lines connecting pots to buoys or to each other.

AIS probably under-records actual fishing effort due to poor signal reception, or fishers themselves failing to turn on transmission. It is therefore likely to be less useful in calculating total effort.

For this study, the objective is to identify risk in relative terms, and for that, AIS does appear to have a role to play. Comparisons between VMS and AIS maps of fishing effort for different gear types show good correspondence in distribution patterns across all three ecoregions, with most areas of high effort showing up in both sources of data. Given the many opportunities for miss-assignment, the results are very encouraging.

The modelled seabird and cetacean species distributions also have their limitations. Efforts are made to account for these but combining a large number of different surveys on a variety of platforms (between vessels, and vessels vs planes) to derive density surfaces is challenging. Survey effort is patchy in space and time, and models may not fully account for those data gaps. Introducing environmental variables can improve predictions but may on occasions produce misleading results. For highly mobile species such as some of the pelagic cetaceans, there may be marked annual variation in seasonal occurrence in particular areas. A good example is the common dolphin which from the French SAMM surveys showed a peak in numbers in the Bay of Biscay in summer whereas the most recent PELAGIS surveys show increases in winter. There may therefore have been a seasonal change in distribution, given also the significant winter mortality revealed in recent years along the French coast of northeastern Bay of Biscay. At present, we cannot conclude whether this is a long-lasting change.

Finally, assessing actual risk is particularly challenging because we are far from understanding the precise factors leading to capture, which may vary with age and experience, gender, physiological constraints, foraging behaviour, preferred prey, and so on. Chance may also play a part if a large school of dolphins or flock of birds happens to encounter a gear action that risks capture.

Several areas and times have been identified as posing a higher risk of bycatch for particular species. No validation exercise has been undertaken, but there is some evidence that areas with predicted high bycatch correspond to those of known high bycatch. Examples include harbour porpoise bycatch in the southern North Sea (ICES WGBYC, 2011-20), common dolphin bycatch along the French coast of north-eastern Bay of Biscay (Peltier *et al.*, 2016, 2019, 2020; Dars *et al.*, 2019; ICES WGBYC, 2020b), and bycatch of a variety of delphinid species along the coasts of Atlantic Spain (Fernández-Contreras *et al.*, 2010; Goetz *et al.*, 2015) and Portugal (Vingada *et al.*, 2012; Henriques *et al.*, 2013; Marçalo *et al.*, 2015). Bycatch mortality of fulmars and shearwaters, notably Balearic and Cory's shearwaters from longlining in the eastern North Atlantic is also well-known (Dunn and Steel, 2003; ICES, 2013; Fangel *et al.*, 2015; Northridge *et al.*, 2020), as is gannet bycatch from a variety of gears (ICES, 2013; ICES WGBYC 2011-20; Northridge *et al.*, 2020).

6. Recommendations

Fishing effort maps could be refined further by using VMS data and incorporating the logbooks to correct incorrect gear type assignments. This would provide a more accurate and complete measurement of fishing effort than is currently possible and allow better separation of different gears for a more precise comparison. If the catch data were available, by linking to the vessel register the seasonal location of catches could be mapped by target species which would greatly enhance our understanding of one of the main factors likely to be influencing bycatch rates.

Species distribution maps were produced for 12 species of cetaceans and 12 seabird species regularly occurring in the region (plus Balearic shearwater that enters the region from the Mediterranean but has additionally been considered due to its conservation status). These could potentially be extended to include other European species known to be vulnerable to bycatch. Amongst birds, these include great northern diver, red-breasted merganser, European eider, common scoter, and black guillemot. Amongst cetaceans, all the major ones were included but it may be possible to provide modelled distributions also for humpback whale. Maps were provided seasonally (by quarter); however, it would be possible to use monthly maps for risk mapping at a finer temporal resolution. There is also scope to incorporate predicted distributions of other protected species such as sea turtles for identifying areas of relatively high risk.

In the time frame available, it was not possible to arrange for inclusion of a number of recent survey data sets that cover one or more of the years, 2016-20. An update would be valuable, for example in better understanding any recent temporal trends in species distributions and abundance.

