Hornsea Project Four: Derogation Information

PINS Document Reference: B2.8.1
APFP Regulation: 5(2)(q)

Volume B2, Annex 8.1: Compensation measures for FFC SPA: Bycatch Reduction: Ecological Evidence

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Doc. No: B2.8.1
Version: A

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Glossary

Term	Definition
Commitment	A term used interchangeably with mitigation and enhancement measures. The purpose of Commitments is to reduce and/or eliminate Likely Significant Effects (LSEs), in EIA terms. Primary (Design) or Tertiary (Inherent) are both embedded within the assessment at the relevant point in the EIA (e.g., at Scoping, Preliminary Environmental Information Report (PEIR) or ES). Secondary commitments are incorporated to reduce LSE to environmentally acceptable levels following initial assessment i.e., so that residual effects are acceptable.
Development Consent Order (DCO)	An order made under the Planning Act 2008 granting development consent for one or more Nationally Significant Infrastructure Projects (NSIP).
Environmental Impact Assessment (EIA)	A statutory process by which certain planned projects must be assessed before a formal decision to proceed can be made. It involves the collection and consideration of environmental information, which fulfils the assessment requirements of the EIA Directive and EIA Regulations, including the publication of an Environmental Impact Assessment (EIA) Report.
Grey Literature	Information that is not produced by commercial publishers. It includes research reports, working papers, conference proceedings, theses, preprints, white papers and reports produced by government departments, academics, business and industry.
Hornsea Project Four Offshore Wind Farm	The term covers all elements of the project (i.e., both the offshore and onshore). Hornsea Four infrastructure will include offshore generating stations (wind turbines), electrical export cables to landfall, and connection to the electricity transmission network. Hereafter referred to as Hornsea Four.
Landfall	The generic term applied to the entire landfall area between Mean Low Water Spring (MLWS) tide and the Transition Joint Bay (TJB) inclusive of all construction works, including the offshore and onshore ECC, intertidal working area and landfall compound. Where the offshore cables come ashore east of Fraisthorpe.
Mitigation	A term used interchangeably with Commitment(s) by Hornsea Four. Mitigation measures (Commitments) are embedded within the assessment at the relevant point in the EIA (e.g., at Scoping, or PEIR or ES).
National Grid Electricity Transmission (NGET) substation	The grid connection location for Hornsea Four.
Orsted Hornsea Project Four Ltd.	The Applicant for the proposed Hornsea Project Four Offshore Wind Farm Development Consent Order (DCO).
Planning Inspectorate (PINS)	The agency responsible for operating the planning process for Nationally Significant Infrastructure Projects (NSIPs).

Acronyms

Term	Definition
AEoI	Adverse Effect on Integrity
DCO	Development Consent Order
ECC	Export Cable Corridor
EIA	Environmental Impact Assessment
ES	Environmental Statement
FFC	Flamborough and Filey Coast
GRCP	Guillemot and Razorbill Compensation Plan
GRIMP	Guillemot and Razorbill Implementation and Monitoring Plan
MLWS	Mean Low Water Springs
MMO	Marine Management Organisation
NGET	National Grid Electricity Transmission
OOEG	Offshore Ornithology Engagement Group
PEIR	Preliminary Environmental Information Report
PINS	The Planning Inspectorate
RIAA	Report to Inform Appropriate Assessment
SACO	Supplementary Advice on Conservation Objectives
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
UK BMP	United Kingdom Bycatch Monitoring Program
WTGs	Wind Turbine Generators

1 Summary

1.1 Background

1.1.1.1 Orsted Hornsea Project Four Limited (hereafter the 'Applicant') is proposing to develop Hornsea Project Four Offshore Wind Farm (hereafter 'Hornsea Four'). This document has been prepared to support the identification of compensatory measures for Hornsea Four and its potential impacts on guillemot and/or razorbill and/or gannet. In light of the conclusions of the Report to Inform Appropriate Assessment (RIAA) which will support the Hornsea Four DCO application, Hornsea Four's position is that no Adverse Effect on the Integrity (AEoI) on the FFC SPA will arise from Hornsea Four alone or in-combination with other plans and projects (**B2.2: Report to Inform Appropriate Assessment**). Nevertheless, in light of the Secretary of State's clear direction in his decision letter for Hornsea Three, Hornsea Four's DCO application will be accompanied by a derogation case (including compensatory measures) which will be provided on a "without prejudice" basis i.e., the derogation case will be provided without prejudice to Hornsea Four's conclusion that no AEoI will arise.

1.1.1.2 The reduction in bycatch to benefit guillemot and/or razorbill and/or gannet is one compensation measure being proposed by the Applicant and is the focus of this report. Seabird bycatch in the UK has been acknowledged by governmental and non-governmental organisation as a threat to seabird populations and work is already being undertaken by organisations to investigate it. Specifically, the UK Seabird Plan of Action (PoA)[1]) outlines work to be completed in understanding the level of bycatch by UK vessels. In addition to this, the Defra funded Clean Catch UK is an initiative that was developed to work with fisherman to further understand potential bycatch levels and how bycatch can be reduced. Work is also being undertaken by RSPB and BirdLife to trial seabird bycatch reduction methods.

1.1.1.3 The purpose of this report is to review the biological evidence base on the potential to use bycatch reduction techniques as a management option to provide benefits to guillemot and/or razorbill and/or gannet with the aim to increase their survival. This report provides evidence of bycatch of guillemot, razorbill and gannet in the UK and identification of fishing effort in the UK in order to identify areas of high bycatch as well as identify potential techniques to reduce bycatch rates.

1.1.1.4 The scale of compensatory population that is required to compensate for the annual predicted mortality of guillemot and razorbill from FFC SPA due to displacement from Hornsea Four is presented in the Hornsea Four RIAA (**B2.2: Report to Inform Appropriate Assessment**).

1.1.1.5 This report discusses the following;

- An introduction to seabird bycatch and fisheries;
- An overview of the most recent bycatch knowledge in the UK;
- Identification of static gillnet fishing effort in the UK;
- Preliminary analysis quantifying guillemot and razorbill bycatch estimates in the UK, identifying:
    - Annual trends;
    - Season trends;
    - Spatial distribution;

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[1] UK Seabird Plan of Action (PoA) – ME6024. Available at: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=20461

- Results of a bycatch risk mapping exercise identifying potential "high risk zones" of guillemot and razorbill bycatch;
- Evidence gathered through questionnaires on bycatch levels in the Cornish gillnet fishery;
- Preliminary evidence of gannet bycatch in UK waters (both UK and non-UK fleet);
- A review of potential gillnet bycatch reduction measures, and identification of short-listed techniques to reduce guillemot and razorbill bycatch in the UK;
- A review of potential bycatch reduction techniques for gannet in the UK;
- Bycatch reduction as an effective compensation measure (an analysis of the scale of bycatch reduction to be an effective compensation measure); and
- Potential further compensation workstreams.

1.1.1.6 In addition, there are three accompanying appendices:

- 1) Connectivity and race distribution of guillemot and razorbill;
- 2) GIS mapping of guillemot and razorbill at sea distributions per month; and
- 3) An in-depth analysis of the potential bycatch reduction methods evaluating the feasibility as a compensation measure for guillemot and razorbill.

1.1 Key findings

1.1.2 Guillemot and Razorbill

1.1.2.1 According to Northridge et al. (2020) bycatch by static net vessels within the UK was identified as the lead cause of guillemot and razorbill bycatch (and is therefore the focus of the compensation measure for guillemot and razorbill). In 2018, bycatch by static net vessels was estimated at 1,946 and 88 individuals caught for guillemot and razorbill respectively. The majority of bycatch was estimated to have been caused by <10 m vessels as they have a higher bycatch rate for both guillemot and razorbill (note no razorbill reported caught in >10 m vessels). Therefore, areas of high <10 m fishing effort have a greater effect on bycatch numbers than areas of high >10 m fishing effort, subsequently causing >75% of both guillemot and razorbill bycatch occurring within the English Channel (1,313 guillemot and 66 razorbill). These results coincided with the bycatch risk analysis, which identified "high-risk zones" within the English Channel. It is therefore proposed that the English Channel and the waters surrounding Cornwall is the focus location for bycatch reduction measures as compensation for Hornsea Four (Figure 1).

1.1.2.2 The highest bycatch risk was identified over the wintering period[2] when guillemot and razorbill have dispersed from their breeding colonies, therefore future trials and bycatch reduction measures shall focus within this season. Note that fishing effort is higher during the summer, however, a low density of birds would result in a low bycatch risk, thus the winter is more important.

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[2] Note preliminary bycatch estimates estimated higher bycatch from April to October, however, these estimates were based solely on fishing effort and therefore not identifying bycatch risk.

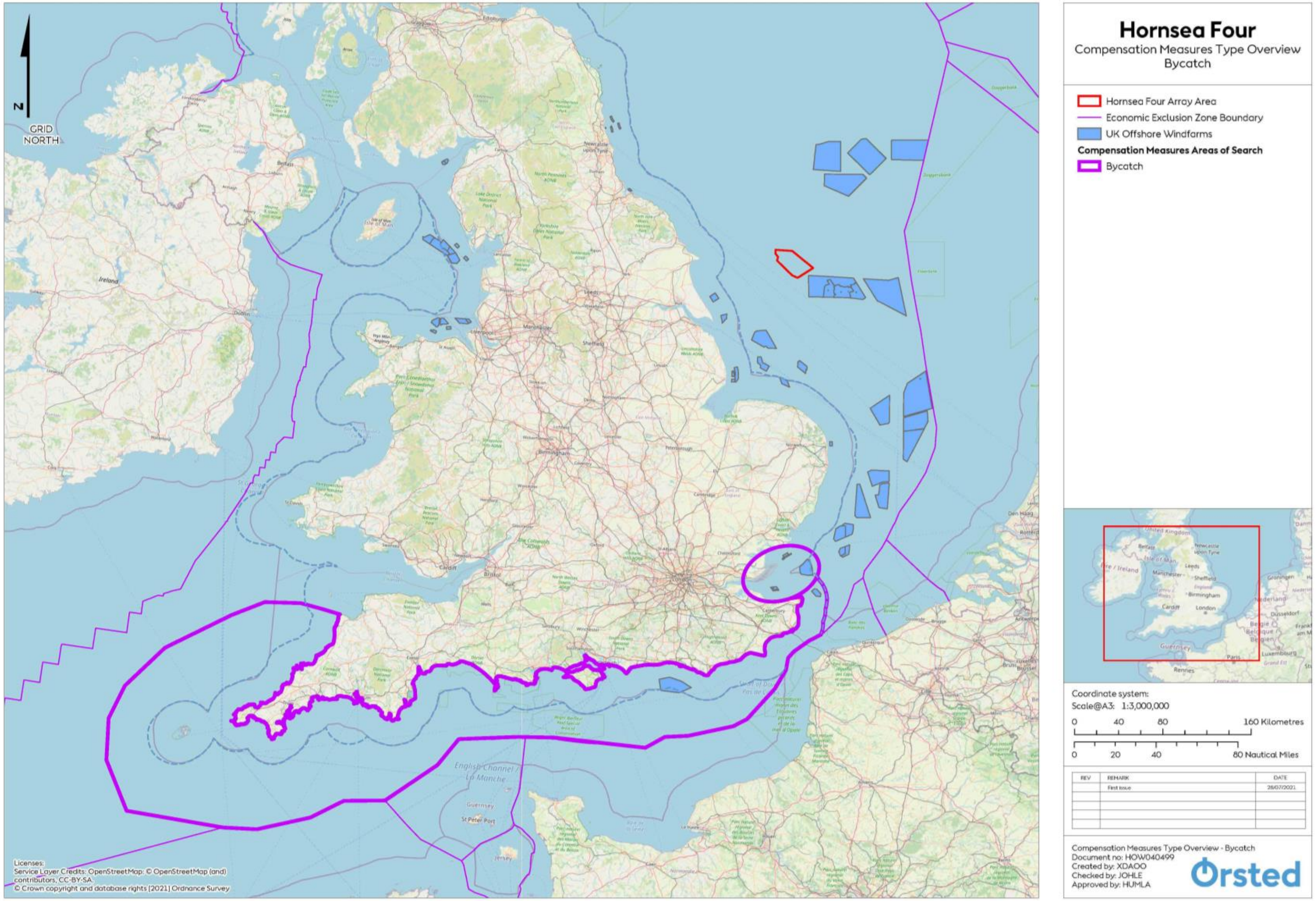

Figure 1: Areas considered for potential bycatch reduction implementation (represented in purple) in the UK.

1.1.2.3 There are a number of potential bycatch reduction techniques that have been trialled and used in gillnet fisheries across the globe. However, the scale of success varies depending on several factors, including, technique, species and location, therefore, each technique has a varied success rate. Of the methods reviewed, four have been identified as feasible in the UK with the potential to reduce guillemot and razorbill bycatch without causing negative impacts to the fishing industry (e.g., by not reducing target fish catch). These are net illumination, visual net modifications (reflective nets and high visibility nets), acoustic deterrents and above water deterrents (e.g., Looming Eyes Buoy (LEB)). The Applicant is planning to complete a pilot study to review the success of the chosen bycatch reduction technique which will gather data to identify the levels of bycatch and bycatch reduction to ensure that the bycatch reduction measure deployed creates enough additional adults to compensate for Hornsea Four. An adaptive management plan will be produced in consultation with Offshore Ornithology Engagement Group (OOEG) members which will account for any unforeseen issues which may hinder the implementation of the measure (see the Gannet, Guillemot and Razorbill Compensation Plan (**B2.8.7 Outline Gannet, Guillemot and Razorbill Compensation Implementation and Monitoring Plan**) for more information on adaptive management).

1.1.3 Gannet

1.1.3.1 Gannets are highly vulnerable to bycatch in surface gears, whilst also being vulnerable to pelagic and benthic gears during deployment and hauling and hauling of nets (Bradbury et al., 2017). In the UK, Northridge et al. (2020) estimated gannet bycatch to be within the hundreds per year (2016/2017):

- 220/241 by longline fisheries;
- 22/19 by <10 m static gillnet fisheries; and
- 36/31 by >10 m static gillnet fisheries.

1.1.3.2 The above estimates solely account for UK fleet, however, foreign fleet also fish within UK waters. There are multiple foreign trawlers operate in the area surrounding the FFC SPA, including Danish, Dutch and Belgium vessels. Danish fishermen contacted during fisheries consultation as part of the Project stated that gannet dive into trawl nets whilst they are being hauled, therefore, trawlers will be looked into as a potential compensation measure (despite Northridge et al. (2020) not observing gannet bycatch in midwater trawls).

1.1.3.3 Potential bycatch reduction techniques have been identified for longline, static gillnet, and trawl fisheries with positive results from species with similar foraging ecology to gannet. Therefore, there is the potential for bycatch reduction techniques to greatly reduce the bycatch of gannet in UK-based fisheries.

1.2 Summary of Conclusions

1.2.1.1 In summary, based upon the evidence presented within this report, the following conclusions have been made:

- 1) Bycatch of guillemot and razorbill in static nets occurs in UK fisheries (updated estimates of 1,946 guillemot and 88 razorbill in 2018);
- 2) Guillemot and razorbill static net bycatch is highest by the coast, and decreases with increasing distance from shore;
- 3) Guillemot and razorbill static net bycatch in the UK is highest within the English Channel during winter, these areas have been labelled as “high risk zones”;

- 4) The estimated bycatch is underestimated within these "high risk zones", this has been confirmed by information from a Cornish fisherman who stated to have caught 2-3 birds a day (which was lower than their average bird bycatch, with up to 20 birds bycaught per day);
- 5) There are many potential bycatch reduction techniques for guillemot and razorbill in static net fisheries, however some are unsuitable due to negative impacts on fisheries. The following techniques have the highest potential for reducing guillemot and razorbill bycatch:
    - Net illumination;
    - Net visibility;
    - Acoustic deterrents; and
    - Above water deterrents.

- 6) A pilot study will be conducted in winter 2021. The Applicant is confident in the success of the LEB as seabirds are deterred from a 50 m radius, which is greater than the distance guillemot and razorbill can travel horizontally underwater. If this technique is unsuccessful, discussions will elicit which alternative short-listed technology to take forward;
- 7) Gannet bycatch was estimated by Northridge et al. (2020) to be within the hundreds, mostly my longline fisheries. However, this did not include foreign fleet that fish in UK waters. Evidence from fisheries consultation identified bycatch of gannet within trawlers during the hauling of the net;
- 8) Bycatch reduction techniques have been identified for longline, static gillnet, and trawl fisheries with positive results from species with similar foraging ecology to gannet. Techniques used to deter individuals from warp lines (trawls) or reduce access to the hooks (longlines) reduce access to all seabirds and therefore would be a successful bycatch reduction technique for gannet; and
- 9) Previous bycatch reduction techniques have been up taken by the fishing industry therefore the Applicant is confident of the deployment of the static gillnet bycatch technique.

1.2.1.2 A bycatch reduction technology will be trialled in a pilot study to gain a better understanding of its success in bycatch reduction on guillemot and razorbill to ensure an accurate number of technologies can be deployed for compensation. This has been described in more detail in the Guillemot and Razorbill Predator Eradication Roadmap (**B2.8.4 Compensation measures for FFC SPA: Predator Eradication: Roadmap**). If the trials are unsuccessful then then alternative technologies will be considered, and adaptive management will ensure guillemot and razorbill compensation.

1.2.1.3 The bycatch reduction techniques suitable for gannet have previously been trialled and tested, therefore, there is confidence in the success of bycatch reduction as a compensation measure for gannet. Further evaluations will determine the location for technique deployment.

2 Introduction

2.1 Project Background

2.1.1.1 Orsted Hornsea Project Four Limited (hereafter the 'Applicant') is proposing to develop Hornsea Project Four Offshore Wind Farm (hereafter 'Hornsea Four'). Hornsea Four will be located approximately 69 km offshore of the East Riding of Yorkshire in the Southern North Sea and will be the fourth project to be developed in the former Hornsea Zone. Hornsea Four will include both offshore and onshore infrastructure including an offshore generating station (wind farm) including up to 180 wind turbine generators (WTGs), export cables to landfall, and connection to the National Grid Electricity Transmission (NGET) network at Creyke Beck. Detailed information on the project design can be found in **Volume A1, Chapter 1: Project Description**, with detailed information on the site selection process and consideration of alternatives described in **Volume A1, Chapter 3: Site Selection and Consideration of Alternatives**.

2.1.1.2 This document has been prepared to support the identification of compensatory measures for Hornsea Four and its potential impacts on guillemot and/or razorbill and/or gannet. In light of the conclusions of the Report to Inform Appropriate Assessment (RIAA) which will support the Hornsea Four DCO application, Hornsea Four's position is that no Adverse Effect on the Integrity (AEoI) on the FFC SPA will arise from Hornsea Four alone or in-combination with other plans and projects (**B2.2: Report to Inform Appropriate Assessment**). Nevertheless, in light of the Secretary of State's clear direction in his decision letter for Hornsea Three, Hornsea Four's DCO application will be accompanied by a derogation case (including compensatory measures) which will be provided on a "without prejudice" basis i.e., the derogation case will be provided without prejudice to Hornsea Four's conclusion that no AEoI will arise.

2.2 Purpose of document

2.2.1.1 Bycatch is the incidental capture of non-target species in fisheries and can present a significant pressure on seabird populations (Miles *et al*., 2020). Within recent decades, seabird populations have plummeted, largely due to commercial fisheries (direct competition and bycatch) (Croxall *et al.,* 2012). It has been estimated that hundreds of thousands of seabirds are killed globally each year in gillnets (400,000; Žydelis *et al.*, 2013) and longline fisheries (320,000; Anderson *et al.,* 2011). Within the UK, Northridge *et al.* (2020) identified static net (set gillnet) fisheries as an important fishery with regards to guillemot, razorbill and gannet bycatch, and longline fisheries as an important fishery with regards to gannet bycatch.

2.2.1.2 The reduction in bycatch to benefit guillemot and/or razorbill and/or gannet is one compensation measure being proposed by the Applicant and is the focus of this report. The purpose of this report, therefore, is to review the biological evidence base on the potential to use bycatch reduction techniques as a management option to provide benefits to guillemot and/or razorbill and/or gannet with the aim to increase their survival. This report provides evidence of bycatch of guillemot, razorbill and gannet in the UK. Moreover gillnet fishing effort is identified in the UK in order to identify areas of high bycatch risk. The report also identifies potential techniques to reduce bycatch rates. The scale of compensatory population that is required to compensate for the annual predicted mortality of guillemot, razorbill and gannet from FFC SPA due to displacement from Hornsea Four is presented in the Hornsea Four RIAA (**B2.2: Report to Inform Appropriate Assessment**) is defined.

2.2.1.3 This report should be read alongside the Gannet, Guillemot and Razorbill Compensation Plan (**B2.8 FFC SPA: Gannet, Guillemot and Razorbill Compensation Plan**) which describes a potential plan for execution of the compensation measure for all species (should it be required), including potential techniques for reducing bycatch.

2.2.1.4 Should this compensation measure be taken forward, further details on the precise delivery methodology for the measure would also be provided in a Gannet, Guillemot and Razorbill Implementation and Monitoring Plan (GRIMP). The GGRIMP would be submitted to the Secretary of State for approval (in consultation with the MMO and Natural England) at least one year prior to the commencement of any wind turbine generator[3]. An outline of the GRIMP (**B2.8.7 Outline Gannet, Guillemot and Razorbill Compensation Implementation and Monitoring Plan**) has been prepared and is submitted with the DCO application.

2.2.1.5 An outline of the steps proposed to take forward bycatch reduction measures as a compensation measure is described in the Bycatch Reduction Roadmap (**B2.8.2 Compensation measures for FFC SPA: Bycatch Reduction: Roadmap**) which accompanies the DCO application.

2.3 Guillemot, Razorbill and Gannet Overview

2.3.1 Guillemot

2.3.1.1 Common guillemot are part of the family Alcidae, which contains auks/ alcids such as guillemots (including the razorbill), auklets, puffins and murrelets. Currently the global population of guillemot is increasing (BirdLife International, 2018a), and in the UK, it is estimated that there are currently 950,000 breeding guillemot pairs, (RSPB, 2021a) which equates to approximately 12.9% of the global population (Mitchell et al., 2004). There are several different subspecies (races) of the guillemot, however, the exact number has been widely debated. Knox (2012) states there are currently five distinct races each with their own species range (Appendix A of this report).

2.3.1.2 Guillemots breed along many of the coasts in the UK and Ireland where there is suitable habitat. Guillemots are mainly recorded nesting on low-lying flat-topped islands and stacks and on broad and narrow cliff ledges, however they are also occasionally recorded nesting under boulders and in caves (Tuck, 1960; Parslow, 1966). In areas where there is a shortage of suitable ledge habitat on cliffs, guillemots have the potential to breed in greater numbers in boulder fields and caves (Furness, 1981). However, their preferred habitat is cliff ledges as guillemots cannot fly off as easily from the flat ground at boulder sites (Birkhead, 1978) and access to the sea is more difficult when birds are disturbed (Furness, 1981). Guillemot do not build nests, the single relatively large egg is incubated on bare rock, guano or soil. Breeding success is highest where birds breed at high density or where sites are well protected from predators (Mitchell et al.,2004)

2.3.1.3 Guillemots dive from the sea surface, using their wings to propel themselves underwater in pursuit of small fish and can dive to depths and distances of at least 100m. Guillemot diets in the North Sea comprise of around 70% fish. During the summer, in the North Sea guillemots feed mainly on sandeel, with sprats being the main alternative prey source (e.g., Anderson et al., 2013). During the winter, they have a more varied diet made up mainly of fish. Unlike other seabirds they can take sandeel from the seabed by digging or scaring them out of the sediment. During the breeding season, the mean foraging range for guillemot is 33.1km (mean maximum is 73.2 km) and the maximum recorded is 338 km (Woodward *et al.*, 2019).

2.3.1.4 FFC SPA is located on the east coast of England and supports the largest guillemot and razorbill colonies in England (Natural England, 2020), supporting over 60,000 breeding guillemot pairs (Aitken et al., 2017). At FFC SPA the population of guillemot has increased by

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[3] "Commencement of any wind turbine generator" means the first day on which installation of any wind turbine generator foundation is programmed to be undertaken.

81% between 2000 and 2018, compared to 1% increase overall in the total UK guillemot population (JNCC, 2020a; JNCC, 2020b). The breeding guillemot colony within the FFC SPA is of the southern *albionis* race, with FFC SPA supporting 15.6% of the southern *albionis* biogeographical population (Natural England, 2020). Outside of the breeding season, guillemots of the *aalge* race have been recorded off the Flamborough coast whilst traveling south from their breeding colonies. The *albionis* race also have populations recorded in Scotland, Wales, Northern Ireland, Ireland and other parts of England (minus Northumbria).

2.3.1.5 Guillemots have a relatively high degree of breeding philopatry (Lyngs, 1993; Harris et al., 1996; Halley et al., 1995), however display inter-colony movement with first-time breeders breeding away from their natal colony (Lyngs, 1993; Lavers et al.,2007). Therefore, there is potential for this species within the FFC SPA to exhibit colony movement to other UK colonies (potentially even outside of the UK). Outside of the breeding season guillemots disperse from their breeding grounds and can be seen all around the UK (Sweet, 2008). The majority of individuals travel south over the winter, but some have been recorded moving further north than their breeding colony. Juvenile birds travel further distances and have been recorded from Portugal to north Norway, whereas adults mostly stay within UK waters (Swann and Ramsay, 1983; Furness, 2015). More information on the race, dispersion and connectivity of guillemots from FFC SPA to other parts of the UK and as part of the species biogeographic population can be found in Annex A of this report.

2.3.2 Razorbill

2.3.2.1 Razorbills are part of the family Alcidae, which contains auks/ alcids such as guillemots (including the razorbill), auklets, puffins and murrelets. Currently, the global population of razorbill is decreasing (BirdLife International, 2018b), however is increasing in the UK (JNCC, 2020c) with populations currently estimated at 30,000 breeding razorbill pairs, which equates to approximately 20.2% of the global population (Mitchell *et al*., 2004). There are two subspecies of razorbill recognised by the American Ornithologists' Union; *Alca torda torda* which is found in the Baltic and White Seas, Norway, Bear Island, Iceland, Greenland and eastern North America and *Alca torda islandica* which occurs throughout Ireland, Great Britain and north-western France.

2.3.2.2 Razorbills, like guillemot, nest predominately on small ledges or in cracks of rocky cliffs and in associated scree and on boulder-fields resulting in them exhibiting a similar distribution around the UK as guillemot (JNCC, 2020a; 2020b, 2020c). Razorbill 'nest' sites are usually hidden from view, making census for this species difficult.

2.3.2.3 Razorbill are pursuit divers that use their wings to propel themselves underwater in order to catch small fish prey. Razorbills tend to make shallower dives than guillemot and feed on more sandeel and less sprat. Razorbills only make pelagic dives compared to guillemot, which make both pelagic and benthic dives (Chimienti et al., 2017). Razorbill diets in the North Sea comprise of around 70% fish, mainly sandeel followed by sprat and herring (ICES, 2011). During the breeding season, the mean foraging range for razorbill is 61.3 km (mean maximum is 88.7 km) and the maximum recorded is 313 km (Woodward et al., 2019).

2.3.2.4 FFC SPA supports the largest razorbill colony in England (Natural England, 2020), supporting over 20,000 breeding pairs (Aitken et al., 2017). At FFC SPA the population of razorbill has increased by 228% from 2000, compared to 33% increase overall in the total UK population (JNCC, 2020b; JNCC, 2020c). The FFC SPA represents 2.3% of the biogeographic population of the *Alca torda islandica* subspecies (Natural England, 2014).

2.3.2.5 Razorbills have a high degree of breeding philopatry (Lyngs, 1993; Harris et al., 1996; Halley et al., 1995), however display inter-colony movement with first-time breeders breeding away from their natal colony (Lyngs, 1993; Lavers et al.,2007). Therefore, there is potential for this species within the FFC SPA to exhibit colony movement to other UK colonies (potentially even outside of the UK). Winter dispersal of razorbills is similar to that of guillemots, however, much less is known about razorbill winter dispersal as there is currently no published winter geolocator tagging data (currently in press Lila Buckingham *pers comm*). The majority of individuals move south, with a few from northern colonies dispersing north towards Norway. Lloyd (1974) identified different dispersive movements for different geographical locations with adults from the North Sea being more inclined to stay within this region, however some individuals have been recorded moving south to the Bay of Biscay. More information on the race, dispersion and connectivity of razorbill from FFC SPA to other parts of the UK and as part of the species biogeographic population can be found in Appendix A of this report.

2.3.3 Gannet

2.3.3.1 Northern gannet are the largest species of the *Sulidae* family, which contains gannets and boobies. Currently the global population of gannet is increasing (BirdLife International, 2018c), and in the UK, it is estimated that there are currently 220,000 breeding gannet pairs, (RSPB, 2021c) which equates to approximately 60-70% of the global population (Wildlife Trust, 2021). Gannets are monotypic (no races/subspecies of *Morus bassanus*) and therefore all gannet within the UK are part of the Northern Atlantic biogeographic population (Robinson, 2005).

2.3.3.2 Gannet breed on coastal cliffs around the north of the UK where there is suitable habitat. In the UK, there are 21 colonies (gannetries), mainly on offshore islands and stacks, two on mainland cliffs (Bempton Cliffs and Troup Head) (JNCC, 2021; RSPB 2021c). Gannet create compact nest “cups” typically 30-60 cm in height (made from seaweed, plants, earth, and debris from the sea). They lay only one egg per breeding season, which they incubate for 42-46 days (Cramp and Simmons, 1997; Nelson, 2005).

2.3.3.3 Gannet plunge dive from heights of 30 m, in pursuit of small fish and can dive to depths of up to 20 m, and sometimes can feed from the surface (JNCC, 2021; Wildlife Trust, 2021). Additionally, they also feed from fishing discards from fishing vessels (JNCC, 2021). During the breeding season, FFC SPA gannet tend to dive for herring, mackerel and sand eels in waters relatively close to the Bempton colony (Hammer *et al.,*2000). During the breeding season, the mean foraging range for gannet is 120.4 km (mean maximum is 315.2 km) and the maximum recorded is 709 km (Woodward *et al.*, 2019).

2.3.3.4 FFC SPA is located on the east coast of England and supports the only mainland breeding colony of gannet in the UK (Natural England, 2020), supporting over 13,000 breeding pairs of gannet (JNCC, 2021). At FFC SPA the number of breeding pairs of gannet has increased by 240% between 2003 and 2017, compared to 34% increase overall in the total UK breeding gannet pairs[4] (JNCC 2021) The FFC SPA supports 2.6% of the biogeographical population (Natural England, 2020). Gannet are highly philopatric and often return to the same breeding colony (Nelson, 2002). Gannet are also monogamous and breed with the same partner year after year. Outside of the breeding season, gannet migrate south from their breeding colonies, and can travel to locations as far as west Africa (Furness *et al.*, 2018). Colonies on the west coast of the UK travel south through the North Sea and English Channel past Spain and Portugal to West Africa (Kubetzki et al.,2009; Fort et al.,2012; Furness et al.,2018).

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[4] Between 2003 and 2015.

3 Methods

3.1 Literature Review

3.1.1.1 A literature review was undertaken to determine the key fishing gears that cause guillemot, razorbill and gannet bycatch in the UK, estimate current bycatch numbers, and explore bycatch reduction techniques. Sources included, but were not limited to, scientific journals, government reports, and grey literature.

3.2 Data Search

3.2.1.1 Relevant bycatch data was identified by searching for available bycatch databases. Databases reviewed included those held by the JNCC, MMO, ICES and Cefas, however, no bycatch database was identified. Therefore, scientific literature was searched for bycatch data. Relevant fisheries data were also identified through the same method as above. Specific databases from the organisations named above are listed throughout the document at relevant locations.

3.2.1.2 To estimate bycatch of guillemot and razorbill[5] (Section 6), bycatch rates were extracted from Northridge *et al.* (2020[6]) and combined with fishing effort estimates extracted from the Marine Management Organisation[7] (MMO). Fishing effort data was extracted by days fished by Brown and May Marine, then converted into hauls per day using Northridge *et al.* (2020) estimates. Further detail on the methods used to estimate guillemot and razorbill bycatch is in Section 6.2.

3.3 Fisherman Consultation

3.3.1.1 In November 2020, Orsted issued survey questionnaires to fishermen in the northeast and southeast of England (Round 1) to establish the prevalence of seabird bycatch within the UK fishing industry. The questionnaires were developed in collaboration between GoBe Consultants Ltd ornithologists, Orsted, and commercial fisheries experts. The surveys included questions regarding fishing methods, fish target species, the incidence of seabird bycatch and whether fishermen would be interested in participating in an Orsted bycatch reduction pilot study (if one were deemed necessary). The aim of this exercise was to provide an overview of the prevalence of seabird bycatch by region and fishing techniques as well as to determine if there are existing bycatch reduction measures in place and if so, their success rates.

3.3.1.2 Further questionnaires were distributed to fishermen in Cornwall in February 2021 (Round 2), these questionnaires contained the same questions, however some questions were adapted to give better clarity. Fishery type and survey locations were initially determined based on the results of Northridge et al., (2020) publication which provided an initial estimate of guillemot and razorbill bycatch in UK waters through the UK Bycatch Monitoring Programme (UK BMP). Fixed net (static gillnet) fisheries were identified as major contributors to guillemot and razorbill bycatch, therefore were the target of these questionnaires. Cornwall was highlighted as being an area of high gillnet fishing activity and reports of seabird bycatch. Fishermen liaison was led by Orsted, and their appointed commercial fisheries experts. The northeast was also selected due to proximity to Flamborough and Filey Coast Special

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[5] Bycatch was not estimated for gannet (updated from Northridge *et al.* (2020) as longline fishing effort was not available as fishing effort per location.

[6] Northridge *et al.* (2020) is a study completed under the UK Seabird Plan of Action. The paper analysed data from the UK Bycatch Monitoring Programme and estimated specific bycatch rates per haul per net type (static net, midwater trawl, and longline). More information on this study is stated in Section 5.2)

[7] Most recent fisheries data at the time of application was 2018.

Protection Area (FFC SPA), which is the site that is potentially affected by Hornsea Four.

3.3.1.3 In June 2021, Orsted distributed additional questionnaires to fishermen working on trawlers in the southwest of England (Round 3). These questionnaires mirrored those issued previously however, some questions were adapted to this type of fishing technique. Most vessels were based in Devon and operated as a multipurpose platform where trawling made up 9 months of the year's operations. Fishermen liaison was led by Orsted and their appointed commercial fisheries experts.

3.3.1.4 Section 8 presents a response from a fixed gillnet fisherman (Cornwall) who wished to remain anonymous. The response provides strong evidence that supports the findings of this document and has therefore been included as supporting evidence. Longline fishermen were not included within the questionnaires due to the focus being on static net fishermen for key seabird species in UK waters, and the recent addition of gannet to the compensation measure.

3.3.1.5 GoBe Consultants Ltd. are in the process of undertaking a descriptive analysis on the survey questionnaire results, disaggregated by location and fishing method.

3.4 Other Communication

3.4.1.1 To further understand bycatch within the UK and potential bycatch reduction measures, the Applicant discussed the matters with bycatch specialists (Simon Northridge, University of St Andrews; Rory Crawford, RSPB/BirdLife; FishTek Marine) and fisheries correspondents.

3.4.1.2 The Applicant has also received feedback from Natural England, RSPB, JNCC, MMO and NFFO through compensation workshops (see **B2.9 Record of Consultation** for details of consultation carried out). These workshops discussed the potential compensation workstreams (including bycatch reduction) and the outcomes have shaped the compensation measures discussed within this document.

4 Seabird Bycatch

4.1 Introduction to fishing methods

4.1.1 Gillnetting

4.1.1.1 Gillnetting is a common fishing practice used worldwide. A gillnet is a wall of netting that hangs in various parts of the water column, typically made from monofilament or multifilament nylon. The mesh is designed to only allow the head through the netting causing the gills to be caught in the mesh. This technique is commonly used to catch salmon, herring, sharks and tuna. A variety of regulations and factors determine the mesh size, length, and height of commercial gillnets, including location and target fish species.

4.1.1.2 Although there are various setting methods, there are two main types of gillnets (Figure 2):

- 1) set gillnets (static nets), where nets are attached to poles fixed in the substrate or an anchor system to prevent movement of the net; and
- 2) drift gillnets, which are kept afloat at the required depth using a system of weights and buoys attached to the headrope, footrope or float line.

4.1.2 Midwater trawl

4.1.2.1 Trawling is a common fishing technique used worldwide due to its efficiency in capturing large numbers of fish. Trawl nets are designed to be towed by a boat through the water column, although there are a number of trawling methods, they fall into two categories (Figure 3):

- 1) demersal (bottom) trawling; and
- 2) pelagic (midwater) trawling.

4.1.2.2 Both techniques use a cone or funnel-shaped body with a wide opening to catch fish or crustaceans and a narrow, closed end (known as the cod-end) that holds the catch. Both bottom and midwater trawls use otterboards/ trawl doors to keep the mouth of the net open. They differ by targeting different sections of the water column (near the sea floor/ in the water column) (Figure 3).

4.1.3 Longline

4.1.3.1 Longlining is a fishing practice whereby a longline, or main line, trails behind a boat with baited hooks attached at regular intervals (Figure 4). A longline can be set at different depths depending on target catch species, namely pelagic or demersal.

4.2 Introduction to Seabird Bycatch

4.2.1.1 The impact of bycatch from commercial fishing activity on global seabird populations is an acknowledged concern (Žydelis et al.,2013; Anderson et al.,2011; Miles et al.,2020). Bycatch as a threat to seabirds has been identified by governmental and non-governmental organisations. Defras UK Seabird Plan of Action, Cefas' Clean Catch UK initiative programme, and RSPB/BirdLife have begun trialling potential bycatch reduction techniques.

4.2.1.2 Dias *et al.* (2019) reports that seabird bycatch is one of the top three threats to global seabird numbers, affecting just under 100 species globally and being responsible for the greatest average impact on seabird numbers. A large focus on fisheries bycatch research and subsequent bycatch reduction has focused on long line fisheries, however, it has been reported that gillnet fisheries are likely to pose a greater risk to global seabird populations (Žydelis et al., 2013; Pott and Weidenfeld, 2017; Dias et al., 2019). Žydelis et al. (2013) conservatively estimated that 400,000 seabirds are killed each year globally in gillnet fisheries. Despite this, bycatch monitoring and reporting is vastly underestimated, with low onboard observer monitoring coverage compared to the scale of commercial fishing (Pott and Wiedenfeld, 2017). Many estimates of bycatch mortality are derived from incidental recordings of bycatch. There are few monitoring programmes of long-term datasets available and fewer from dedicated bycatch monitoring programmes (ICES, 2018).

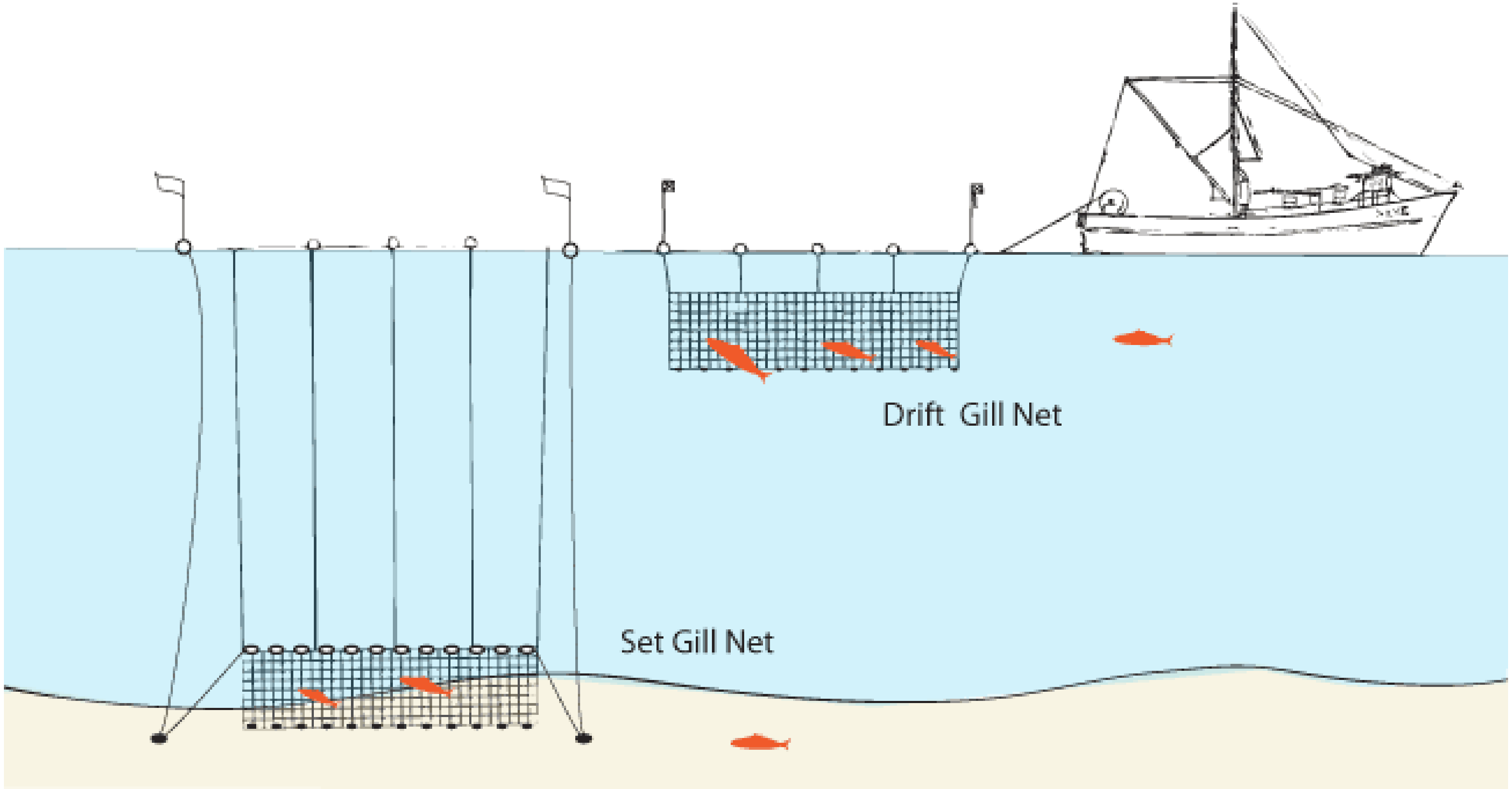

Figure 2: Set gillnet and drift gillnet diagram (taken from Wild Seafood (2021)).

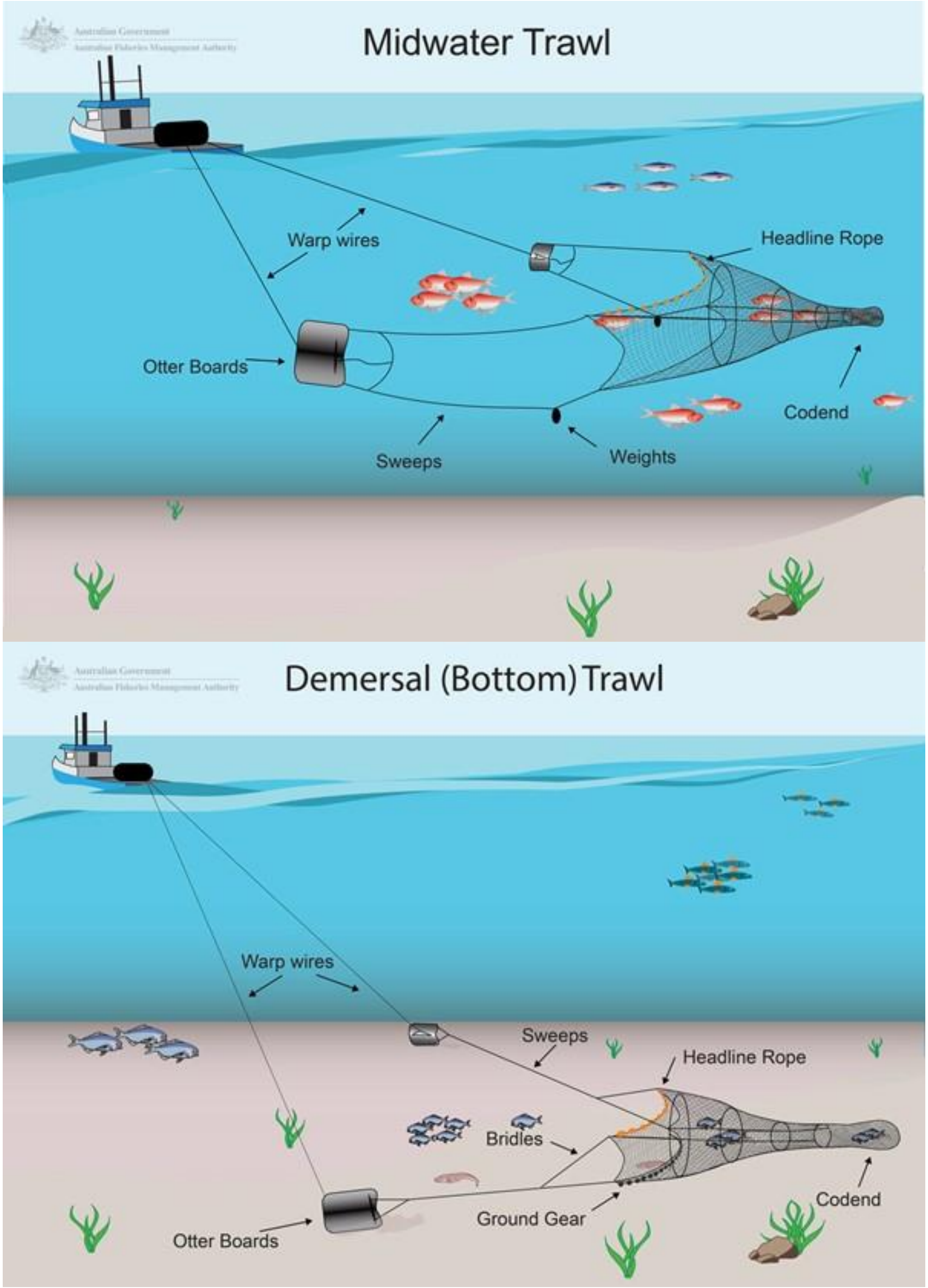

Figure 3: Above: Pelagic (midwater) trawl diagram. Below: Demersal (bottom) trawl diagram. (Taken from the Australian Fisheries Management Authority (Trawling | Australian Fisheries Management Authority (afma.gov.au)).

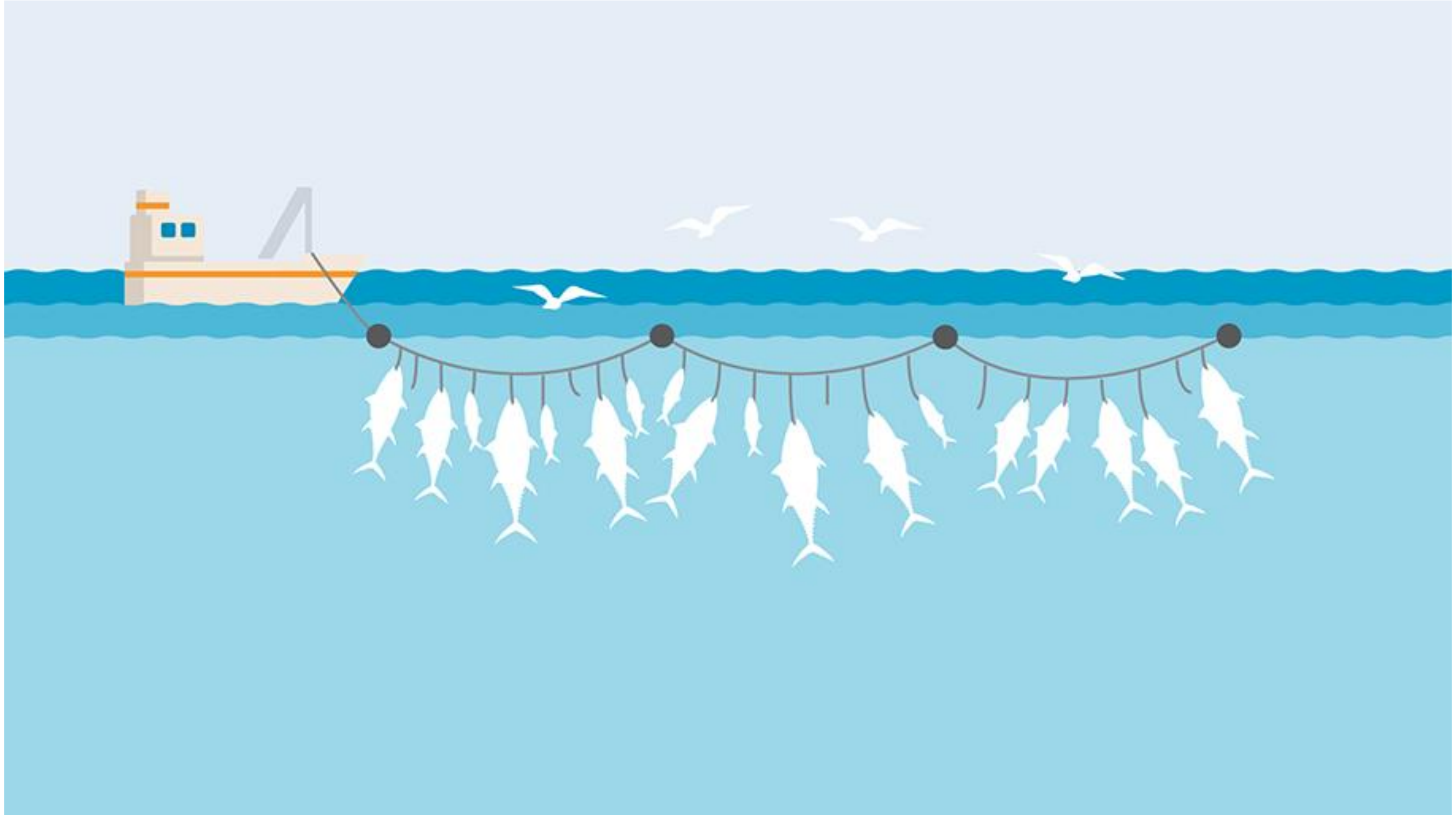

Figure 4: Longline fishing diagram (taken from the Marine Stewardship Council ([Longlines | Marine Stewardship Council (msc.org)](msc.org))/

4.2.1.3 In the UK, a preliminary assessment (running since 1996) has focused on quantifying protected species bycatch, through an at-sea observer data collection programme under the UK Bycatch Monitoring Programme (BMP). The UK BMP have collected data from over 21,000 monitored fishing operations from around the UK and adjacent waters with the aim to collect operational, environmental, and catch/bycatch data, to estimate bycatch rates of several protected species. Between 1996 and 2018, bycatch was measured for three gear types: static net (set gillnet), midwater trawl and longline. Recent analysis of the data collected by the UK BMP has helped to close some knowledge gaps and identify areas of concern (Northridge *et al.,* 2020; Miles *et,* 2020). Nevertheless, the coverage of the UK BMP is low, with <1% of static net, 1-2% of longline, and roughly 5% of midwater trawl fishing effort being monitored.