Risk is currently measured almost entirely as a function of spatiotemporal overlap. However, the susceptibility to bycatch from interaction with a specific gear type for each species could be incorporated directly into the risk maps. It might also be worthwhile developing a risk map for each gear type at an animal community level. A risk score for each species could be summed (as was proposed in the fishPi project but which could be further developed) and incorporated into the maps of spatiotemporal overlap. This could refine the areas and times that deployment of a particular gear poses greatest risk, thus making monitoring and mitigation resources even more targeted.

Bycatch from fisheries is considered the greatest cause of mortality at sea for most marine mammal and bird species. Despite decades of effort to robustly determine bycatch rates and to develop ways to reduce its impact, the problem remains. A primary reason for it not having been adequately addressed is the cost in terms of human and financial resources when applied across entire fleets, particularly given the fact that bycatch tends to occur sporadically. Risk maps that identify areas and times of greatest overlap between deployment of gear known to cause bycatch and those species most susceptible to it, can help to use resources for monitoring and mitigation (e.g. spatiotemporal closures, use of pingers etc) in a more targeted manner.

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Appendix 1. Gear Codes used by EU STECF and ICES

Trawls	
Beam trawls	твв
Bottom pair trawls	РТВ
Bottom otter trawls	OTB
Otter twin trawls	OTT
Beam trawls	TBB
Trawls (unknown)	NK
Seines	
Fly shooting seines (Scottish seines)	SSC
Anchored seines (Danish seines)	SDN
Pair seines	SPR
Beach seines	SB
Boat seines	SV
Surrounding Nets	
Purse Seines	PS
Encircling Gill Nets	GNC
Gill Nets and Entangling Gear	
Set Gill Nets (anchored)	GNS
Driftnets	GND
Trammel Nets	GTR
Combined gill nets-trammel nets	GTN
Gillnets & entangling gillnets (not specified)	GEN
Gillnets (not specified)	GN
Lampara Nets	LA
Pots & Traps	
Pots and Traps	FPO
Traps (not specified)	FIX
Fyke Nets	FYK
Stationary uncovered Pound Nets	FPN
Hooks & Lines	
Handlines & pole-lines (hand operated)	LHP
Handlines & pole-lines (mechanised)	LHM
Drifting Longlines	LLD
Set Longlines	LLS
Trolling Lines	LTL
Longlines (not specified)	LL
Hooks and Lines (not specified)	LX

Appendix 2. Description of Gear Types referred to in this report (adapted from FAO Descriptions and Fernández et al., 2019)

Midwater otter trawling (OTM) A midwater otter trawl is a cone-shaped net which is towed in mid-water. It consists of a cone-shaped body, normally made of four panels, ending in a codend and the net has lateral wings extending forward from the opening. The horizontal opening is maintained by otter boards. Floats and/or sailkites on the headline and weights on the groundline provide for the vertical opening. Large modern midwater trawls are rigged in such a way that the weights in front of and along the groundline provide for the vertical opening of the trawl. To reduce the resistance of the gear and achieve a large opening, the front part of the trawls is usually made from very large rhombic or hexagonal meshes. The use of nearly parallel ropes instead of meshes in the front part is also a common design. They target pelagic fish (sardine, anchovy, hake, sea bass, horse mackerel, herring, mackerel, and, offshore, tuna and blue whiting) and small crustaceans (e.g. shrimps).

Midwater pair trawls (PTM) have a roughly similar design as other midwater trawls, but may, however, be designed to have a more rectangular opening than ordinary midwater otter trawls. They can be rigged with two towing warps from each vessel or alternatively with one towing warp from each vessel and a bridle arrangement. Pair trawling has the advantage of the possibility to tow the trawl very close to the surface. A herding effect on fish by the two vessels may increase the capture efficiency in shallow waters and at the surface. They target species such as herring, sardine, hake, seabass, seabream, and sprat.

Bottom otter trawls (OTB) use a cone-shaped net consisting of a body, normally made from two, four and sometimes more panels, closed by one or two codends and with lateral wings extending forward from the opening. The net is hauled at a towing speed of 4 knots at depths ranging from 30 m to 200 m. A boat can be rigged to tow a single or two parallel trawls from the stern or from two outriggers.

Bottom pair trawling (PTB) involves two vessels pulling a single fishing net across the seabed by two boats. Within the Bay of Biscay, the fleet uses trawl nets with a very high vertical opening to primarily target hake. This may pose a greater risk of bycatch for pelagic dolphins such as common and striped dolphins.