4.3 Guillemot, Razorbill and Gannet

4.3.1.1 Guillemot, razorbill and gannet have been identified as being especially vulnerable to fisheries bycatch by Bradbury et al. (2017). In that report, Bradbury et al. (2017) used a risk assessment model to identify species most likely to be caught as bycatch. Within this assessment, guillemot, razorbill and gannet were within the top ten (out of 53) seabird species for surface, pelagic, and benthic fishing gear, for the species sensitivity index score gear (Table 1). This suggests that bycatch disproportionately affects these species. Originally it was thought that only surface and pelagic fishing gears would result in bycatch of shallow diving species due to the overlap in diving range with fishing depth. However, it has since been identified that shallow diving species are susceptible to be caught in deep nets as the nets are being deployed/hauled (Bradbury et al., 2017), with evidence of gannet being bycaught in trawls during the hauling process as gannet dive into the net to retrieve the fish (per. comms[8].).

Table 1: Seabird sensitivity index (SSI) score for guillemot, razorbill and gannet. Rank is compared to other assessed UK seabirds: 1 is the highest SSI score (most vulnerable to bycatch). Total of 53 seabirds compared, total rank 61 (some seabirds ranked for breeding and winter). Data extracted from Bradbury *et al*. (2017).

Species		SSI Score	Rank
Guillemot (breeding)	Surface	77	4
	Pelagic	77	1
	Benthic	61	5
Razorbill (breeding)	Surface	72	5
	Pelagic	72	2
	Benthic	58	8
Gannet	Surface	96	1
	Pelagic	58	7
	Benthic	58	10

5 Recent Advancements in Bycatch Research

5.1.1.1 UK action to monitor and reduce bycatch of seabird species was implemented under the EU Birds Directive and the EU Seabird Plan of Action. This was a voluntary action plan; 'EU Action Plan for reducing incidental catches of seabirds in fishing gears' (COM (2012) 665 final), with the aim 'to minimise and where possible eliminate the incidental catches of seabirds', an objective echoed in the UK Marine Strategy Regulations 2010. The UK Seabird Plan of Action

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[8] Stated during a telephone conversation between Danish fishermen and Orsted fishery liaisons. Waiting on written comments.

(PoA)[9] has since been developed (2018) to estimate the level of bycatch in the UK and the impact it has on seabird populations.

5.1.1.2 The following assessments have been completed by the UK Seabird PoA:

- **Bycatch Estimates** – Guillemot, razorbill and gannet bycatch estimates from extrapolations of the UK BMP dataset (Northridge *et al.,* 2020) (summarised in **Section 5.2**); and
- **Population Impacts from Bycatch** – Percentage of guillemot, razorbill and gannet deaths caused by bycatch estimates derived in Northridge *et al.* (2020) (Miles *et al.,* 2020) (summarised in **Section 5.3**).

5.2 Bycatch Estimates

5.2.1.1 Northridge *et al.* (2020) analysed the UK BMP dataset to identify key bycatch locations and species. The total bycatch observed was extrapolated to estimate the possible total bycatch for the entire UK fishing fleet.

5.2.1.2 Guillemots account for approximately 75% of bycatch observed in static net fisheries, both coastal and offshore, and 85% from midwater trawls, with no observations of guillemot being caught in longline fishing. Annual bycatch mortality of guillemot is estimated in the region of between 1,600 to 2,500 individuals per year, with the majority of these attributed to coastal net fisheries (Northridge *et al.,* 2020).

5.2.1.3 Razorbill were observed in coastal static net fisheries, English Channel midwater trawl fisheries, with few recorded in longline fisheries. The majority of mortalities are attributed to static net fisheries with estimated mortality approximately 100-200 birds per annum in static net and midwater trawls (Northridge *et al.*, 2020).

5.2.1.4 Gannet were observed to be caught within longline and static net fisheries, in estimates of hundreds per year (mostly from longline fisheries). The ICES divisions IVa (4.a.) and VIa (6.a.) were identified as the most important areas for longline fishery bycatch (2016 = 130; 2017 = 159) (Northridge *et al.*, 2020). Both divisions are within Scotland. ICES divisions VIIb (7.b.), VIIc (7.c.), VIIj (7.j.) were also identified as important regions of gannet longline bycatch (2016 = 91; 2017 = 80). These regions are located off the southwest coast of the UK. (See Figure 5 in Section 6 for exact locations of these ICES regions). The locations of the remaining bycatch were not stated within the analysis.

5.2.1.5 However, as the UK BMP only monitored a very small proportion (<1% of static net effort, 1-2% of longline effort and ~5% of midwater trawl effort), the extrapolations cause large margins of error. Nevertheless, lower estimates are still cause for concern (see Section 5.3).

5.3 Population Impacts from Bycatch

5.3.1.1 Miles *et al.* (2020) estimated population effects using the bycatch estimates from the UK BMP (analysed by Northridge et al. (2020) (Section 5.2)). Median bycatch as a percentage of annual mortality was estimated for two regions of the UK (MSFD regions: Celtic Seas and Greater North Sea) (Table 2; Miles et al., 2020).

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[9] UK Seabird Plan of Action (PoA) – ME6024. Available at: http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=20461

Table 2: Summary of bycatch estimate for guillemot, razorbill and gannet by region. Data does not include non-UK vessels. Data derived from Miles *et al.* (2020).

Species	Region	Breeding Pairs	Median Bycatch as % of Annual Mortality	Median Bycatch Estimate
Guillemot	UK	950,060	1.7	1984
	Greater North Sea	631,905	1.5	1194
	Celtic Sea	318,156	2.0	790
Razorbill	UK	163,836	0.4	130
	Greater North Sea	70,419	0.9	129
	Celtic Sea	93,417	0.0	1
Gannet	UK	293,161	0.7	318
	Greater North Sea	146,581	0.3	83
	Celtic Sea	146,581	1.0	235

5.3.1.2 As part of the summary of responses of the Marine Strategy for good environmental status, a bycatch threshold of 1% of natural annual mortality was suggested to ensure "the long-term viability of marine bird populations is not threatened by deaths caused by incidental bycatch in mobile and static fishing gear" (Defra, 2019). Guillemot bycatch mortality is >1% in both regions of the UK (Table 2), therefore reducing bycatch could have a profound positive effect on their populations. Razorbill bycatch is much lower compared to guillemot due to razorbill being less likely to be bycaught (most likely due to the lower densities of razorbill) (Northridge *et al.*, 2020). Gannet bycatch varies between the regions. Gannet bycatch mortality is 1% of annual mortality in the MSFD Celtic Seas region whereas the bycatch estimate is much lower in the Greater North Sea as there is less fishing activity (Table 2).

5.3.1.3 The annual mortality is based solely on the UK fishing fleet, however, foreign vessels are also active within UK waters. The scale of bycatch in UK waters and the impact on the UK populations will therefore be higher than those stated above. Therefore, bycatch reduction would be beneficial to these seabirds to ensure bycatch is not detrimental as the significance of bycatch is already high (especially guillemot) without considering bycatch from other vessels.

5.4 Summary

5.4.1.1 Although the impact of accidental bycatch from commercial fishing activity on global seabird populations is an acknowledged concern (Žydelis et al.,2013; Anderson et al.,2011; Miles et al.,2020), bycatch is vastly under monitored and reported (Pott and Wiedenfeld, 2017). The UK Seabird PoA has begun to close the knowledge gap of bycatch within the UK and created a strong starting point for identifying bycatch in UK fisheries, however, due to the low scale of coverage of the UK BMP, the margins of predicted bycatch estimates are large. Moreover, bycatch was estimated for the UK without looking into potential "high risk" areas, therefore areas of high risk may have been missed. The smallest scale of analysis focused on two large regions (MSFD regions: Greater North Sea and Celtic Seas). Discussions have elicited that the English Channel may be an important region for static net bycatch (Simon Northridge *pers. comm.*). However, due to the scale of the analysis, this was not assessed. It is therefore important to evaluate bycatch over smaller spatial scales to identify "high risk" bycatch zones. Moreover, a more up to date assessment would be beneficial due to the changes of fishing effort annually. The following sections have developed these analyses further:

- **Section 6** progresses the *Northridge et al.* (2020) workstream (**Section 5.2**) using updated static net fishing effort estimates and analyses potential spatial and temporal trends; and
- **Section 7** identifies high static net bycatch risk zones to identify potential spatial and temporal trends through seabird density and fishing effort.

5.4.1.2 As longline monthly fishing effort was not available per ICES rectangle, gannet have not been included within the above assessment. An evaluation of gannet bycatch is within **Section 9**.

6 Updated Bycatch Estimates

6.1 Introduction

6.1.1.1 As stated above in **Section 5.2**, Northridge et al. (2020) estimated bycatch through extrapolating data collected by the UK BMP. It was estimated that between 1,600 to 2,500 guillemot and 100 to 200 razorbill are caught as bycatch annually. Fishing effort changes annually (and seasonally), however, this data was based on 2016 and 2017 fishing effort and no spatial or seasonal figures were estimated. To analyse this data further, this section of the report aims to:

- 1) Identify annual trends over a longer period of time;
- 2) Identify the most recent possible bycatch estimates;
- 3) Identify spatial trends; and
- 4) Identify seasonal trends.

6.1.1.2 This section solely focuses on bycatch of guillemot and razorbill. Bycatch evidence for gannet is provided in **Section 9**.

6.2 Methods

6.2.1 Fishing Effort

6.2.1.1 The UK fishing fleet at sea is evaluated annually by the Marine Management Organisation (MMO) to assess the fleet, landings, effort, and trade, and subsequently incorporated into the UK Sea Fisheries Annual Statistics dataset managed by the MMO. Static net (set gillnet) data was obtained for 2015-2018 (noting that 2018 was the most recent data available) and analysed by Brown and May Marine Consultants[10]. Vessel size was divided into <10m and >10m in length as Northridge et al. (2020) identified a significant different in bycatch rate between the size of static net vessels.

Fishing effort (number of hauls) was estimated using

6.2.1.2 **Equation 1** below. Average hauls per day at sea were extracted from Northridge et al. (2020) (**Table 3**) which were based on evidence provided by the UK BMP. Fishing effort was calculated per year and per month.

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[10] Original data from the Marine Management Organisation (https://www.gov.uk/government/collections/uk-sea-fisheries-annual-statistics). Extracted by gear type (netting), and fishing effort (days at sea) identified.

Equation 1: Fishing effort for static net vessels. Number of days at sea extracted from the MMO (handled by Brown and May Marine). Average hauls per day extracted from Northridge *et al.* (2020) (Table 3).

$$fishing\ effort = number\ of\ days\ at\ sea\ \times average\ hauls\ per\ day$$

Table 3: Average hauls per day observed and bycatch rate per 1000 hauls for static nets. Data extracted from Northridge et al. (2020).

Species	Fishing Gear	Average Hauls/Day	Bycatch Rate/1000 Hauls
Guillemot	Static net <10m	4.57	20.07
	Static net >10m	3.49	4.22
Razorbill	Static net <10m	4.57	1.02
	Static net >10m	3.49	0.00

6.2.1.3 Fishing effort for both <10 m and >10 m static net vessels were compared between ICES divisions and ICES rectangles (Figure 5) with further investigation into the English Channel (Figure 6). ICES rectangles were the smallest scale available to monitor fishing effort by location and thus were used to map UK fishing effort in ArcGIS (Desktop 10.5.1).

6.2.2 Preliminary Bycatch Estimates

6.2.2.1 The number of guillemot and razorbill caught in bycatch were estimated using a method adapted from Northridge *et al.* (2020). Northridge *et al.* (2020) used data collected by the UK BMP between 1996 to 2017 on the numbers of individuals caught as bycatch. As the UK BMP only monitored <1% of static net UK fishing fleet, the data was extrapolated to estimate bycatch for the entire UK fleet[11]. To create the most accurate estimate, the data was analysed by Northridge *et al.* (2020) to identify temporal and spatial trends that may impact the extrapolation. Static net data was identified to contain significant differences based on vessel size (greater or less than 10m)[12]. The data was therefore separated by vessel size before extrapolation. Extrapolations were completed for 2016 and 2017. The data was extrapolated by extracting average hauls per day (observed) and bycatch rate per 1000 hauls for each individual vessel type and seabird species.

6.2.2.2 For the current analysis, only information for guillemot and razorbill with static nets were extracted. The average hauls per day observed and bycatch rate per 1000 hauls for guillemot and razorbill were extracted (Table 3). These estimates were then used to extrapolate the fishing effort identified in Section 6.2.1. Total bycatch was then estimated using Equation 2. Comparisons were made by location (ICES divisions and ICES rectangles (Figure 5)), by month, and year.

Equation 2: Bycatch estimated by fishing effort (Section 6.2.1) and bycatch rate (Table 3). Bycatch rate was extracted from Northridge *et al.* (2020)

$$bycatch\ estimate = fishing\ effort\ \times bycatch\ rate\ per\ 1000\ hauls$$

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[11] Only UK fleet in UK waters.

[12] Northridge *et al.* (2020) noted that within the static nets there was a weak suggestion that there may be a seasonal component to the bycatch rates for both guillemot and razorbill), with slightly higher observed bycatch rates during the winter months. However, a more detailed statistical analysis would be needed to determine the cause therefore seasonal stratification did not occur within the Northridge *et al.* (2020) analysis.

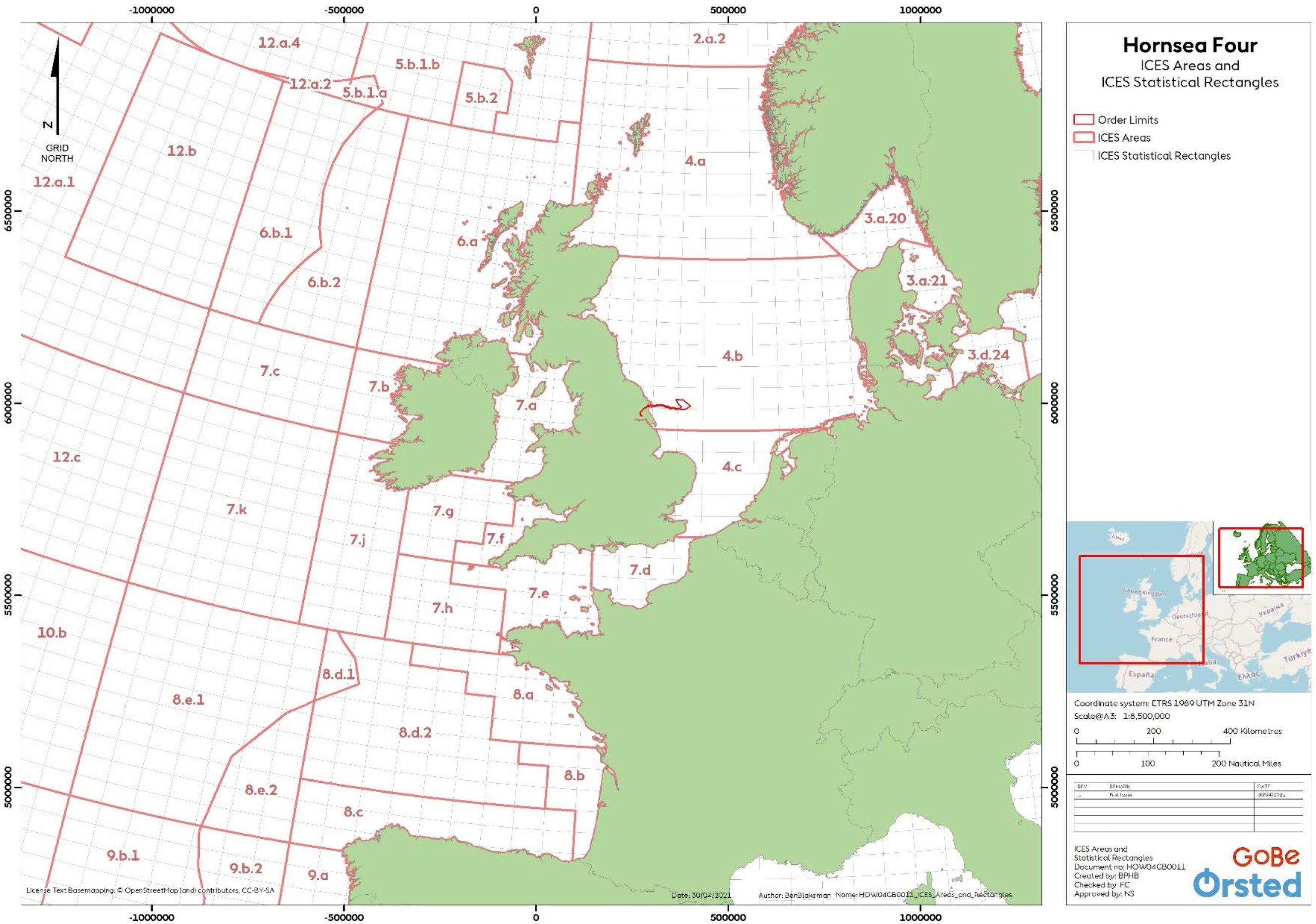

Figure 5: ICES divisions (red lines) and rectangles (grey lines).

Figure 6: ICES divisions (red lines) and rectangles (grey lines) within the English Channel. English Channel ICES divisions = VIId (7.d) and VIIe (7.e).

6.2.3 Potential Channel Estimates

6.2.3.1 Using the UK BMP database (same database used within Northridge et al. (2020), Coram et al. (2015) estimated seabird bycatch rates specifically for the English Channel (**Table 4**). However, these estimates were based on bycatch data from 2005 to 2013. Although the regional focus is more specific than the Northridge et al. (2020) analysis, the data incorporated is older and spans a shorter period of time, therefore changes in target fish species needs to be taken into consideration as UK fishing practices have changed since 2013[13]. The dataset also differed as it contained bycatch rates for static nets (set gillnets), drift nets, and trammel nets. As all three net types identified some bycatch for either species, a bycatch rate was identified for all three net types. All bycatch estimates were projected using the same method above (**Equation 2**).

Table 4: Bycatch rate per 1000 hauls extracted from Northridge *et al.* (2020) and Coram *et al.* (2015).

Species	Fishing Gear	Bycatch Rate/1000 Hauls (Northridge *et al.*,2020)	Bycatch Rate/1000 Hauls (Coram *et al.*,2015)
Guillemot	Static net <10m	20.07	57.36
	Drift Net	N.A.	10.85
	Trammel Net	N.A.	0.78
Razorbill	Static net <10m	1.02	0.00
	Drift Net	N.A.	8.53
	Trammel Net	N.A.	0.00

6.3 Results

6.3.1 Fishing Effort

6.3.1.1 Fishing effort for static net UK fisheries is presented in **Table 5**. Although <10 m vessels have the largest fishing effort in days, >10 m vessels span over a larger area (22 ICES divisions vs 9 ICES divisions). This is most likely due to the correlation between vessel size with coastal verses offshore fisheries. <10 m vessels are related to coastal fisheries and are limited to nearshore fishing areas. Fishing intensity from <10 m static net vessels is therefore more concentrated on specific areas.

Table 5: Fishing effort in days for <10m static net, >10m static nets in 2018. The divisions in bold represent the English Channel (VIId and VIIe). Data extracted from MMO and handled by Brown and May Marine.

ICES Division	<10 m Static nets	>10 m Static nets
IIa (2.a.2)	-	17
Iva (4.a)	91	3367
IVb (4.b)	106	2
IVc (4.c)	1782	91
IXa (9.a)	-	5
Via (6.a)	-	111

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[13] According to Marine Management Organisation dataset series (UK Sea Fisheries Statistics) and communication with the association of Inshore Fisheries and Conservation Authorities.

ICES Division	<10 m Static nets	>10 m Static nets
VIb (6.b.1/6. b.2)	-	3132
VIIa (7.a)	290	9
VIIb (7.b)	-	104
VIIc (7.c)	-	1404
VIId (7.d)	**7021**	**113**
VIIe (7.e)	**7295**	**701**
VIIf (7.f)	2130	466
VIIg (7.g)	130	762
VIIh (7.h)	4	413
VIIj (7.j)	-	1235
VIIk (7.k)	-	2396
VIIIa (8.a)	-	277
VIIIb (8.b)	-	73
VIIIc (8.c)	-	28
VIIId (8.d.1/8. d.2)	-	103
VIIIe (8.e.1/8. e.2)	-	3
TOTAL	*18849*	*14812*

6.3.1.2 Highest density fishing effort location varies between the vessel sizes. Vessels <10m occur at a higher density in the south of England, specifically within the English Channel and Cornwall (Figure 7). Whereas most of the effort for vessels >10m is off the north coast of Scotland and west of the UK (offshore) (Figure 8). Additionally, >10m vessels with less than 100 days spent fishing cover the largest area, including south to the north of Spain. Therefore, fishing intensity from larger vessels occurs only within a few ICES rectangles.

6.3.1.3 In addition to spatial variations, fishing effort fluctuates annually (Figure 9). Fishing effort for <10 m was highest during 2016. For vessels >10 m, there was an increase in fishing effort, with a doubling of fishing effort between 2016 and 2017. Moreover, fishing effort fluctuates during a single year (Figure 10). The fishing effort for <10 m vessels shows a 'seasonal' variation, with an increase of fishing effort during April to October. However, a pattern is not seen within >10 m vessels, instead, fishing effort fluctuates throughout the year.

English Channel

6.3.1.4 Within the English Channel, the fishing effort is mostly comprised of <10 m static net fisheries (Table 5), therefore the analysis of the English Channel bycatch is focused on <10 m vessels. The total fishing effort fluctuated per year, with highest effort observed within 2016, similarly to all the UK. When looking at a smaller spatial scale (ICES rectangles), <10 m fishing effort varies throughout the channel. ICES rectangles 29E5, 30E9 and 30F0 have the highest fishing intensity, of 2919, 2380 and 2494 days at sea in 2018 (Figure 7; Table 6). However, the fishing effort per ICES rectangle fluctuates annually (Table 6). Nevertheless, the highest densities stay within similar ICES rectangles.

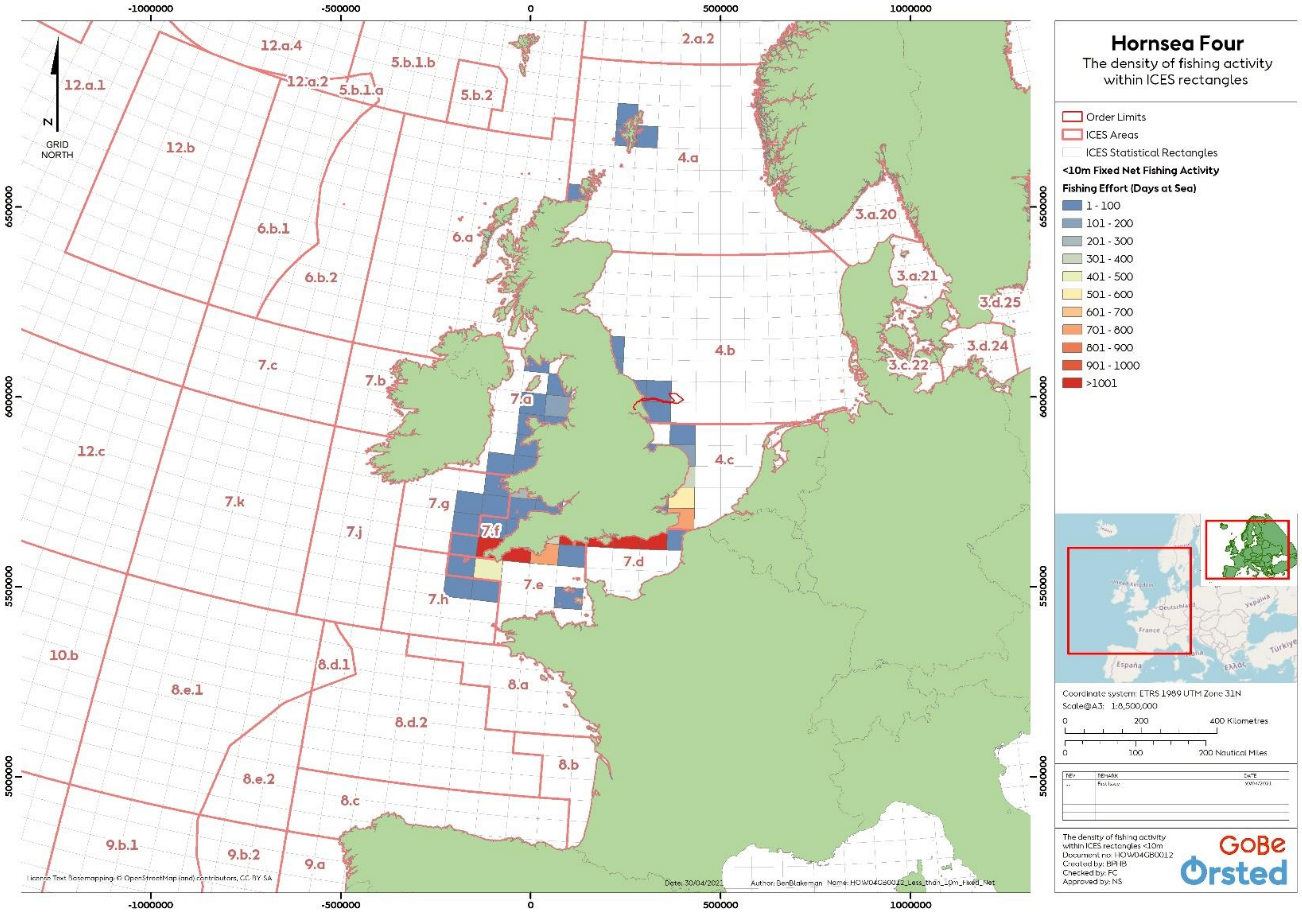


Figure 7: Days at sea for static net fisheries (<10m). Data extracted from MMO and handled by Brown and May Marine.

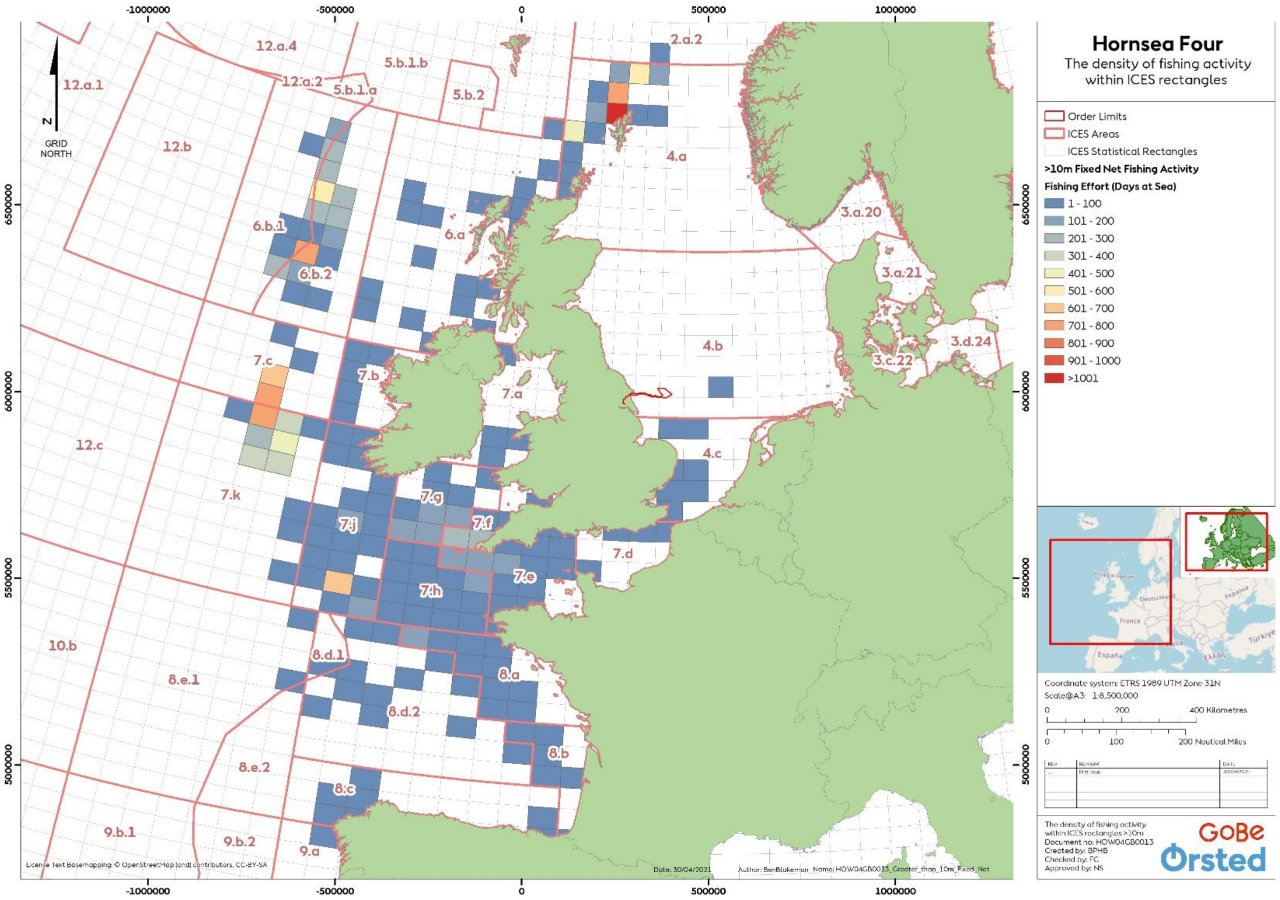
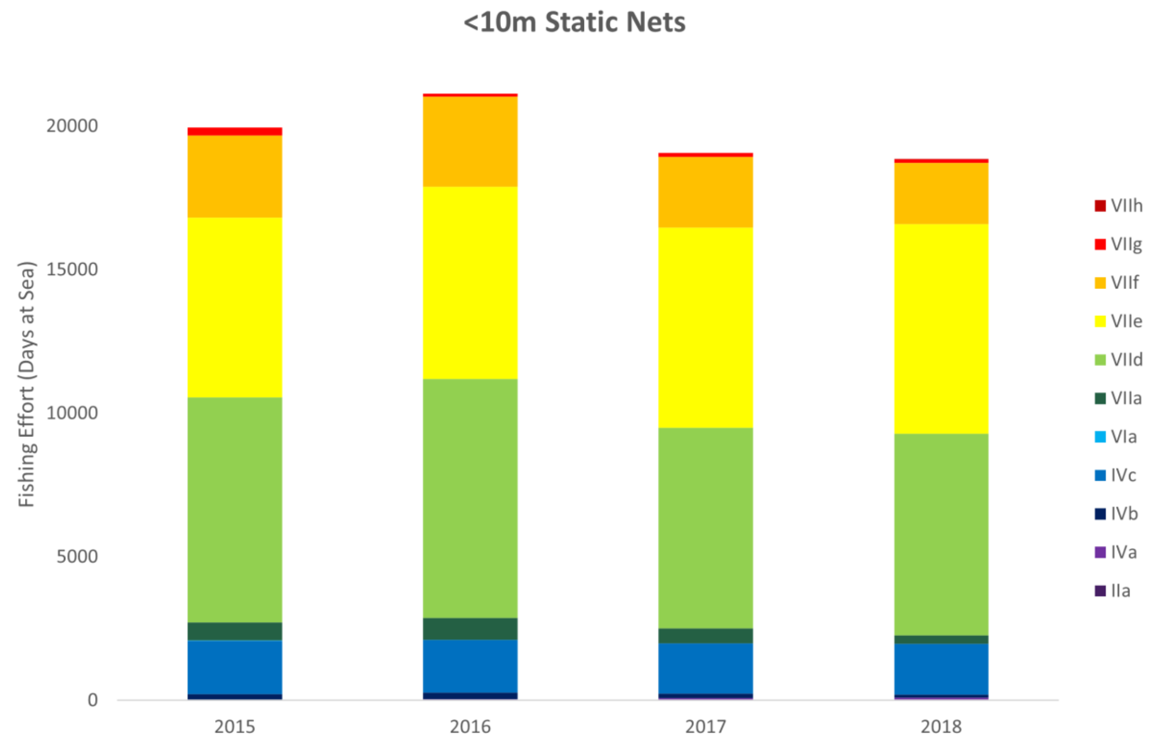


Figure 8: Days at sea for static net fisheries (>10m). Data extracted from MMO and handled by Brown and May Marine.



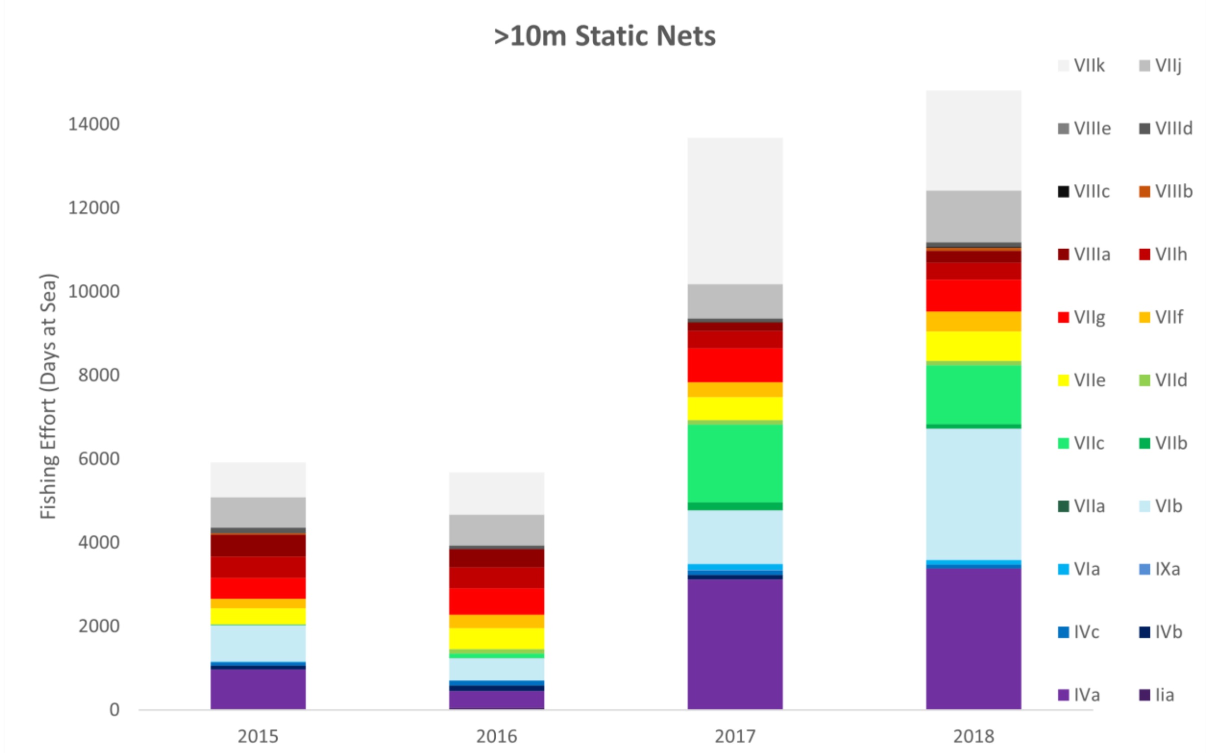


Figure 9: Fishing effort (days at sea) for <10 m (top) and >10 m (bottom) static net vessels by ICES division. Data extracted from MMO and handled by Brown and May Marine

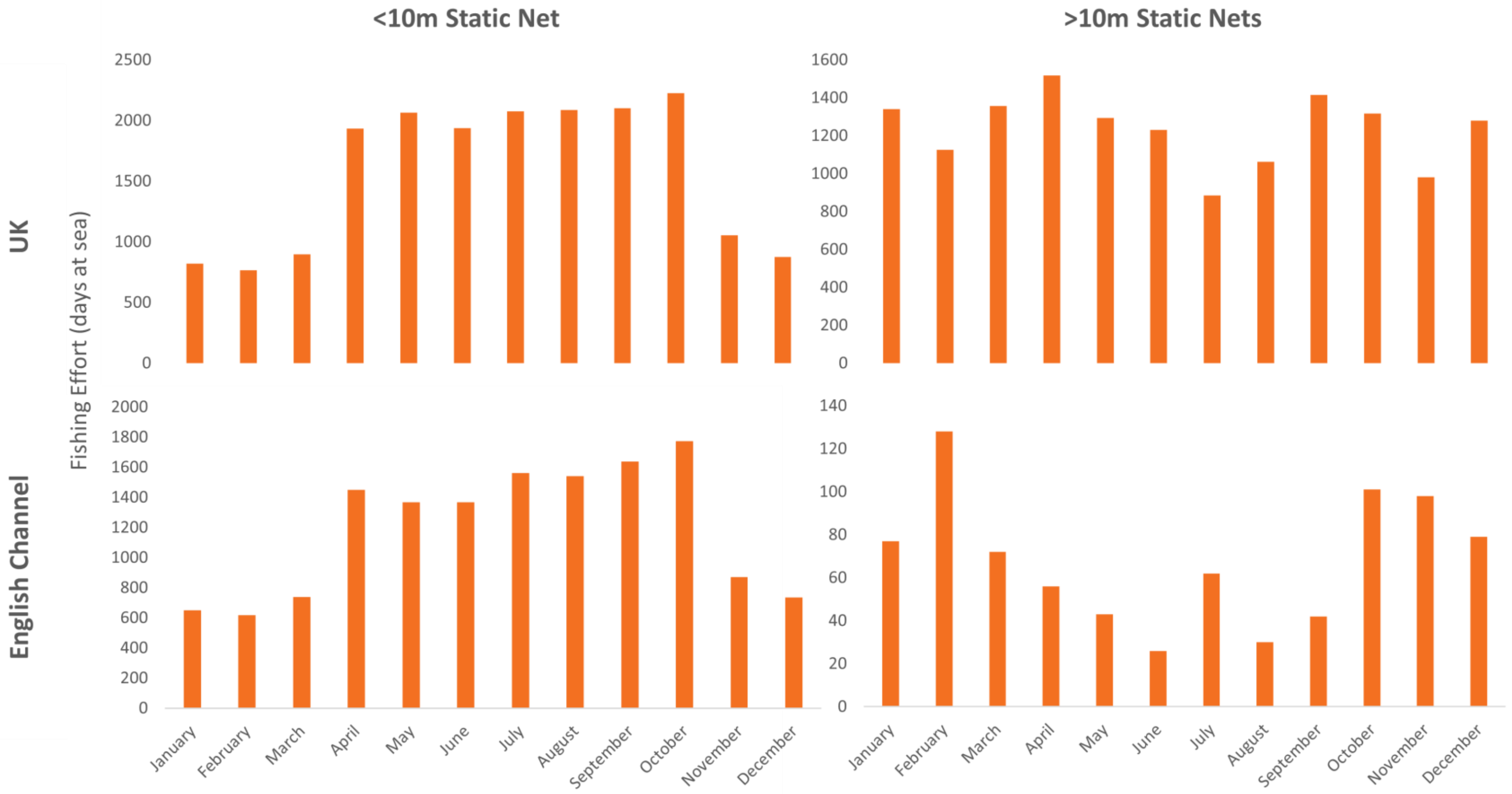


Figure 10: Total days fishing using static nets on vessels <10 m and >10 m in the UK and the English Channel (ICES VIId and VIIe) during 2018. Data separated by size - <10 m (left) and >10 m (right) – and locations – all of UK (top) and English Channel only (bottom). Data extracted from MMO and handled by Brown and May Marine.

Table 6: <10 m static net fishing effort (days at sea) per ICES rectangle within the English Channel. See Figure 6 for ICES rectangle locations. The highest ICES rectangles are identified in bold.

ICES	2015	2016	2017	2018
26E8	1	-	-	-
27E5	-		1	
27E7	-	3	28	1
27E8	-	-	1	
28E3	16	18	93	66
28E4	486	499	452	493
28E5	-	-	7	-
28E6	-	1	-	-
28E8	-	5	3	-
29E4	656	647	755	871
29E5	**2814**	**2850**	**2557**	**2919**
29E6	746	973	941	733
29E7	40	46	15	3
29E8	1	16	21	-
2989	-	-	2	-
30E6	282	466	669	384
30E7	1229	1187	1460	1790
30E8	2026	2377	1931	2085
30E9	**1973**	**2290**	**2389**	**2380**
30F0	**3568**	**3322**	**2457**	**2494**
30F1	266	323	184	97
TOTAL	*14,104*	*15,023*	*13,966*	*14,316*

6.3.1.6 Moreover, the fishing effort in the English Channel varies throughout the year (**Figure 10**). The fishing effort for <10 m vessels doubles between April and October. Whereas vessels >10 m has the opposite correlation, with the highest fishing effort occurring October through to February.

Flamborough and Filey Coast SPA

6.3.1.7 The ICES division that encompasses the Flamborough and Filey Coast (FFC) SPA is IVb. This is the source SPA of the potential displacement impacts associated with Hornsea Four and was the initial focus of reducing bycatch as a compensation measure. Fishing effort from 2018 for both <10 m and >10 m static net vessels represents just 0.32% of all UK fishing effort (**Table 5**; ICES division 4.6 in **Figure 7** and **Figure 8**). Northridge *et al.* (2020) showed a pronounced area of seabird bycatch (particularly guillemot) within this region. However, that estimate was likely based on the north-eastern gillnet fishery which no longer operates at a capacity anywhere near historic effort. Regional estimates (discussed in **Section 6.3.2**) show bycatch of guillemot and razorbill in this area is likely to be low. Focus has therefore been turned to identifying up to date key risk areas of bycatch of guillemot and razorbill. Focusing on areas of high bycatch rather than the FFC SPA will allow for a greater benefit to the wider guillemot and razorbill breeding populations of the UK.

6.3.2 Preliminary Bycatch Estimates

6.3.2.1 The total estimated bycatch for 2018 for the UK is 1,946 guillemot and 88 razorbill (Table 7). The majority of bycatch was by <10 m static net – 89% of guillemot bycatch and 100% of razorbill bycatch. Although only 56% of static net effort is from vessels <10m, a higher percentage of bycatch is observed due to a higher bycatch rate in the smaller vessels, with no bycatch of razorbill observed on vessels >10 m (Table 3). These current estimates are lower than the estimates presented in Northridge et al. (2020), which were 2,298 guillemot and 113 razorbill.

Table 7: Total estimated bycatch of guillemot and razorbill in the UK, as well as estimated bycatch in the English Channel (VIId and VIIe) and the ICES division for the Flamborough and Filey Coast (FFC) SPA (IVb). The percentage of bycatch within these two areas from total UK bycatch have also been calculated.

Species	Vessel Size	Bycatch Estimate		
		UK	Channel *(% of UK)*	FFC SPA *(% of UK)*
Guillemot	<10m Static net	1728	1313 *76%*	9 <1%
	>10m Static net	218	11 *6%*	<0.1 <0.01%
	TOTAL	*1946*	*1325* *68%*	9 *<0.5%*
Razorbill	<10m Static net	88	66 *76%*	<0.5 <1%
	>10m Static net	-	-	-
	TOTAL	*88*	66 *76%*	*<0.5* *<1%*

6.3.2.2 Bycatch estimates vary over ICES division (guillemot: 1.5 - 679 Figure 11, razorbill: 0.00 – 34 Figure 12). Over two thirds of both guillemot and razorbill bycatch occurred within the English Channel, of which the majority was due to <10m static nets (Table 7). This is linked to bycatch increasing with fishing effort (Section 6.3.1). Less than 1% of total UK guillemot and razorbill bycatch occurred within the ICES division related to the FFC SPA (Table 7, Figure 11, Figure 12). This is due to <0.5% of fishing occurring within the area (Paragraph 6.3.1.7). This is significantly lower than the observed bycatch presented in Northridge *et al.* (2020) between 1996 and 2018 for the waters around FFC SPA due to a change in fishing practices (from gillnets to potting) (Tim Smith NE IFCA, *pers comm.*). Potting was not identified by Northridge *et al.* (2020) as a bycatch risk for guillemot or razorbill. It is therefore important to focus bycatch reduction efforts within the English Channel to ensure the greatest benefit to UK guillemot and razorbill populations.

Annual Variation

6.3.2.3 The bycatch estimates fluctuate from 2015 to 2018 (Table 8). Bycatch was estimated to be highest in 2016 at 2,022 for guillemot and 99 for razorbill. The lowest year for bycatch was different between guillemot and razorbill: 1,917 guillemot in 2015, 88 razorbill in 2018. Razorbill bycatch fluctuated more than guillemot due to no bycatch observed within >10m vessels. The increase of bycatch from >10m vessels in 2017 and 2018 caused guillemot bycatch to stay at a similar rate to 2016.

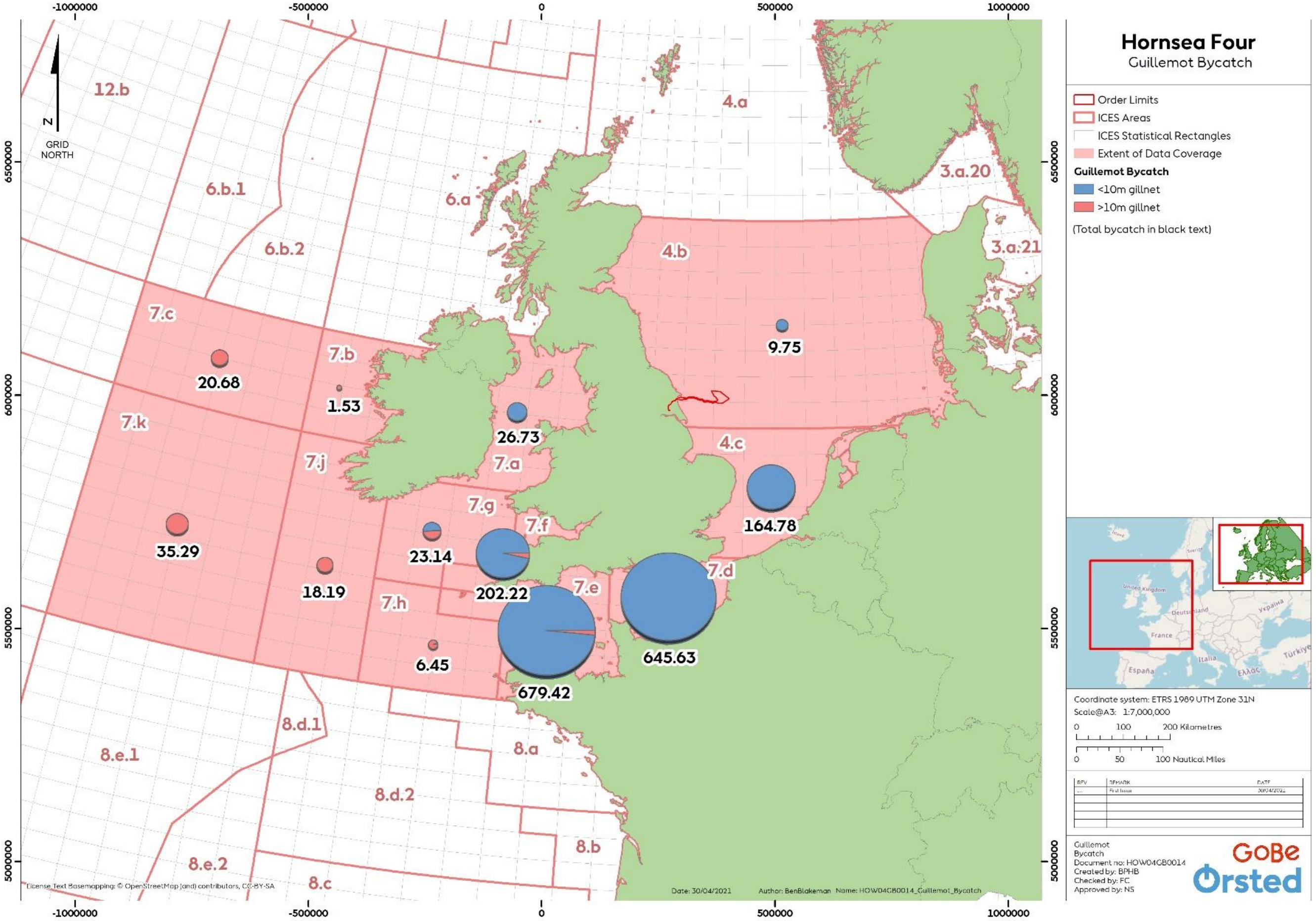


Figure 11: Estimated guillemot bycatch per static net vessel size and ICES division.