Purse seines (PS) are made of a long wall of netting framed with a float-line and a lead-line, having purse rings hanging from the lower edge of the gear, through which runs a purse line made from steel wire or rope to allow pursing or closing the net. The net hangs vertically in the water by the attachment of weights along the bottom edge and floats along the top. Purse seines primarily target shoaling species including small pelagic species such as sardine and anchovy, but they can also target herring, horse mackerel, mackerel and tuna species.

Demersal seines involve a net that is vertical in the water, with very long ropes attached leading back to the vessel. These drag on the ground, setting up a sand or mud cloud, which herds fish into the net. Sometimes seining may involve two vessels together (**pair seining**, SPR). Target fish include cod, haddock and whiting. They can be deployed from a beach or from a vessel. **Danish seines** (SDN) are boat seines consisting basically of a conical netting body, two relatively long wings and a bag. An important component for the capture efficiency

of boat seines is the long ropes extending from the wings, which are used to encircle a large area. Many seine nets are very similar in design to trawl nets. Frequently, however, the wings are longer than on trawl nets. This fishing technique is particularly applicable where there are areas with a flat seabed but no large trawlable bottom; a Danish seine can be operated between several rough spots. This fishing method, also known as "anchor seine", evolved in Denmark and is the original seine netting technique from which "fly dragging" (Scottish seining) was a later development. In the **Scottish seine** (SSC), the gear is shot on the seabed in a rounded triangle shape with very long weighted ropes attached to each end of the net. The net is gradually hauled in with the vessel maintaining station using its engine power rather than an anchor as in anchor seining. Seining is especially suitable for the capture of both flatfish and demersal round fish either scattered on or close to the bottom, such as cod, haddock, pollack, hake, and flounder.

Set gillnets (GNS) consist of a single netting wall kept more or less vertical by a float-line and a weighted ground-line. Set gillnets target hake, seabass and seabream species as well as a variety of pelagic and demersal species such as anglerfish, pollack, plaice, sole, cod and haddock. They are generally considered to have the greatest bycatch impact on marine birds and mammals.

Driftnets (GND) are gillnets that are attached to buoys which keep them suspended between the surface and the seabed, and allowed to drift in the currents. Now banned on the high seas, they previously caused very large amounts of seabird (e.g. auks) and cetacean (e.g. porpoises) bycatch when set to catch salmon.

Trammel nets (GTR) consist of three layers of netting with a slack small mesh inner netting between two layers of large mesh netting to entangle fish. Trammel nets are used to capture benthic fish, such as common sole, plaice, monkfish, turbot, and brill.

Set longlines (LLS) consist of a mainline and snoods with baited, or occasionally unbaited, hooks at regular intervals, generally set on or near the bottom. Set longlines are considered an artisanal fishery in the Bay of Biscay, generally with lines of less than 1,000 hooks (maximum 2,000). Longlines are often used as selective fishing gears targeting high value species such as hake, pollack, saithe, cod, haddock, ling and tusk in specific seasons and regions.

Drifting longlines (LLD) consist of a mainline kept near the surface or at a certain depth by means of regularly spaced floats and with relatively long snoods with baited hooks evenly spaced on the mainline. They usually target deep sea species such as scabbardfishes and sharks.

Troll lines (LTL) consist of a line with natural or artificial baited hooks trailed by a vessel near the surface. In the Bay of Biscay, troll lines target albacore tuna.

Pots and traps (FPO) refer to small or large cages or baskets made with various materials and designs (e.g. one or more openings). Most pots are set on the bottom, while a few models are designed to be in mid-water. They target high value species such as lobster, velvet crab,

brown crab, and common octopus. Pots are often deployed at the limit between rock beds and sand patches in sets of up to 60 traps per line when targeting lobsters.

Handlines and pole-lines can be used manually (LHP) or mechanized (LHM). A pole and line consists of a hooked line attached to a pole. This method is common in recreational fisheries (i.e. angling) but is also used in commercial fisheries. For handline, crew members handle a line which has up to 30 hooks. Each hook has a fragment of wool, normally red coloured, acting as bait. In the Bay of Biscay, LHM mainly targets mackerel which is a seasonal fishery where catches are predominantly in March and April. LHM may also target albacore and bluefin tuna using live bait, but this activity occurs mainly between July and October.