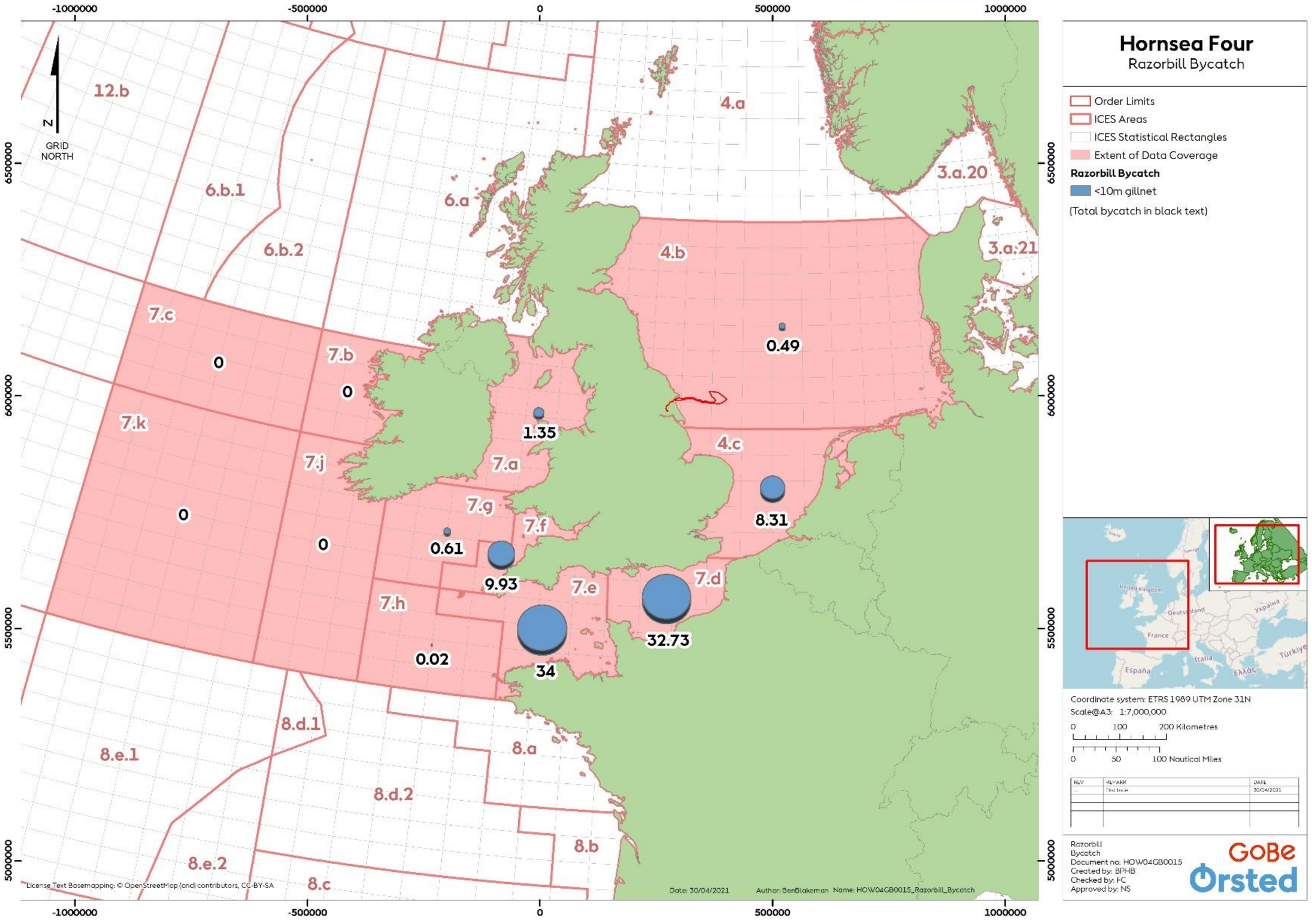


Figure 12: Estimated razorbill bycatch per static net vessel size and ICES division.

Table 8: Total bycatch estimates (< and >10m static net) for guillemot and razorbill within the UK as well as the English Channel (VIId and VIIe) and FFC SPA (IVb) ICES divisions.

Species	Year	Bycatch Estimate		
		UK	Channel	FFC SPA
Guillemot	2015	1917	1299	21
	2016	2022	1387	22
	2017	1951	1291	16
	2018	1947	1325	10
Razorbill	2015	93	66	1
	2016	99	70	1
	2017	89	65	0.7
	2018	88	67	0.5

6.3.2.4 Within the English Channel (VIId and VIIe) the bycatch estimates also fluctuate from year to year (Table 8, Figure 13). As seen in section 6.3.1, low density of >10m vessels within the English Channel. This has caused bycatch to fluctuate more within the English Channel compared to the UK, as the UK-wide increase of >10m vessels did not occur within the Channel (Figure 9).

6.3.2.5 The bycatch estimates within the area surrounding the FFC SPA (IVb) fluctuated slightly, however, decreased by 50% from 2016 to 2018 coinciding with the fishermen switching from gillnets to other fishing gear (Table 8).

Seasonal Variation

6.3.2.6 Within the UK, mean bycatch per month in 2018 from <10m static net vessels was 144.07 ± 56.38 S.D. (guillemot) and 7.32 ± 2.87 S.D. (razorbill). For >10m static net vessels, mean bycatch per month was 18.18 ± 2.73 S.D. (guillemot), and no bycatch of razorbill was recorded. A similar pattern is observed within the English Channel. With <10m vessels bycatch was estimated at 109.42 ± 39.71 S.D. (guillemot) and 5.56 ± 2.02 S.D. (razorbill). 1.00 ± 0.45 S.D. guillemot bycatch for >10m vessels was also estimated, with no razorbill bycatch recorded. The high variations around the mean (~40% for <10m vessels, 15-45% for >10m vessels) show that specific months are more significant for bycatch. However, these bycatch estimates were created solely using bycatch rate and fishing effort (bycatch rate x number of hauls). As the same bycatch rate was used for the entire year, the seasonal variation only represents the variation in fishing effort (number of hauls). Bycatch risk (and therefore bycatch rate) is likely to change seasonally due to variations in seabird density (higher density of birds will increase the chance of bycatch). Bycatch risk combining fishing effort and seabird density has been addressed in Section 7.

6.3.2.7 Bycatch from <10m static nets was higher between April and October for both the UK and the English Channel. Bycatch from >10m static net vessels was different within the Channel compared to the UK as within the UK, bycatch fluctuates without a particular seasonal difference, whereas, within the English Channel, bycatch decreased within March to September (except for July) (Figure 14).

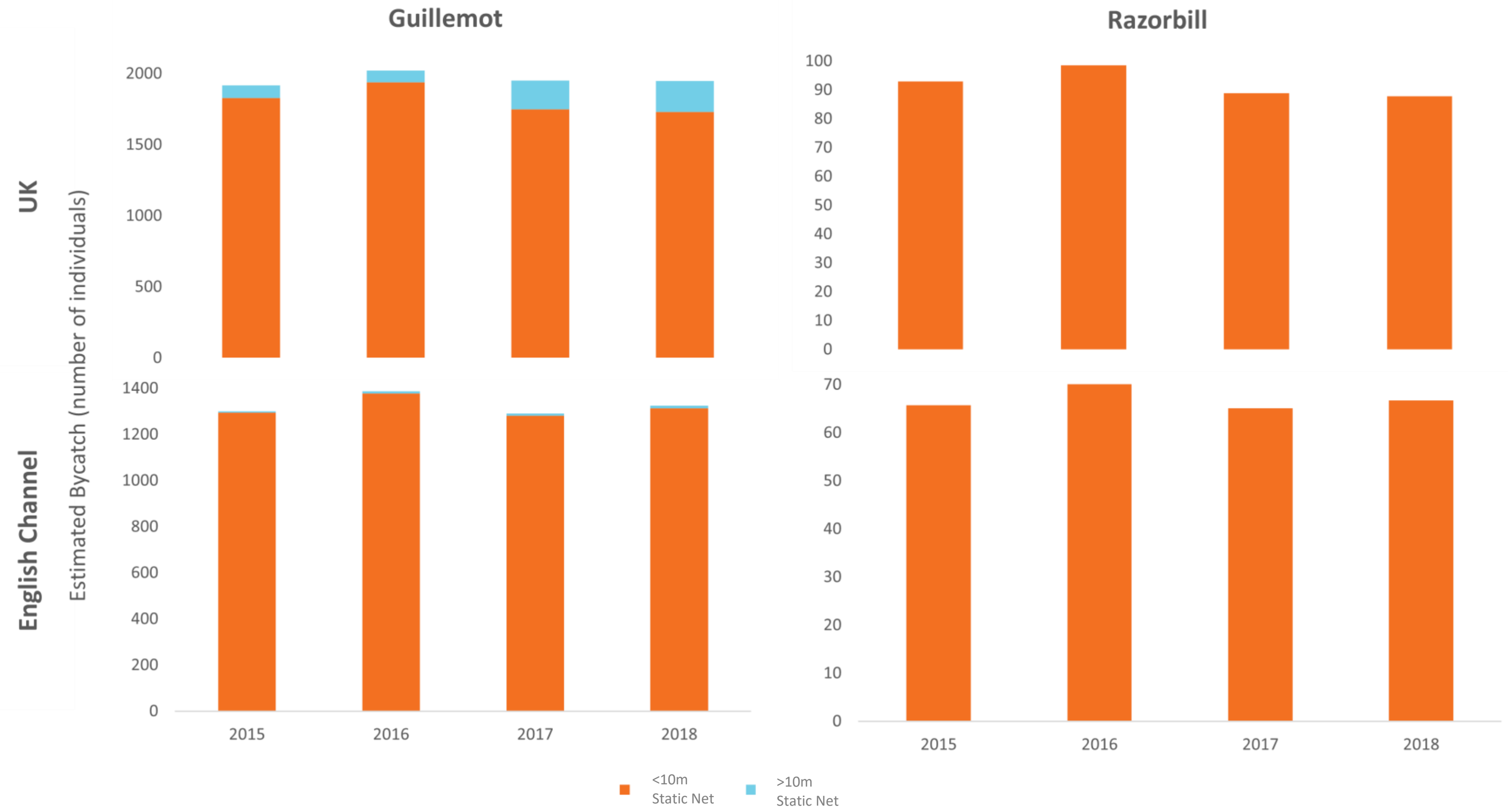


Figure 13: Bycatch estimates for guillemot and razorbill from 2015 to 2018. Data separated by species - guillemot (left two charts) and razorbill (right two charts) – and locations – all of UK (top) and English Channel only (bottom). Data extracted from MMO and handled by Brown and May Marine.

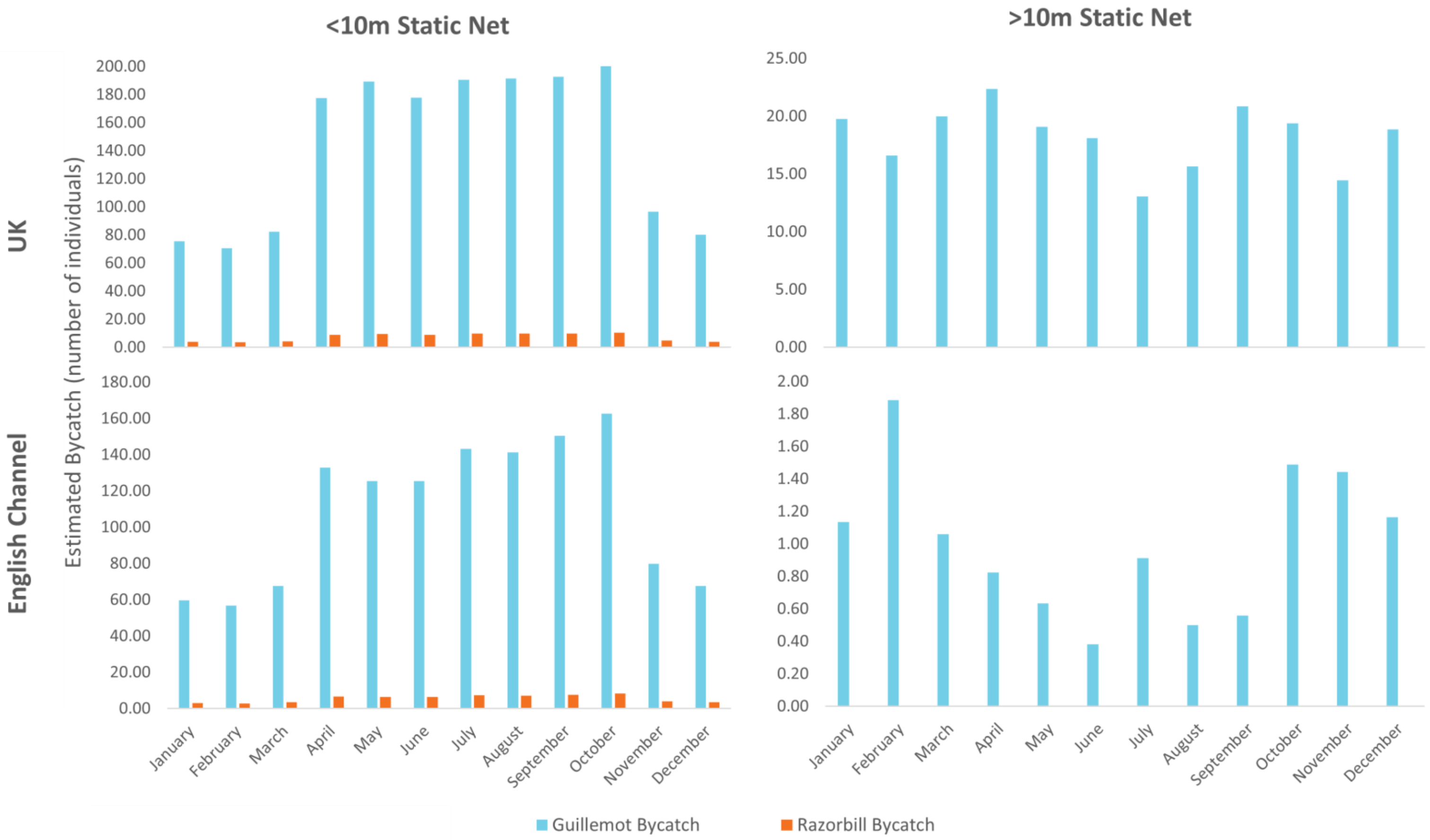


Figure 14: Bycatch estimates for guillemot and razorbill per month in 2018. Data separated by size - <10m (left two charts) and >10m (right two charts) – and locations – all of UK (top) and English Channel only (bottom). Data extracted from MMO and handled by Brown and May Marine.

6.3.3 Potential Channel Bycatch

6.3.3.1 The bycatch estimates between Northridge *et al.* (2020) and Coram *et al.* (2015), differ substantively. Firstly, guillemot bycatch is nearly triple (when considering Coram *et al.*, 2015) from that estimated from the initial analysis (using Northridge *et al.*, 2020) whereas razorbill was much lower (Table 9). More net types were included within the Coram *et al.* (2015) analysis, therefore enabled bycatch for drift and trammel nets to also be included. Drift and trammel nets only make up a small amount of English Channel <10m netting effort, <2% and 17% (>10m drift nets – 334 days, >10m trammel nets – 2974 days)[14]. Static nets (set gillnets) are therefore the most substantial netting gear for guillemot bycatch. Razorbill on the other hand is more complicated; with bycatch observed in static nets in Northridge *et al.* (2020), but none in Coram *et al.* (2015). Bycatch was instead seen at a higher rate within drift nets, but due to the low drift net effort the bycatch estimates were low.

Table 9: Bycatch estimates projected using bycatch rates from Northridge *et al.* (2020) and Coram *et al.* (2015) for guillemot and razorbill. Bycatch estimates are for gillnets, drift nets, and trammel nets. The difference between the two bycatch estimates has then been calculated.

Species	Fishing Gear	Bycatch Estimate		% Difference
		Northridge *et al.* (2020)	Coram *et al.* (2015)	
Guillemot	Static net (gillnet)	1313.06	3752.73	*+285.80%*
	Drift Net	-	16.56	
	Trammel Net	-	10.60	
Razorbill	Static net (gillnet)	66.73	0	*-100%*
	Drift Net	-	13.02	
	Trammel Net	-	0	

6.4 Discussion

6.4.1.1 Seabird bycatch is directly impacted by fishing effort, when calculated using the method from Northridge *et al.* (2020) where seabird bycatch rate is multiplied by fishing effort. As no seasonal or spatial variations have been considered within this equation, fishing effort will be the only cause of the trends observed. The only exception is bycatch vulnerability where the bycatch rate varies for guillemot and razorbill, as well as between <10m and >10m vessels. These factors have caused the variations between the results from fishing effort and the bycatch estimates.

6.4.1.2 Total fishing effort for UK static net fisheries for 2018 was 33,661 days at sea (<10m 18,849, >10m 14,812), subsequently causing a total of 1,946 guillemot and 88 razorbill bycatch. These bycatch estimates are underestimated as the UK BMP data focuses solely on UK vessels in UK waters. As vessels registered to other countries also fish in UK waters, UK seabird populations will also be susceptible to be bycaught in these vessels and therefore the negative impact on their populations is even greater. The estimate in this analysis and in Northridge *et al.* (2020) is therefore a material underestimate to the number of UK seabirds caught in bycatch in UK waters each year.

6.4.1.3 Although fishing effort was greatest in the <10m vessels, catch quantity was bigger for the larger vessels due to bigger ships with greater power and tonnage (MMO, 2019). The fishing

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[14] Noting a drift net ban in 2017. Potential for drift net fishing to increase if the ban is lifted.

effort varied between both space and time, however, <10m and >10m vessels did not have similar spatial or temporal trends when compared to each other. In 2018, <10m vessels were located near to shore around England and Wales, with some fishing off the North-East of Scotland. The greatest effort occurs within the English Channel. Whereas >10m vessels are located off the coast of most of the UK (with the exception of the east coast), noting that the effort extends out offshore into the Bay of Biscay (to the North of Spain) and West of Ireland into the Atlantic Ocean. The greatest effort occurs off the North-east of Scotland and West of Ireland. The difference in location is mainly due to <10m vessels targeting inshore areas whereas >10m vessels target offshore areas. As the vessel size directly impacts the bycatch rate (Northridge *et al.,* 2020), this directly impacts the spatial distribution of high areas of bycatch. Therefore, areas of high <10m fishing effort have a greater effect than areas of high >10m fishing effort, subsequently causing >75% of both guillemot and razorbill occurring within the English Channel (1,313 guillemot and 66 razorbill).

6.4.1.4 On top of spatial variation, there is also variation annually. Between 2015 and 2018, the year with the highest fishing effort for <10m vessels was 2016, however, there was no distinct increase/decrease over time. Whereas >10m vessels showed a dramatic increase in 2017, over double the effort in 2016. This subsequently caused annual variation in bycatch. The variations differed between guillemot and razorbill due to no razorbill being observed in >10m vessel bycatch. Therefore, when the increase in >10m vessels occurred in 2017 and 2018, this did not impact razorbill bycatch. Instead, razorbill bycatch was at its lowest in 2018. This differs to guillemot bycatch which displayed a more similar pattern to the total fishing effort (lowest in 2016).

6.4.1.5 Fishing effort also varies seasonally. There is no distinct pattern for vessels >10m as fishing effort fluctuates throughout the year. Whereas <10m vessels have a distinct seasonal correlation, with highest effort from April to October. For the same reasons stated above, bycatch follows the same fluctuations as fishing effort (with the exception of razorbill and >10m vessels).

6.4.1.6 ICES division VIb (waters around FFC SPA) has a fishing effort of 0.32% of the UK static net fishing effort, resulting in <0.5% of UK guillemot and razorbill bycatch. For bycatch reduction to have a large enough benefit to be considered as compensation, it is important to target areas of high fishing effort and therefore potentially high levels of bycatch. The English Channel (VIId and VIIe) had the highest fishing effort compared with all other ICES divisions (mostly <10m vessels) and has been shown to have links with the FFC SPA population during the non-breeding season (Mead, 1974; Furness, 2015) (for an in-depth analysis on guillemot and razorbill connectivity between FFC SPA and the English Channel, see Appendix A). Therefore, the English Channel is an important area for bycatch reduction as compensation would cause much larger benefits to the wider guillemot and razorbill biogeographic populations compared to focusing around the FFC SPA.

6.4.1.7 The fishing effort within the English Channel varies throughout the year, with <10m vessels increasing through April to October. >10m vessels have less of a pattern, with highest activity during February, October, and November. As <10m vessels are present at a higher density and have a higher bycatch rate compared to >10m vessels, the highest months of <10m fishing effort will likely be the most important to consider (i.e., April to October). Using the Northridge *et al.* (2020) estimates, bycatch within the English Channel accounts for >75% of all UK bycatch. However, it is likely that this has been underestimated due to no consideration of bycatch "risk zones". As the Northridge *et al.* (2020) estimate solely considers an average of all the bycatch rates, however, some areas may be higher than others, causing high risk zones to be underestimates and low risk zones to be overestimates (see Section 0). This has been demonstrated by the difference between the bycatch estimates from using the bycatch risk from Northridge *et al.* (2020) and Coram *et al.* (2015). The Coram *et al.* (2015)

estimate increased guillemot bycatch risk by 285%. Therefore, there is the potential for bycatch estimates to be much higher than anticipated due to high bycatch risk zones, and the uncertainties (accuracy of the estimates) are discussed below.

6.4.2 Accuracy of fishing effort and bycatch estimates

Fishing Effort Estimates

6.4.2.1 According to the MMO (2021), vessels >10m are legally required by EU legislation to submit information on: catch by species, quantity of fish retained onboard, fishing gear used, and the area the species were caught. This is submitted via their fishery logbooks within 48hrs. Landing declarations and sales notes must also be submitted within 48hrs (sales notes by the registered buyer). Data checks are completed to ensure the data is complete, and crosschecks are completed to ensure the data is valid (e.g., activity data reported with satellite observations). Whereas vessels <10m do not legally have to declare their catches. Instead, registered buyers are legally required to report commercially sold fish. Nevertheless, any fish sold of 30kg or under do not have to be declared. Therefore, any fish not sold, or sold in a mass under 30kg, will not be accounted for, and seabird bycatch will therefore go unreported. If a catch is being sold direct to an individual, then there is also no requirement for the catch to be declared. Additionally, buyers do not report the gear or fishing area, instead coastal staff add in this additional information based on local knowledge of the vessels they administer (observations of the vessel during inspections, air and sea surveillance, discussions with the operator of the vessel). The accuracy is therefore not 100% precise as it is based on local knowledge rather than logged locations.

6.4.2.2 To our knowledge, there is no legal obligation for fishermen to report seabird bycatch. Additionally, bycatch of seabirds is likely to be associated with negative connotations. In locations where there are IFCA byelaws in place, triggered by specific levels of seabird bycatch, there may be a negative incentive for accurate reporting (e.g., the closure of the Filey Bay gillnet fishery (Quale, 2015)). Under reporting of bycatch may contribute to uncertainty and underestimation in bycatch estimates.

Bycatch Estimates

6.4.2.3 The bycatch estimates produced have a great level of uncertainty. Firstly, due to the collection of the UK BMP dataset. Less than 1% of static net vessels were sampled therefore the estimates needed to be projected for 99% of the UK fishing fleet. When extrapolating data, it is important to identify factors that may impact the result, e.g., if there are spatial/temporal differences in seabird density and fishing effort. However, due to the small sample size, there was not enough statistical power to identify these even though there seemed to be some seasonal differences (Northridge *et al.*, 2020). Nevertheless, one difference was identified – bycatch rates between <10m and >10m static net vessels. When the data was extrapolated after separating these values, the bycatch estimate varied greatly. Figure 15 displays the bycatch estimates for static net vessels during 2016 and 2017. For both guillemot and razorbill, the total bycatch after stratification was higher than when all nets were extrapolated together. This is most likely due to an underestimation caused by weighting from the larger vessels where less bycatch was observed reducing the estimate. Therefore, if there are also spatial and temporal differences in bycatch rate, this could also impact the overall bycatch estimate and the bycatch within the UK could be even higher than estimated.

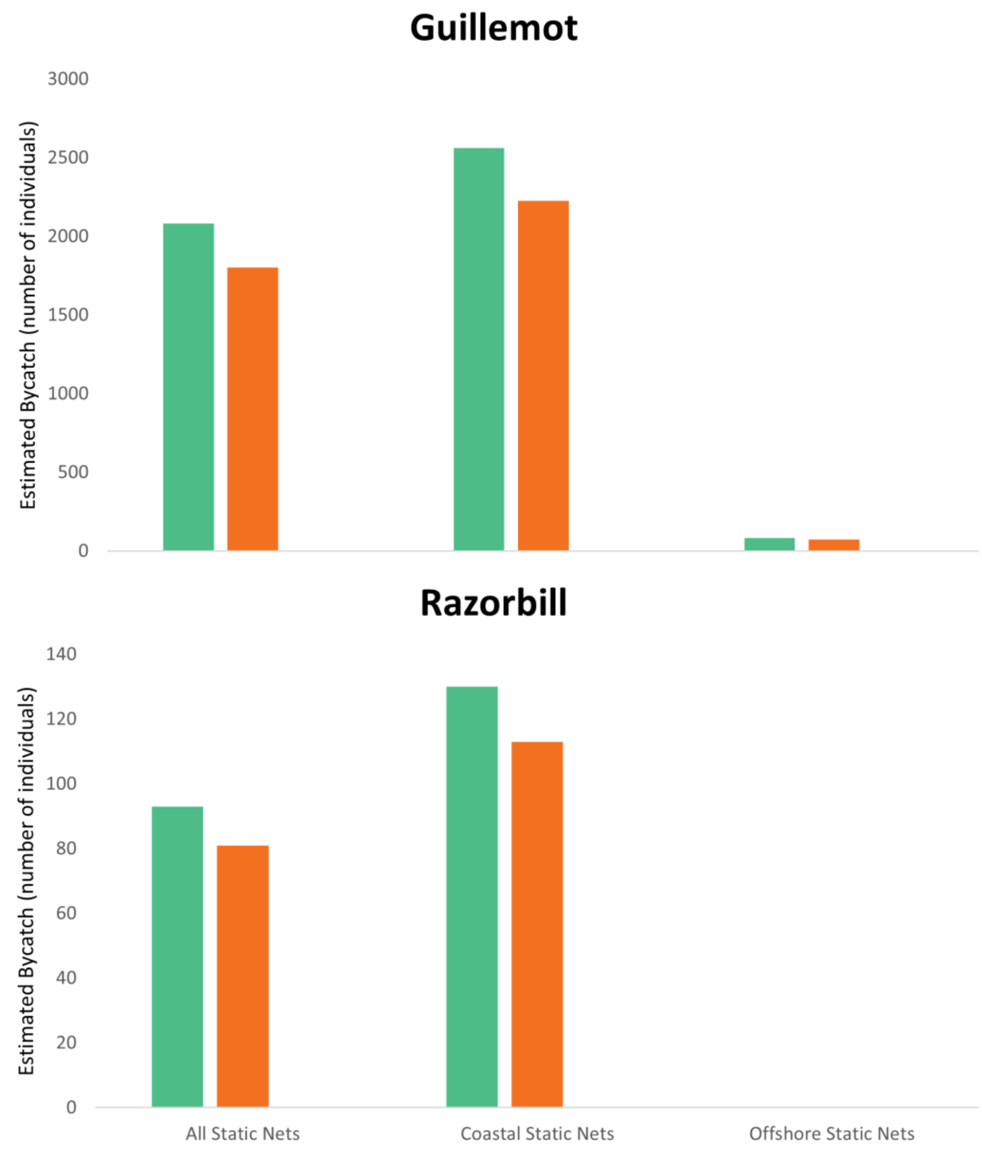

Figure 15: Estimation of guillemot and razorbill caught in static nets in 2016 (green) and 2017 (orange). Data derived from Northridge *et al*. (2020).

6.4.2.4 Based on the brief overview of the accuracy of estimates presented above, including the absent legal requirement for fishermen to report seabird bycatch or their fishing effort, along with the low sampling rate of the UK BMP, it is likely that the current estimates of bycatch produced in this report are underestimates and actual bycatch of guillemot and razorbill in the UK are much higher than previously thought.

7 Bycatch Risk Mapping

7.1 Introduction

7.1.1.1 As stated above (Section 6), the bycatch estimates using the Northridge *et al.* (2020) method did not consider spatial or temporal trends in bycatch rates. These trends are difficult to assess due to the multiple factors that may affect likelihood of bycatch (e.g., poor visibility, target catch species, gear depth, time of day, seabird density etc.) combined with the low statistical power of the UK BMP database (due to low sampling effort).

7.1.1.2 To understand high bycatch "risk zones", a bycatch risk assessment has been undertaken by GoBe Consultants Ltd on behalf of the Applicant in the UK to understand the areas where the highest densities of guillemot and razorbill encounter fishing gear. This section solely focuses on the relationship between seabird density and fishing effort. Only <10m gillnets have been considered due to this gear causing the highest bycatch rate of both guillemot and razorbill (Northridge *et al.,* 2020).

7.2 Methods

7.2.1 Seabird Distribution

7.2.1.1 Monthly distribution densities of guillemot and razorbill were mapped in ArcGIS (Desktop 10.5.1) (Appendix B). Seabird density for guillemot and razorbill was aggregated by Waggitt *et al.* (2019) per month at a 10km resolution. As the smallest scale for fishing effort was ICES rectangles the seabird density data was also extracted by ICES rectangles (1 degree longitude, 0.5 degrees latitude). The average density per rectangle was used.

7.2.2 Bycatch Risk

7.2.2.1 Bycatch risk was estimated by comparing seabird density (Section 7.2.1) and fishing effort (Section 6.2.1) per ICES rectangle. using Equation 3 (adapted from Bradbury *et al.* (2017)). The natural logarithm (+1 to avoid undefined values) was taken to transform each density into an order of magnitude to smooth out smaller discrepancies in counts, but still allowed large-scale patterns to be highlighted. Bycatch was then mapped in ArcGIS (Desktop 10.5.1) to identify high bycatch risk locations.

Equation 3: Bycatch risk calculated with the natural logarithm of seabird density (+1) and fishing effort.

$$Bycatch\ risk = ln\ (seabird\ density + 1) \times fishing\ effort$$

7.3 Results

7.3.1 Seabird Distribution

7.3.1.1 Monthly distribution densities of guillemot and razorbill were mapped around the UK (data derived from vessel and aerial survey data from 1980 to 2018 (Waggitt *et al.,* 2019); Appendix

B). Both species show a similar seasonal pattern, however, guillemot cover a greater area offshore throughout the year compared to razorbill.

7.3.1.2 From April to July, both guillemot and razorbill are located tightly around their colonies. This is expected as it aligns with the known breeding season when adults are nesting onshore. Outside of the breeding season, both species move further offshore, then start moving south post September. By December both species are located offshore around all UK coasts (Wright *et al*., 2012).

7.3.2 Bycatch Risk

7.3.2.1 The risk of seabirds being caught in fishing gear increases with the density of fishing effort and individuals, therefore, guillemot are more vulnerable than razorbill due to being present in higher numbers. The risk for guillemot and razorbill have been mapped in below (guillemot: Figure 16, Figure 17, Figure 18; razorbill: Figure 19, Figure 20, Figure 21). The bycatch risk for both guillemot and razorbill is greatest within the English Channel, specifically ICES rectangles 30F0, 29E5, and 28E4 ("hotspots"). Moreover, bycatch risk changes throughout the year. Lowest bycatch risk occurs between June to August. The highest total bycatch risk for guillemot occurs within April and October whereas for razorbill it is within January and February. Within the "hotspots", bycatch risk is highest from January to April for guillemot and January to February for razorbill.

7.4 Discussion

7.4.1.1 By taking into consideration seabird distribution density combined with fishing effort, more accurate estimates of high bycatch risk locations have been estimated. Coinciding with the preliminary bycatch estimates, highest bycatch was identified within the English Channel. Moreover, highest fishing density was identified within 29E5, 30E9, and 30F0, similarly to the identified "risk-zones" (30F0 and 29E5). A slight difference was identified, 30E9 was not identified as a bycatch "risk-zone", and the "hotspot" 28E4 was not identified as highest fishing effort. Both density of fishing effort and seabird presence is therefore important in bycatch risk.

7.4.1.2 The major difference between the bycatch risk and preliminary bycatch estimates is the seasonal variation. The preliminary bycatch estimates (based solely on fishing effort) identified highest bycatch within April to October for both guillemot and razorbill. Whereas when accounting for seabird density (bycatch risk) the lowest bycatch risk was during this period, from June to August. More research is needed to analyse the effects of seabird density on bycatch to create more accurate seasonal bycatch estimates, however, due to the lack of data this is not yet possible.

7.4.1.3 Overall, the English Channel over winter (particularly January and February) has been identified as a high "risk-zone". It is therefore considered appropriate to focus further work by the Applicant on bycatch reduction and bycatch sampling on this area during winter (to understand a more accurate bycatch rate for the area).

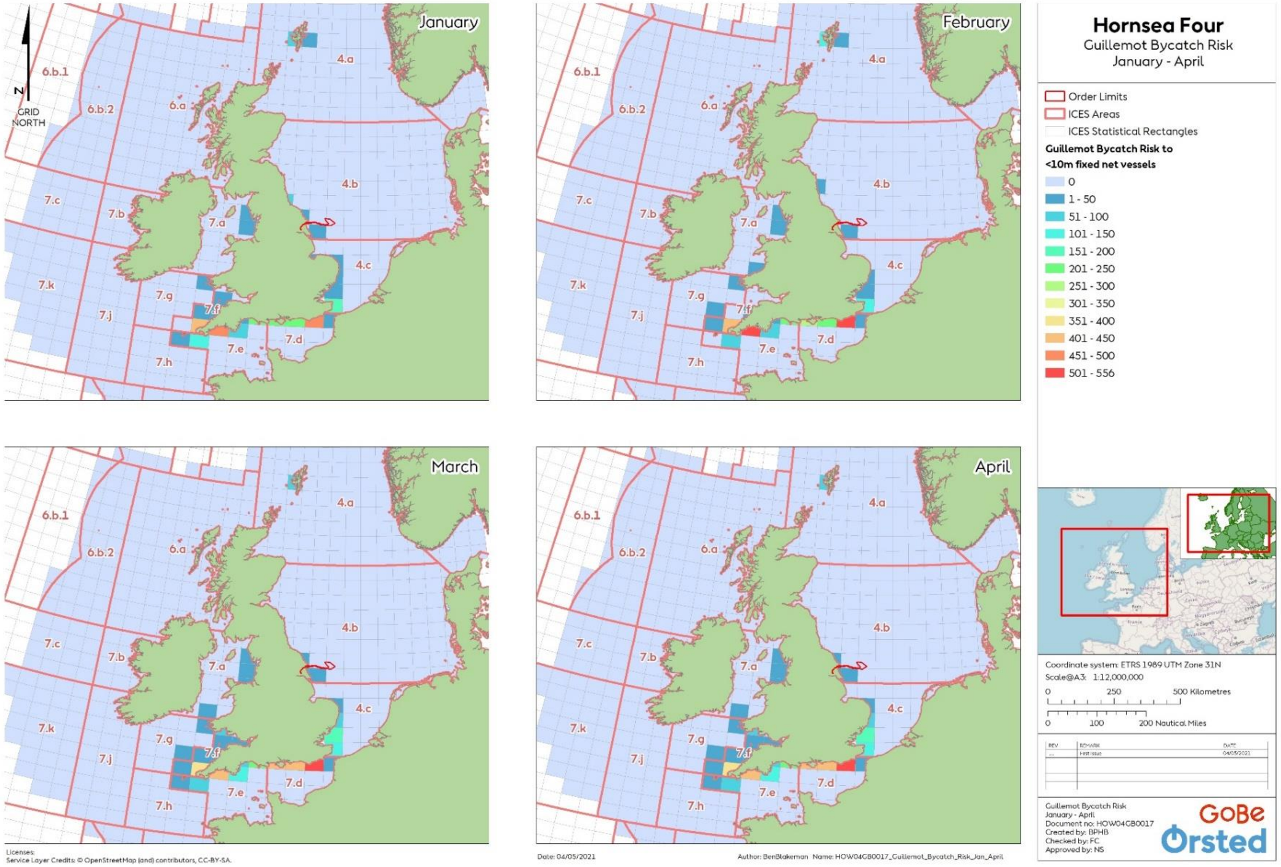

Figure 16: Guillemot bycatch risk (fishing effort density combined with guillemot density) to <10m static net vessels from January to April.

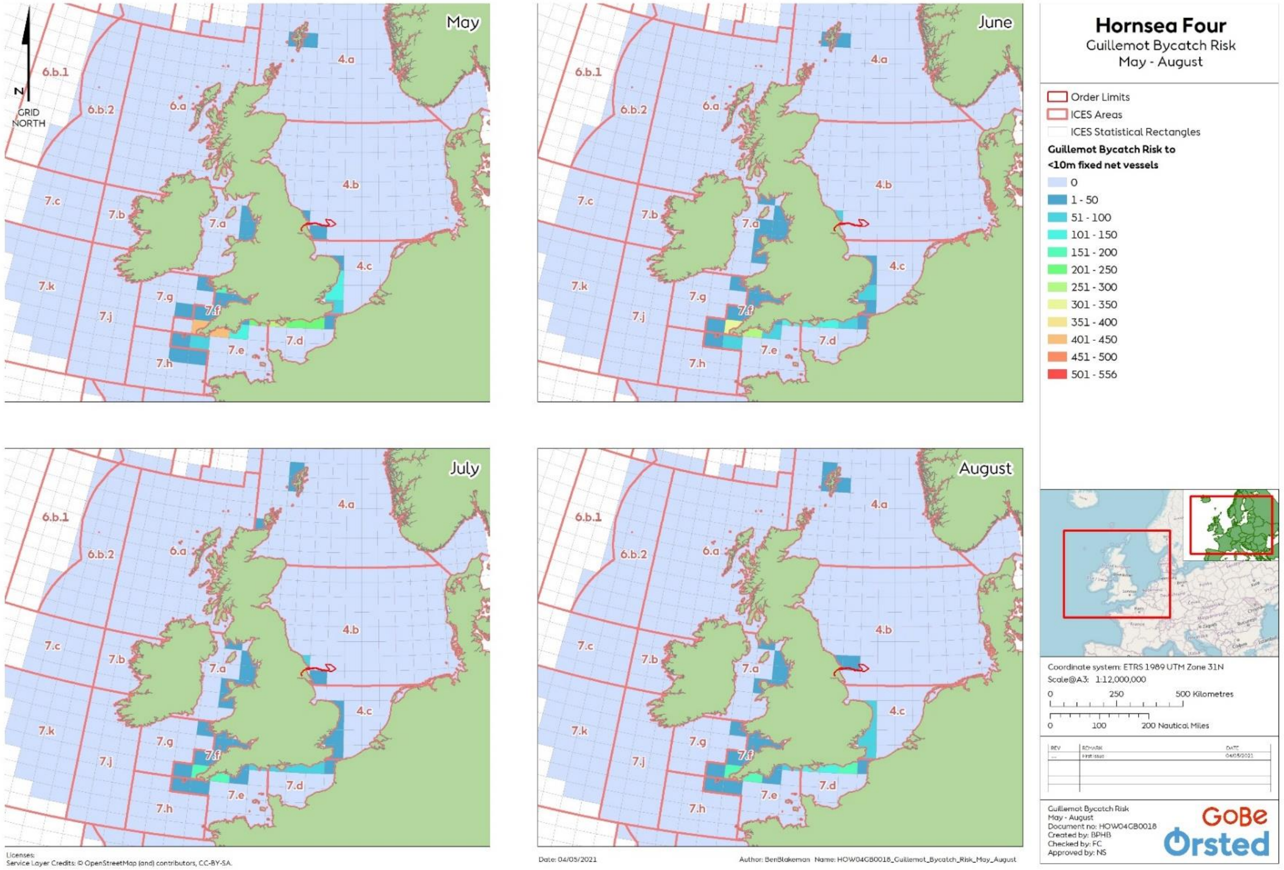

Figure 17: Guillemot bycatch risk (fishing effort density combined with guillemot density) to <10m static net vessels from May to August.

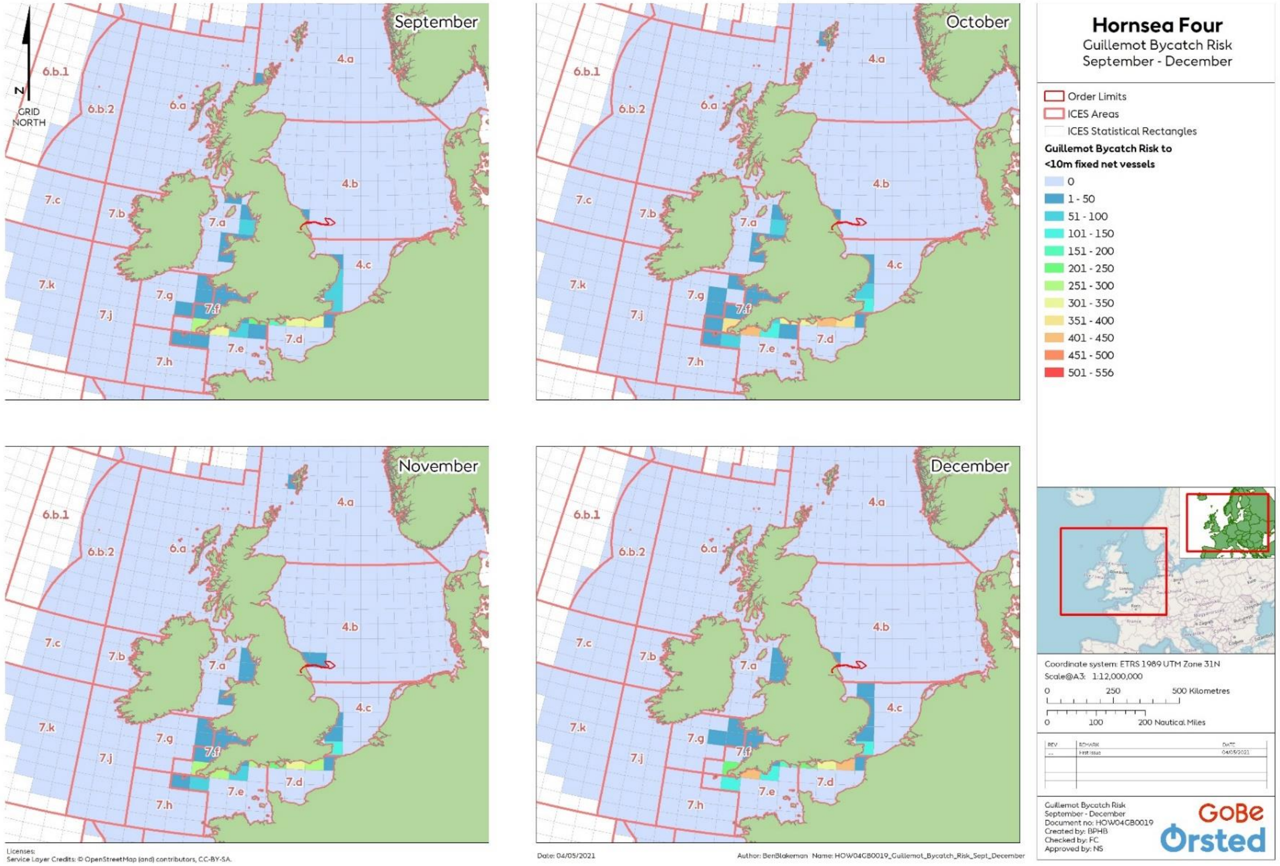

Figure 18: Guillemot bycatch risk (fishing effort density combined with guillemot density) to <10m static net vessels from September to December.

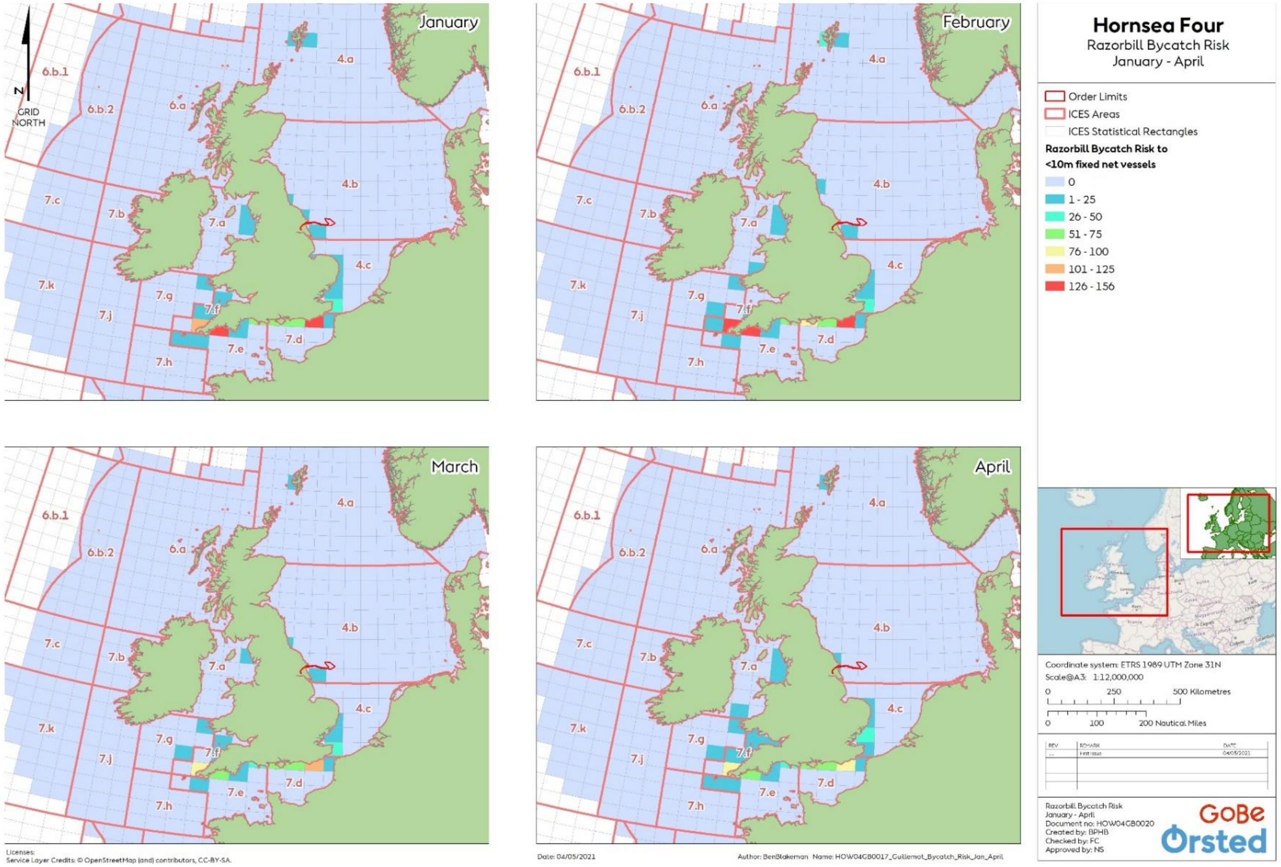

Figure 19: Razorbill bycatch risk (fishing effort density combined with guillemot density) to <10m static net vessels from January to April.

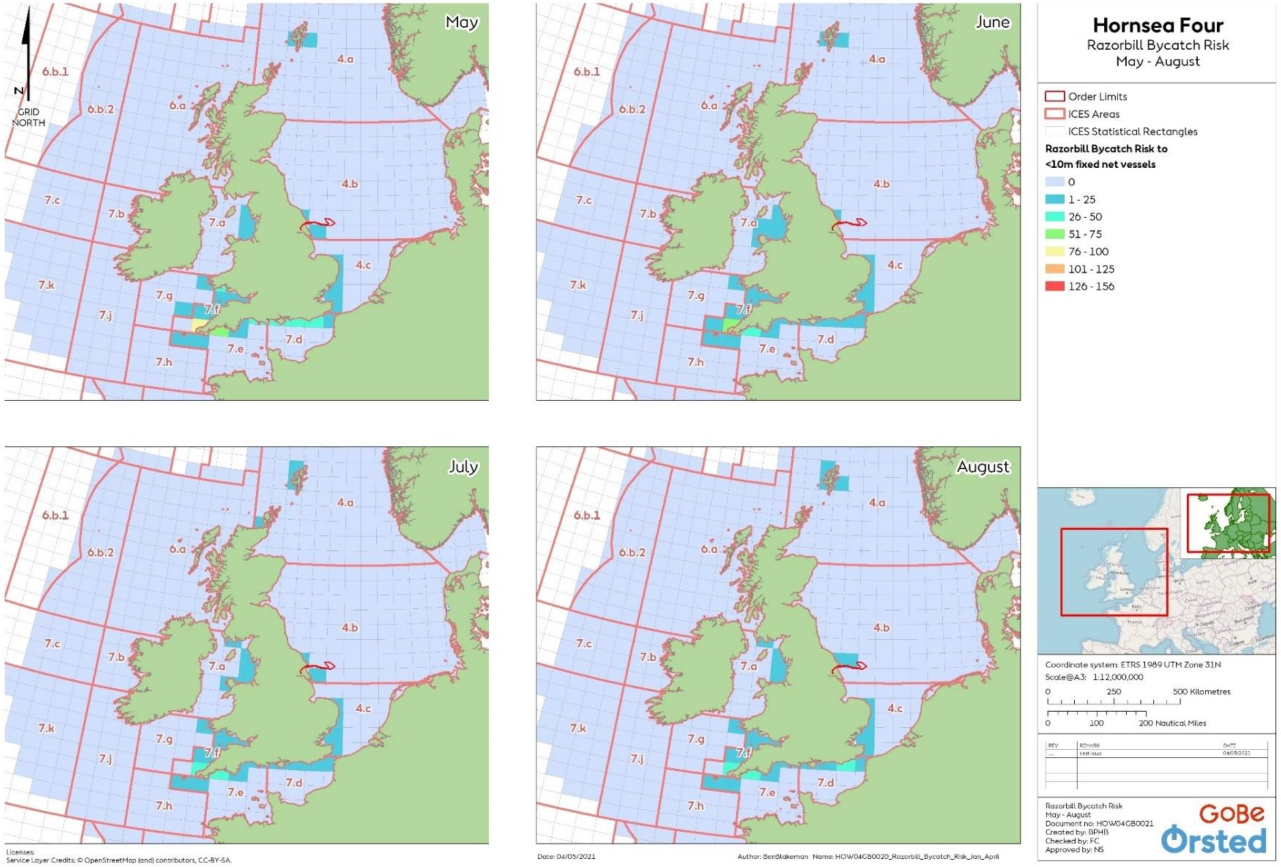

Figure 20: Razorbill bycatch risk (fishing effort density combined with guillemot density) to <10m static net vessels from May to August.

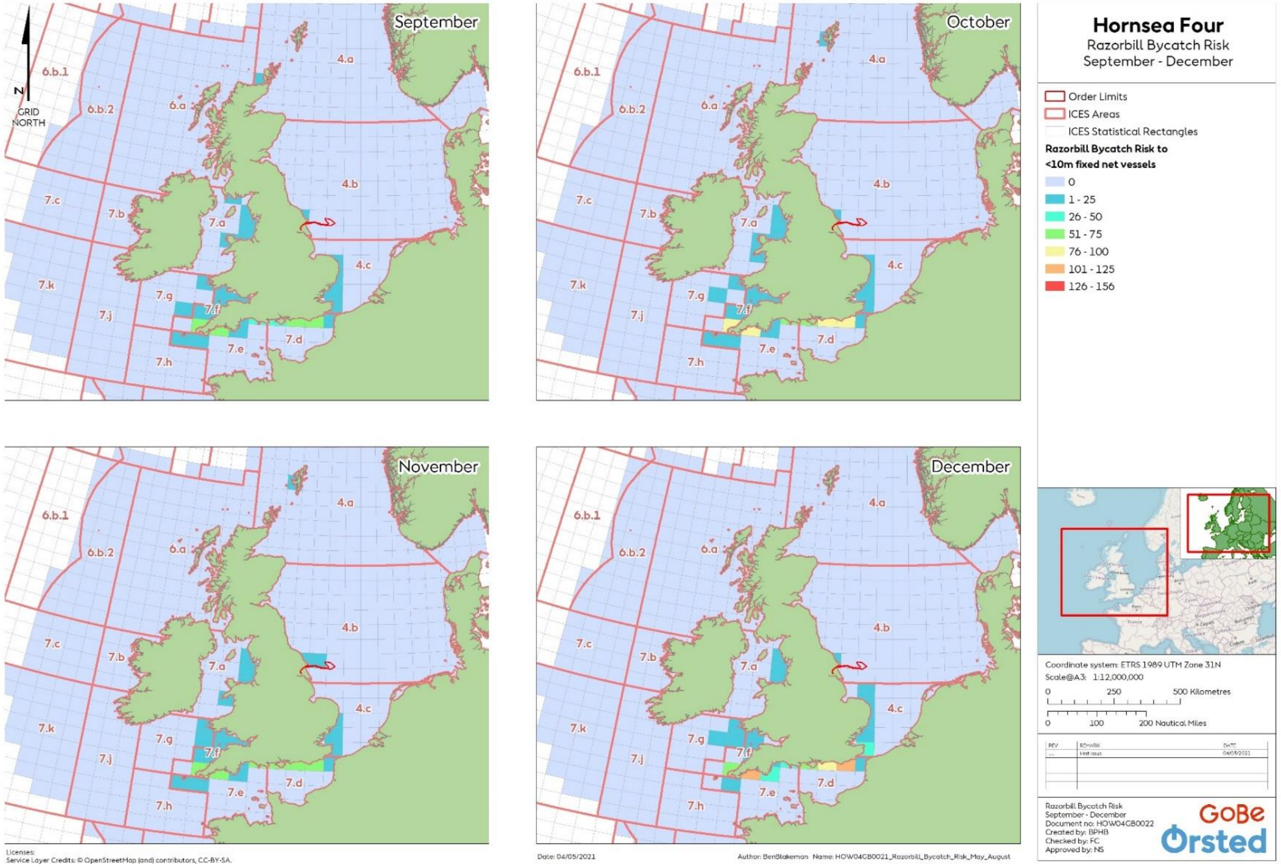

Figure 21: Razorbill bycatch risk (fishing effort density combined with guillemot density) to <10m static net vessels from September to December.

8 Fisherman Consultation

8.1 Introduction

8.1.1.1 Orsted have carried out a series of questionnaires with fishermen in various location in the UK to gather data on the level of bycatch of guillemot and razorbill within the UK fishing industry (see Section 3.3 for further details on the methodology of the questionnaires).

8.1.1.2 Presented below are the observations of a fixed gillnet fisherman who responded to the questionnaire and who wished to remain anonymous (hereafter referred to as Fisherman A). These results are presented now as they provide strong evidence to support a number of the findings of this document.

8.1.1.3 Fisherman A reported occurrence of seabird bycatch (predominantly guillemot, with 2 razorbill). They fish around the North and South coast of West Cornwall. The fisherman fishes for pollack using static gillnets from February through to April, whilst potting for brown crab the other proportion of the year. The response regarding seabird bycatch is solely related for February through to April.

8.2 Location of Seabird Bycatch

8.2.1.1 Fisherman A stated:

> *"Bird mortality seems to be higher when fishing closer to shore (within Mounts Bay, VIIf 29E4) and drops away dramatically as the weather allows me to fish further offshore.*
>
> *In 2019 my fishing effort was well spread out, an equal mix of inshore (within 3 miles of land) and offshore (more than 6 miles and up to 30 miles). Bird mortality was high on the inshore grounds (perhaps as high as 10-15 birds/day from 5-6 tiers) and decreased rapidly to zero the further offshore I fished.*
>
> *In 2020 weather conditions were atrocious for much of the early part of the netting season, with severe gales and storms predominantly from a NW or N direction, a notably unusual weather pattern. This forced me to fish much closer to land than I would normally have tried. Bird mortality during this period was higher, up to 20 birds from 6-7 tiers of net (I used several different length tiers during this period, typically 3 net tiers on wrecks and 5 net tiers on reefs) a disproportionately higher mortality was observed on the longer nets. I believe this to be due to the aggregation of feed fish (Sardines, Sprats and Anchovies) across the reefs and open ground rather than the wrecks.".*
>
> *"I fished differently in 2021, reducing the length of my tiers down to just 2 nets and just targeting wrecks. Weather also allowed me to fish further offshore and I believe because of these two factors the bird mortality experienced during this season was much lower (2-3 birds/day from 6-7 tiers)."*

8.2.1.2 This coincides with the UK BMP dataset which stated that smaller <10m (coastal) vessels had a higher bycatch rate compared to larger >10m (offshore) vessels. However, it should be noted that the vessel length of the fisherman is 11m. Vessel length is a good proxy for onshore versus offshore however larger vessels should not be excluded if fishing in an inshore region.

8.2.1.3 Nevertheless, in 2021, when Fisherman A was able to fish further offshore, they still caught

2-3 birds a day, which is much greater than estimated in Northridge *et al.* (2020). For static gillnets >10m, bycatch per 1000 hauls was estimated at 4.22, with 3.49 hauls per day. This results in an estimate of <0.015 guillemot caught per vessel per day. Fisherman A's response shows that the bycatch rate is greatly underestimated. Therefore, it should be considered that bycatch is a much greater problem than previously thought, especially if 2-3 birds was identified as *"much lower"* than average.

8.3 Seabird Mortality

8.3.1.1 When a net is hauled, a bycaught bird may potentially be alive, allowing it to be released and reduce the number of birds drowned (note that survival post release is unknown). However, Fisherman A stated that:

> *"On only two occasions were birds recovered alive and both instances they were carefully extricated from the net and released. Sadly in every other instance the birds recovered were drowned."*

8.3.1.2 It can therefore be assumed that in most cases the bycaught birds do not survive. It is therefore important to introduce a bycatch reduction measure to reduce bycatch rather than focusing on safe release of caught birds (as they will have drowned prior to hauling).

8.4 Data Sensitivity

8.4.1.1 Seabird bycatch is a sensitive topic to discuss with fishermen due to the nature of high seabird bycatch resulting in byelaws or fishing restrictions. There is therefore a risk to fishermen's livelihood if they choose to disclose accounts of bycatch. This was subsequently disclosed during the consultation with Fisherman A:

> *"I believe there is a concern amongst fishing communities that divulging sensitive data of this nature will result in kneejerk reactions from powerful lobbying groups that will seek to further curtail and restrict fisheries and communities they care little for."*

8.4.1.2 Whilst it is vital to evaluate all sources of data, it is important to consider potential biases with qualitative data due to the negative social impacts of fishery closures and/or restrictions.

8.5 Uptake of Bycatch Reduction Measures

8.5.1.1 Within the questionnaires, fishermen were asked *"Would you be willing to adopt any proposed measures in a pilot study, should they be paid for by Orsted?"*. The response was positive, with 80% of fishermen in Cornwall saying they would participate. This shows the positive relationship between Orsted and members of the fishing industry, with strong engagement. This relationship with aid the Applicant when deploying the compensation measure post the pilot study, and the Applicant believes that those willing to participate in the pilot study will participate in the deployment of the techniques.

8.6 Summary

8.6.1.1 Fisherman A's response to bycatch supports the conclusions made elsewhere within this report that:

- Bycatch rate increases closer to shore;
- The bycatch rate from the UK BMP dataset is underestimated; and

- Sensitivity from fishermen around disclosing bycatch may reduce the number of bycatch events recorded.

8.6.1.2 Additionally, the Applicant received a positive response regarding participation in a pilot study. Therefore, it is likely that a positive response will also be received regarding widespread use of the bycatch reduction technique.

9 Gannet Bycatch

9.1 Introduction

9.1.1.1 Northridge *et al.* (2020) identified longline fisheries as the most important UK fishery regarding gannet bycatch. However, there was no data available for longline fishing effort per month per ICES rectangle, therefore the analysis completed in Sections 6 and 7 could not be completed for gannet. The following section therefore summarises the available information for gannet bycatch within UK waters (including UK and non-UK fleet).

9.2 UK Fleet

9.2.1.1 Northridge *et al.* (2020) analysed the UK BMP dataset to identify key bycatch locations and species. The total bycatch observed was extrapolated to estimate the possible total bycatch for the entire UK fishing fleet. Northridge *et al.* (2020) observed gannet bycatch within static gillnet and longline fisheries, and estimates hundreds are caught per year (Table 10).

Table 10: Gannet bycatch estimated by Northridge *et al.* (2020). Extrapolations based on 2016 and 2017 fishing effort. Medium estimate (lowest to highest estimations).

Fishing Gear	2016	2017
Longline	220 (27 to 464)	241 (30 to 510)
<10m Static Gillnet	22 (0 to 54)	19 (0 to 47)
>10m Static Gillnet	36 (14 to 64)	31 (12 to 55)

9.2.1.2 The ICES divisions IVa (4.a.) and VIa (6.a.) were identified as the most important areas for longline fishery bycatch (2016 = 130; 2017 = 159) (Northridge *et al.,* 2020). Both divisions are within Scotland (Figure 5). ICES divisions VIIb (7.b.), VIIc (7.c.), VIIj (7.j.) were also identified as important regions of gannet longline bycatch (2016 = 91; 2017 = 80) (Figure 5). The locations of the remaining bycatch were not stated within the analysis.

9.2.1.3 However, as the UK BMP only monitored a very small proportion (<1% of static gillnet effort, 1-2% of longline effort and ~5% of midwater trawl effort), the extrapolations can cause large margins of error. Moreover, bycatch is not consistent spatially or temporally, therefore the samples could cause "bycatch hot-spots" to be missed. It is therefore important to consider areas of high gannet density (combined with high fishing activity) for any future research.

9.2.1.4 The annual bycatch mortality is based solely on the UK fishing fleet, yet foreign vessels are also active within UK waters. The scale of bycatch in UK waters and the impact on the UK populations will therefore be higher than those stated above. The impacts of foreign fleet vessels have been discussed below in Section 9.3.

9.3 Non-UK Fleet

9.3.1.1 The Northridge *et al.* (2020) analysis solely refers to the UK fishing fleet, therefore bycatch from other Nation vessels has not been included. Because of this, fishing by other fleets in UK waters will increase the population level impacts at UK colonies. As the bycatch mortality is already at 1% of the Celtic population, additions from foreign vessels will take bycatch mortality over the 1% threshold (Section 5.3).

9.3.1.2 The level of foreign fishing effort in UK waters is currently being investigated by Hornsea Four. From an initial literature search and evidence gathering, both trawls and longlines are thought to impact UK gannet. Static gillnets were also identified by Northridge *et al.* (2020) to incidentally catch gannet, and therefore should not be discounted, however, no current evidence of foreign static gillnet effort has been identified at this initial stage.

9.3.2 Trawlers

9.3.2.1 During consultation with the fishing community carried out by Orsted, Danish trawl fishermen stated that gannet are bycaught in trawls during hauling as gannet dive into the net to retrieve fish (*per. comms*[15].). However, trawls were not observed by Northridge *et al.* (2020) as a problem for gannet bycatch. As only 5% of the UK midwater trawl fishery was sampled by the UK BMP, there is the potential that locations of gannet bycatch in UK trawl fisheries have been missed. As a fisherman would not lie about incidentally catching birds (due to the sensitivity of the topic), bycatch by trawlers in the southern North Sea should be identified as high risk to gannet.

9.3.2.2 To identify the level of foreign fleet trawl fishing effort within the North Sea, Brown and May Marine used VMS data to map effort through density/value in Figure 22, Figure 23, and Figure 24. The figures indicate that there are trawlers in the vicinity of the FFC SPA, within the foraging range of gannet and could therefore have potential for high bycatch in this area. The overlap of gannet foraging ranges (e.g., Woodward *et al.,* 2019) and/or distributions will be further evaluated by Hornsea Four, with outputs communicated with stakeholders once available.

9.3.3 Longlines

9.3.3.1 As stated previously western European and African longline fisheries are important regarding UK gannet bycatch during winter migrations (Furness, 2019). Further investigation is currently being undertaken by Hornsea Four, with outputs communicated with stakeholders once available.

9.4 Summary

9.4.1.1 Although only static net and longline fisheries were identified as a bycatch risk by Northridge *et al.* (2020), fisheries consultation identified trawlers as an important fishery for gannet bycatch. There are various foreign trawlers that operate within the North Sea that could potentially impact gannet, including Dutch, Danish and Belgian.

9.4.1.2 Further investigations are continued to be carried out by Hornsea Four regarding gannet bycatch to understand potential "hot-spot" locations and identify the most important fisheries to target bycatch for compensation.

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[15] Stated during a telephone conversation between Danish fishermen and Orsted fishery liaisons. Waiting on written comments.

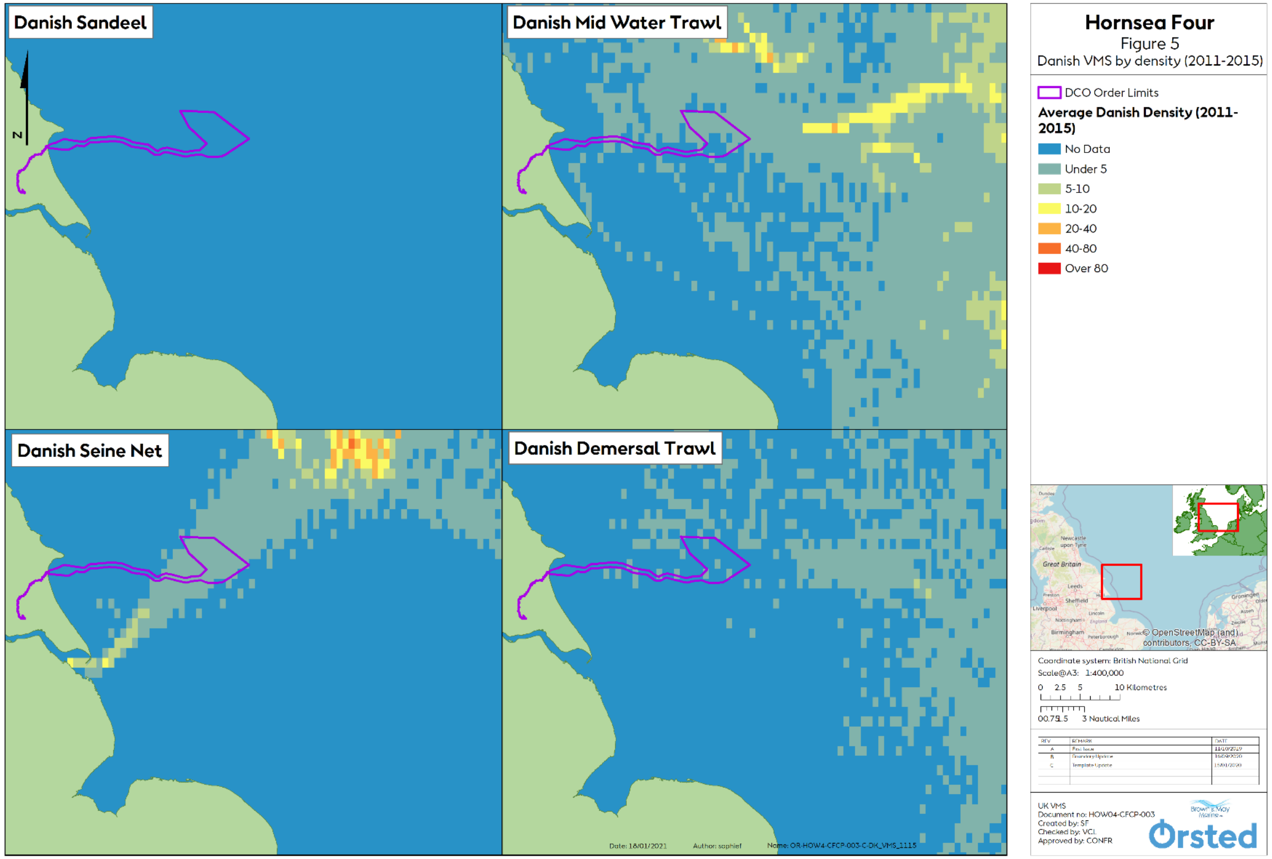

Figure 22: Average Danish VMS by density (2011-2015) for the sandeel (top left), midwater trawl (top right), seine net (bottom left), and demersal trawl (bottom right) fisheries. Figure produced by Brown and May Marine.

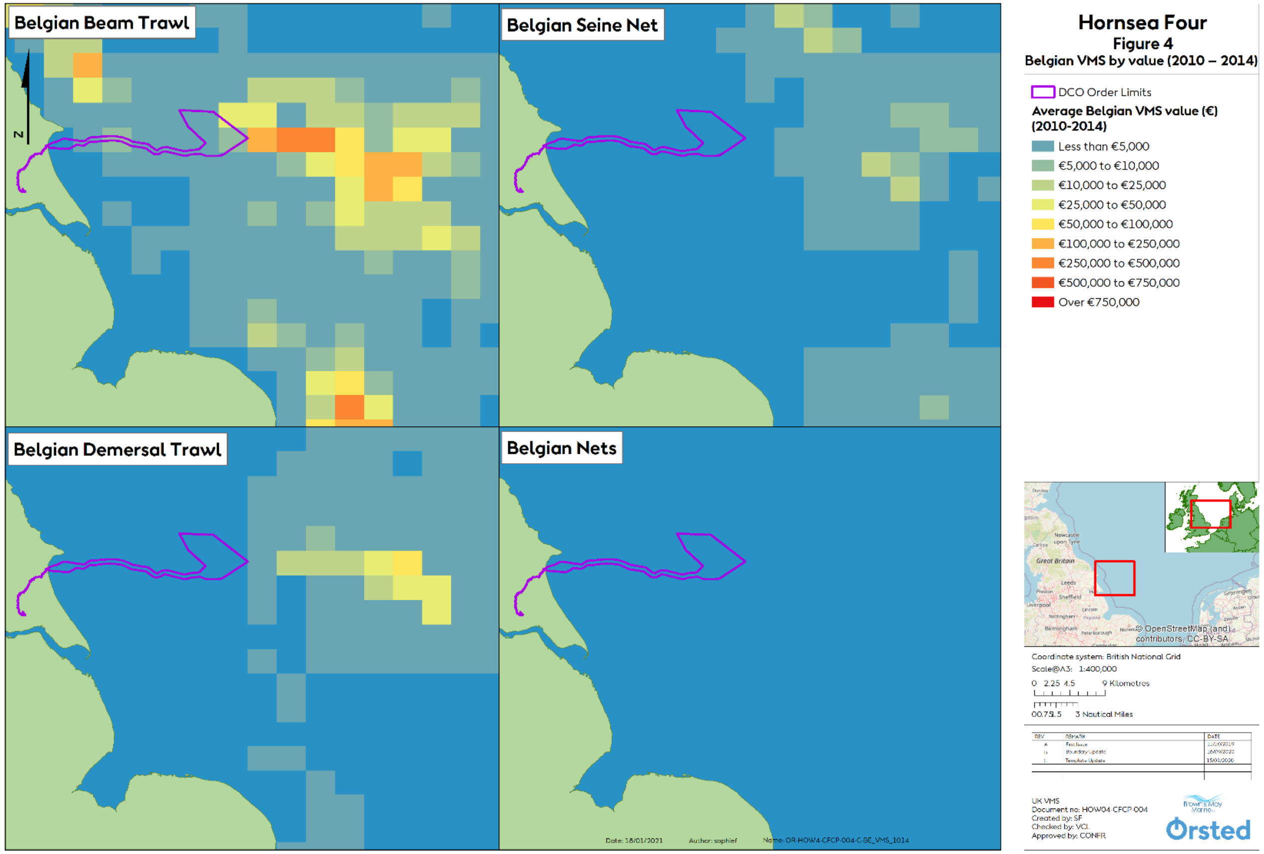

Figure 23: Average Belgian VMS by value (2010-2014) for the beam trawl (top left), seine net (top right), demersal trawl (bottom left), and net (bottom right) fisheries. Figure produced by Brown and May Marine.

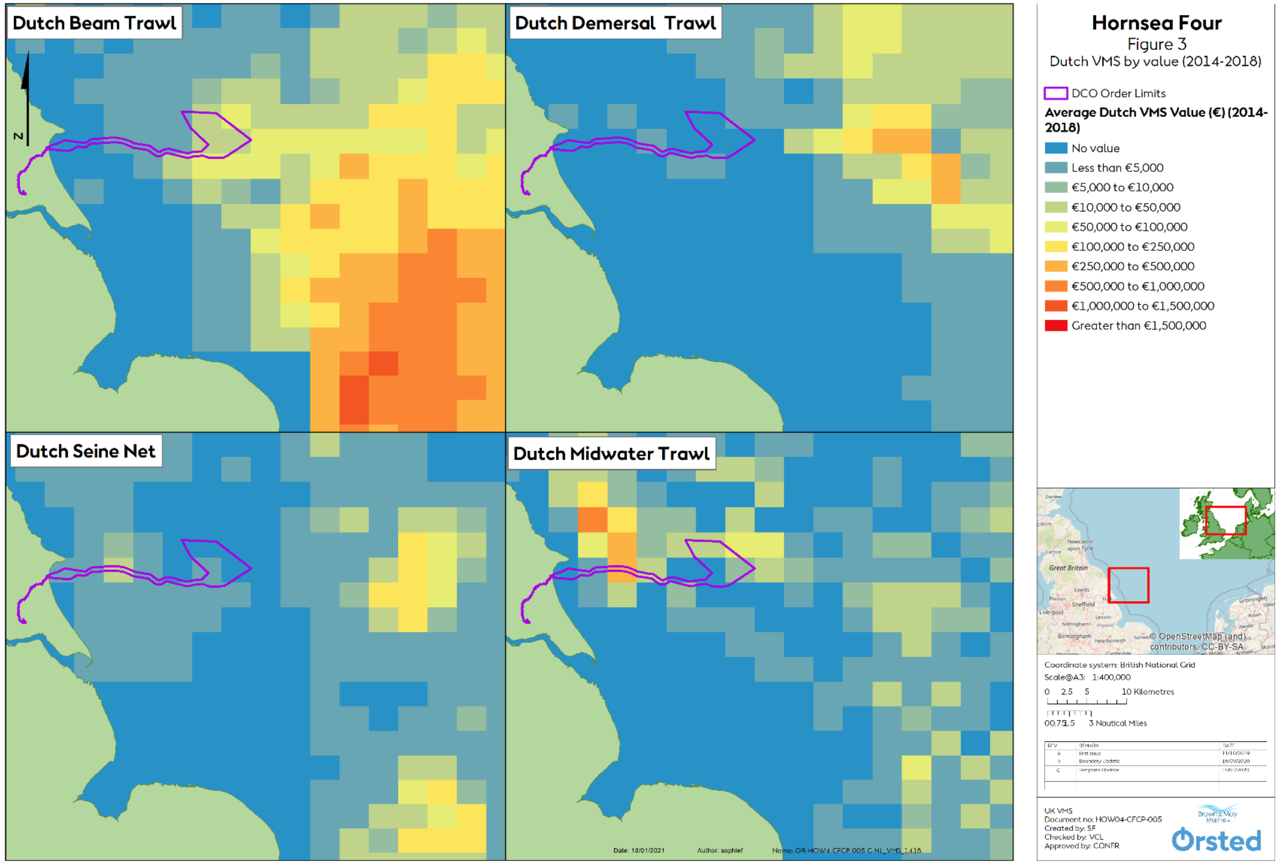

Figure 24: Average Dutch VMS by value (2014-2018) for the beam trawl (top left), demersal trawl (top right), seine net (bottom left), and midwater trawl (bottom right) fisheries. Figure produced by Brown and May Marine.

10 Bycatch Reduction Techniques Review

10.1 Introduction

10.1.1.1 Despite the evidenced impact of incidental catch of seabirds in gillnet fisheries (Žydelis *et al.*, 2013; Northridge *et al.,* 2020), there has yet to be widespread use of bycatch reduction techniques. A range of management measures have been trialled to reduce seabird bycatch in a range of fisheries around the globe, however, significant focus has been placed on longline fisheries management. In recent years there have been various trials testing management measures to reduce gillnet bycatch but there are still currently few practical or technical options available for preventing seabird mortalities (Hanamseth *et al.*, 2017).

10.1.1.2 This section aims to provide an overview of the evidence base of potential bycatch reduction methods that may be used for guillemot, razorbill and gannet, with particular focus on static gillnet fisheries, to reduce bycatch of guillemot and razorbill. The review has tackled several key components, as follows:

- Key criteria for successful bycatch reduction;
- Identification of potential seabird bycatch reduction methods for gillnets;
- Overview of the potential for the long-listed methods to be successful at reducing guillemot and razorbill bycatch; and
- Short-list of methods most suitable to use for reducing guillemot and razorbill bycatch; and
- Overview of the potential methods suitable to reduce gannet bycatch in longline, trawl and gillnet fisheries.

10.1.1.3 An accompanying document (Appendix C) contains:

- Quantification of success for each gillnet method, including examples of previous trials and experiments and their impacts on bycatch and target catch rates.

10.2 Success of Bycatch Reduction Techniques

10.2.1 Outline of key success criteria

10.2.1.1 To design an effective bycatch reduction program, it is necessary to understand the life history of target and non-target species, their interactions with fish and fishing gear, the effects of spatial and temporal shifts in fishing effort, the socio-economic impacts to the fishery and the incentives of fishery participants (O'Keefe *et al.*, 2012).

10.2.1.2 Therefore, in order for any bycatch reduction technique to be deemed successful it is necessary to fulfil at least the following set of criteria (O'Keefe *et al.*, 2012):

- Reduce identified bycatch or discards;
- Does not negatively affect target catch rate;
- Does not increase the bycatch of other vulnerable species;
- Does not lead to spatial or temporal displacement of bycatch;
- Does not negatively impact the ecosystem; and
- Is economically viable for a fishery.

10.2.1.3 For visual bycatch reduction methods that are used to warn vulnerable species about the presence of gillnets, Martin and Crawford (2015) state that the following criteria is required for a bycatch reduction technique to be successful:

- Alert species of net presence over a range of light levels;
- Does not disrupt the dark-adapted state of the species retina;
- High probability of being detected;
- Simple to deploy and robust in sea conditions; and
- Does not significantly reduce the target fish catch rate.

10.2.1.4 As the use of netting types is subject to change annually (depending on available catch), it may be necessary for bycatch reduction techniques to target a range of gillnet types as this bycatch reduction method will need to be installed over a number of years. Therefore, having bycatch reduction strategies that work across a range of gillnet types are most likely to be successful.

10.2.2 Scale of successful bycatch reduction schemes

10.2.2.1 The scale of successfulness is varied depending on several factors, including, but not limited to: bycatch reduction technique, species, and location, with each reduction technique having varied success rates. It must be noted that although many bycatch-avoidance measures have been developed and tested successfully in controlled experiments, successful experiments may not translate to effective bycatch reduction in commercial fisheries as conditions differ (Cox *et al.*, 2007). It is therefore important that experimental study results are taken with caution. Section 10.3 outlines a comprehensive list of the potential bycatch reduction strategies available to reduce seabird bycatch in gillnet fisheries (Table 11), followed by a comparison to the key success criteria (Table 13) (note how each of these bycatch reduction techniques work and success of previous trials can be found in Appendix C).

10.2.3 Previous successful bycatch reduction scheme

10.2.3.1 For bycatch reduction to be successful, uptake by the fishing industry is important. The Applicant is confident in the compliance of fisheries using the suggested bycatch reduction technique due to a positive response of fishermen to take part in the bycatch reduction scheme (80% of Cornish fishermen agreed to take part in the pilot study) (Section 8). In addition to this, previous bycatch reduction schemes have resulted in fishermen using bycatch reduction techniques (without forced implementation). Below is a case study on a previous seabird bycatch reduction technique.

10.2.3.2 In Namibia, the hake fishery is the most important fishery for the country. Previously, the majority of hake were caught by trawl, however in 1991 demersal longlining began. Namibia, historically, had the highest levels of seabird bycatch globally and in 2010 an estimated 20,567 birds were killed in the hake demersal longline fishery alone. Over four years, BirdLife International's Albatross Task Force worked alongside the Namibian Nature Foundation to monitor numbers of birds being killed and to test potential mitigation strategies (BirdLife International, 2017).

10.2.3.3 The use of bird-scaring lines reduced bycatch from 0.57 birds/1000 hooks to 0.04 and no albatross were caught when using this bycatch reduction device. Prior to 2015, Namibian fisherman started voluntarily using the bird-scaring lines on their boats. A total of 15% of the trawl fleet and 25% of the demersal long-line vessels voluntarily took up the use of this technique (BirdLife International, 2014), prior to the introduction of regulations requiring their use in November 2015 (BirdLife International, 2017).

10.2.3.4 The use of bycatch reduction methods without regulations suggests that a percentage of fishermen are willing to take part in reducing seabird bycatch, therefore there will more than likely be uptake of the Applicant's bycatch reduction technique in the UK fishing fleet.

10.3 Bycatch Reduction Technology Review

10.3.1 Guillemot and Razorbill

Long-list

10.3.1.1 Table 11 presents a long-list of potential gillnet fisheries bycatch reduction methods for seabirds discussed in Wiedenfeld *et al*. (2015), Parker (2017) and other potential technologies.

Table 11: Potential bycatch reduction methods in gillnet fisheries.

Thematic Category	Bycatch Reduction Ideas
Net illumination	Light sticks on nets
	Lights of different colours (LEDs or UV)
Visual net modifications	Reflective nets/ materials in panels
	Mesh sizing
	Contrasting net panels/ rope in mesh
	Coloured/ high visibility nets/ materials
	Silhouettes or predator mimics placed in nets
	Moving/twisting elements or streamers
Above water methods	Net surface markers
	Kites or drones flown over net
	Raptor silhouettes
	Looming eyes buoy
Acoustic methods	Multi-frequency pingers
	Audio recordings of predators
Net type and setting	Low profile nets
	Tie downs to reduce profile of net
	Set depth
	Net height
	Headline drops
	Altered float lines
	Hanging Ratio
	Net weights
Net operations	Adjust setting and hauling times
	Soak times
	Nocturnal setting
	Net sensors (alarm, light)
	Net-checking frequency
Operational fishing measures	Fisheries closures (area/ seasonal)
	Gear-switching/ restrictions

10.3.1.2 A literature review of the long-listed bycatch reduction measures (Table 11) was carried out to identify the effectiveness of the techniques on reducing large auk bycatch. However, it must be noted that not all methods have been tested on seabird bycatch and few have been tested on auks, therefore this report collates all available information to best inform potential bycatch reduction solutions. Note not all methods within the long-list were able to be reviewed due to lack of sufficient evidence.

10.3.1.3 Table 13 evaluates the success of each bycatch reduction study from Table 11 using the criteria stated in Section 10.2.1 (O'Keefe *et al.*, 2012) (noting not all columns have been able to be assessed for each case study). A tick was given if the criteria was met and a cross if not (only if addressed within the study). A dash has been used when not incorporated within the study or no evidence was found. See Appendix C for a more in-depth evaluation of each bycatch reduction method. Case studies are also provided in Appendix C.

Short-list

10.3.1.4 From the evaluation of the long-listed bycatch reduction methods, four methods have been identified as feasible to reducing guillemot and razorbill bycatch without causing negative effects on the fishery (Table 12). Visual net modifications (high visibility netting and reflective nets) were short-listed due to meeting the evaluation criteria (Table 13). Note not all evaluation criteria could be assessed. Although there was an effect on non-target species with net illumination (Mangel *et al.,* 2018), the increase of bycatch in non-target species was too small to be statistically significant (four individuals). In addition to this, acoustic pingers have been suggested to increase marine mammal bycatch (Melvin *et al.* 1999), however this is dependent of acoustic frequency. Acoustic pingers have therefore been short-listed to test the success of specific frequencies, ensuring there is no increase in marine mammal bycatch.

10.3.1.5 No operational fishing measures were short-listed due to the potential for these methods to negatively impact target catch (note in Table 13, target catch was not identifiable in all the studies). No bycatch reduction technique will be short-listed that has negative impacts on fisheries.

Table 12: Short-listed bycatch reduction methods in gillnet fisheries.

Short-list	Explanation
Net illumination	Net illumination informs the seabirds of the location of the nets by making them more visible thus reducing bycatch.
Visual net modifications (reflective nets and high visibility nets)	The use of visual modifications of nets causes the net to become more visible to the seabird without affecting target catch.
Acoustic deterrents	High-frequency pulses alert seabirds on the net presence therefore reducing bycatch without affecting target catch.
Above water deterrents	Having deterrents above water may reduce the number of individuals foraging in the area around the net. As seabird eyesight is clearer above water, there is the potential for these methods to drastically reduce bycatch even in turbid conditions.

Table 13: Evaluation of bycatch reduction technique studies conducted on gillnets. Evaluation criteria include Reduced Bycatch (bycatch of the study-specific species was reduced), No Effect on Target Catch (catch of fisheries target species was not reduced or negatively affected), No Effect on Other Non-Target (bycatch did not increase on other species), No Effort Impacts (no negative impacts resulting from a spatial or temporal shift in fishing effort), Economically Viable (no disproportionate effects on any faction of fishing fleet, operational costs were not significantly changed). ✓ = evaluation criteria met, ✗ = evaluation criteria not met and - = evaluation criteria not assessed in the study, or no results found.

BYCATCH REDUCTION PROGRAM	**Study target bycatch**	**Type of fishery**	**Reduced Bycatch**	**No Effect on Target Catch**	**No Effect on Non-Target**	**No Effort Impacts**	**Economically Viable**
NET ILLUMINATION: LIGHT STICKS							
Wang *et al.*, 2010	Turtles	In Mexico	✓	✓	-	-	✗
NET ILLUMINATION: LEDs or UV							
Mangel *et al.*, 2018	Cormorants	Bottom setnets in Peru	✓	✓	✗	-	✓
Bielli *et al.*, 2020	Petrel, penguin, shearwater	In Peru	✓	-	-	-	-
Field *et al.*, 2019	Sea ducks (green lights)	In Baltic Sea	✗	✓	-	-	-
Field *et al.* 2019	Sea ducks (white lights)	In Baltic Sea	✗	✗	-	-	-
VISUAL NET MODIFICATIONS: REFLECTIVE NETS							
Trippel *et al.*, 2003	Shearwater	Demersal gillnet in Canada	✓	✓	✓ (other bycatch also reduced)	-	-

BYCATCH REDUCTION PROGRAM	**Study target bycatch**	**Type of fishery**	**Reduced Bycatch**	**No Effect on Target Catch**	**No Effect on Non-Target**	**No Effort Impacts**	**Economically Viable**
Bordino *et al.*, 2013	Franciscana	In Argentina	✗	✓	-	-	-
VISUAL NET MODIFICATIONS: MESH SIZE							
Bærum *et al.*, 2019	Seabirds	Bottom gillnet in Norway	✗	-	-	-	-
Dagys and Žydelis, 2002	Waterbirds	In Lithuania	✓	-	-	-	✓
VISUAL NET MODIFICATIONS: CONTRASTING WARNING PANELS							
Field *et al.*, 2019	Sea ducks	In Baltic Sea	✗	✓	-	-	-
Almeida *et al.*, 2017	Seabirds including auks	In Portugal	-	✓	-	✗	✗
VISUAL NET MODIFICATIONS: HIGH VISIBILITY NETTING							
Melvin *et al.*, 1999	Guillemot Rhinoceros auklet	In Puget Sound	✓	✓	✓ (accept some marine mammals)	-	-
Quayle, 2015	Razorbill Guillemot	Filey Bay	✓	✓	-	-	-
VISUAL NET MODIFICATIONS: COLOURED NETTING							
Hanamseth *et al.*, 2017	Penguin	Zoo in Australia	✓	-	-	-	-
VISUAL NET MODIFICATIONS: PREDATOR MIMICS							

BYCATCH REDUCTION PROGRAM	**Study target bycatch**	**Type of fishery**	**Reduced Bycatch**	**No Effect on Target Catch**	**No Effect on Non-Target**	**No Effort Impacts**	**Economically Viable**
Wang *et al.*, 2010	Turtle	Bottom setnet in Mexico	✓	✗	-	-	-
VISUAL NET MODIFICATIONS: MOVING/ TWISTING ELEMENTS OR STREAMERS							
Currently no studies quantifying this technique							
ABOVE WATER METHODS: LOOMING EYES BUOY							
Rouxel *et al.*, 2021	Long-tailed ducks	Baltic Sea	✓	-	-	-	-
ACOUSTIC METHODS: PINGERS							
Melvin *et al.*, 1999	Guillemot Rhinoceros auklet	In Puget Sound	✓	✓	✗	-	-
ACOUSTIC METHODS: AUDIO RECORDINGS OF PREDATORS							
Currently no studies quantifying these techniques							
NET TYPE AND SETTING: LOW PROFILE							
Price and von Salisbury in Gilman *et al.*, 2010	Turtle	USA	✓	✗	-	-	-
Armstrong *et al.*, 2013; Wark *et al.*, 2013	Turtle, dolphin	New Jersey	✗	✗	-	-	-
NET TYPE AND SETTING: TIE-DOWNS							

BYCATCH REDUCTION PROGRAM	**Study target bycatch**	**Type of fishery**	**Reduced Bycatch**	**No Effect on Target Catch**	**No Effect on Non-Target**	**No Effort Impacts**	**Economically Viable**
See Section 10.15 – mixed impacts dependent on species							
NET TYPE AND SETTING: SET DEPTHS							
Hayase and Yatsu, 1993	Shearwater	Japanese high-seas drift gillnet	✓	✗	✗	-	-
Mangel *et al*., 2014	Small cetaceans and sea turtles	Driftnet fisheries, Peru	-	✗	-	-	-
Carretta and Chivers, 2004	Guillemot	California	✓	-	-	-	-
NET TYPE AND SETTING: NETTING HEIGHT							
Mentjes and Gabriel., 1999	Sea ducks	German cod setnet fishery	✗	✗	-	-	-
NET TYPE AND SETTING: HEADLINE DROPS							
Currently no studies quantifying these techniques							
NET TYPE AND SETTING: ALTERED FLOAT LINES							
Currently no studies quantifying these techniques							
NET TYPE AND SETTING: HANGING RATIO							
Mentjes and Gabriel., 1999	Sea ducks	German cod setnet fishery	✗	✗	-	-	-
NET TYPE AND SETTING: WEIGHTS							

BYCATCH REDUCTION PROGRAM	**Study target bycatch**	**Type of fishery**	**Reduced Bycatch**	**No Effect on Target Catch**	**No Effect on Non-Target**	**No Effort Impacts**	**Economically Viable**
Erdmann *et al.*, 2005	Seabirds	Surface gillnets in salmon and sea trout fisheries	✓	✗	-	-	-
NET OPERATIONS: SETTING AND HAULING TIMES							
Melvin *et al.*, 1999	Guillemot Rhinoceros auklet	Puget Sound	✓	✗	-	-	-
Mentjes and Gabriel., 1999	Sea ducks	German cod setnet fishery	✗	✗	-	-	-
NET OPERATIONS: SOAK TIMES							
Mixed results – see Section 10.21							
NET OPERATIONS: NOCTURNAL SETTING							
Mixed results dependant on species – see Section 22I n Appendix C							
NET OPERATIONS: NET SENSORS (ALARM, LIGHT)							
Currently no studies quantifying these techniques							
OPERATIONAL FISHING MEASURES: FISHERIES CLOSURES							
Regular *et al.*, 2013	Guillemot	Cod and salmon fisheries in Canada	✓	-	-	-	-
	Herring gull		✗	-	-	-	-
OPERATIONAL FISHING MEASURES: GEAR SWITCHING							

BYCATCH REDUCTION PROGRAM	**Study target bycatch**	**Type of fishery**	**Reduced Bycatch**	**No Effect on Target Catch**	**No Effect on Non-Target**	**No Effort Impacts**	**Economically Viable**
Mentjes and Gabriel., 1999	Sea ducks	Switching to longlines in German Baltic Sea	✓	-	-	-	-
Vetemaa and Ložys, 2009	Seal and seabirds	Switching to longlines in eastern Baltic Sea	✓	-	-	-	-
Vetemaa and Ložys, 2009	Seal and seabirds	Switching to herring trap nets in Lithuania	✓	-	-	-	✗
Bellebaum *et al.*, 2013	Seabirds	Switching to baited pots for cod in German Baltic Sea	✓	-	-	-	-
Koschinski and Strempel, 2012	Seabirds and marine mammals	Switching to baited pots	✓	✗	-	-	-

10.3.1.6 Studies that focused on guillemot or razorbill, if not then pursuit divers, were initially considered for bycatch reduction techniques. Where studies on these species were unavailable (no analysis of the techniques on auks/pursuit divers), other species were also considered. Pursuit divers can be compared to guillemot and razorbill due to similarity in foraging technique, however findings for other species may not be applicable to compare with guillemot and razorbill. The Applicant will be completing a pilot study to address the evidence gaps identified.

Net Illumination

10.3.1.7 Net illumination has the potential to be a successful bycatch reduction method using light sticks (e.g., chemical light sticks) on nets or the use of LED or UV coloured lights (Wiedenfeld *et al.*, 2015). Seabirds can be visually guided foragers, therefore whilst underwater are most likely to detect visual alerts such as lights and highly visible netting (Martin and Crawford, 2015). However, as light sticks need to be changed every 12 hours, they are unsuitable for fisheries with longer soak times. Moreover, light sticks are non-reusable therefore will cause large amounts of plastic waste if used. Plastic waste in itself is a problem to marine fauna and creating additional plastic waste would be problematic. Therefore, only LED or UV lights have been short-listed.

10.3.1.8 Net illumination will only be beneficial in areas of low turbidity due to the need to be seen to reduce bycatch rates. Turbid waters can reduce the light dissipation reducing the distance the birds can see the light source. The success of LED and UV lights differed across the variety of studies: reduced bycatch was observed with cormorants, petrels, penguins, and shearwaters (~80%) (Mangel *et al.,* 2018; Bielli *et al.,* 2020) whereas no reduction was observed for sea ducks (~10% reduction, not statistically significant) (Field *et al.,* 2019). As no previous studies analysed guillemot or razorbill, the success of net illumination on these target species is difficult to confirm therefore further research would be needed (note proposal of further analysis of techniques in the Bycatch Reduction Roadmap (**B2.8.2 Compensation measures for FFC SPA: Bycatch Reduction: Roadmap**)).

Visual Net Modifications

10.3.1.9 There are many types of visual net modifications that may potentially reduce seabird bycatch, however some impact the target catches and therefore are unsuitable as a bycatch reduction technique (net size). Reflective nets and high visibility nets have both had studies which have indicated a positive impact on seabird bycatch rates, reducing guillemot bycatch by 40-45% (Melvin *et al.*, 1999; Trippel *et al.*, 2003).

10.3.1.10 As visibility under water is an important contributor for success, areas of high turbidity, or depths with limited sunlight, visual net modification will be less likely to impact bycatch rates. Therefore, the feasibility of these techniques would need to be tested at the specific locations and depths that are planned to be used to understand the specific rate of reduction of bycatch.

Acoustic Deterrents

10.3.1.11 Acoustic deterrents have been used successfully to reduce cetacean bycatch by 90% without reducing target catch rates (Kraus *et al.*, 1997; Trippel *et al.*, 1999; Larsen *et al.*, 2002). Despite the lack of evidence of subsurface hearing abilities in seabird species (Northridge *et al.*, 2016), pingers have been shown to be successful for guillemot in one study (50% reduction in bycatch) (Melvin *et al.*, 1999). The study used a frequency of 1.5kHz, different from the frequency used in mammal studies to better reflect frequencies at which seabirds may be deterred. The pinger frequencies that have currently been tested have generally been in the following ranges (Wiedenfeld *et al.*, 2015):

- 70 kHz for small cetaceans;

- 10 kHz for porpoises;
- 3 kHz for humpback whales;
- 1.5 kHz for guillemots; and
- 200, 400, 300, 500 Hz for sea turtles.

Above Water Deterrents

10.3.1.12 Various above water deterrents have been tested to reduce seabird bycatch, including (but not limited to): net surface markers, kites, looming eyes buoy (LEB). The purpose of keeping the deterrents above water is to reduce seabirds foraging within the area of net deployment, thus reducing bycatch during foraging. Above water methods have the potential to be a greater bycatch reduction technique compared to below water as they can be used in areas of low underwater visibility.

10.3.1.13 The LEB is a newly developed technique, which proved successful in an initial trial in the Baltic at reducing the number of seabirds within the vicinity of the nets. The LEB reduced bycatch of long-tailed ducks by up to 30%. The buoy aims to reduce seabirds from a 50m radius, which is longer than the horizontal diving distance of both guillemot and razorbill (Rory Crawford, RSPB *pers. comm.*). Therefore, there is confidence that the LEB will be successful at deterring guillemot and razorbill and therefore reduce the number of individuals bycaught.

Future Research

10.3.1.14 The above techniques have the potential for reducing guillemot and razorbill bycatch without reducing target catch, with some studies reducing seabird bycatch by over 80%. Despite the limited research within these areas, the evidence behind the short-listed techniques indicate they are viable techniques. A pilot study will be undertaken to assess the success rate of the LEB. The Bycatch Reduction Roadmap (**B2.8.2 Compensation measures for FFC SPA: Bycatch Reduction: Roadmap**).) outlines the proposal for further research, specifically in the area of proposed bycatch reduction.

10.3.2 Gannet

10.3.2.1 There are currently few studies that assess the impacts of bycatch reduction techniques on gannets. Gannets are plunge diving species alongside boobies, some pelicans, tropicbirds, terns and some shearwaters and petrels (American Bird Conservancy, 2016) and therefore trials impacting these species may be used as an indication of the behaviour that may be exhibited by gannet.

10.3.2.2 Gannets are mainly impacted by longlining and static gillnets in UK fisheries (Northridge *et al.*, 2020) but there is also evidence that they are impacted by trawlers and purse seine fisheries across the world (ICES, 2013). In general, there are a number of bycatch reduction techniques that have been trailed in each of these fisheries types, many of which have assessed impacts on plunge/surface diving seabird species.

Longline Fisheries

10.3.2.3 A number of techniques have been trialled for longline fisheries, including double-weight branch lines, bird-scaring lines and night setting. A combination of these three were considered best practice to reducing seabird bycatch, including petrels and albatross, for pelagic longline fisheries targeting tuna and related species (Melvin *et al.*, 2014). More recently, the Hookpod has been trialled in pelagic longline fisheries with great success (Sullivan *et al.*, 2017). One trial conducted in southern Brazil and South Africa showed that the comparative seabird (including petrels and albatross) bycatch rates of 0.8 birds/1000 hooks for control branchlines, compared to a rate of 0.04 birds/1000 hooks on the Hookpod branchlines (Sullivan *et al.*, 2017).

Static Net Fisheries

10.3.2.4 A number of bycatch reduction techniques that have been proposed for static gillnet fisheries (Wiedenfeld *et al.*, 2015; Parker, 2017), including lights, acoustic deterrents and above and below water visual deterrents. Few have been trialled on plunge diving seabird species, however they may have the potential to reduce bycatch of these species (Bull, 2007).

Trawl Fisheries

10.3.2.5 There are numerous methods that have potential in trawl fisheries (ACAP, 2016; Parker, 2017) including visual deterring methods (tori-lines, bafflers, warp-scarers etc) (e.g. Sullivan *et al.*, 2006a; 2006b; Melvin *et al.*, 2011), net type and setting (netting cleaning, net binding, net weighting etc) (e.g. Varty *et al.*, 2008; ACAP, 2011), acoustics and operational fishing measures (offal management and fisheries closures) (e.g. Abraham *et al.*, 2009; Pierre *et al.*, 2012; Paz *et al.*, 2018). Many of these methods have been trialled on species such as shearwaters, petrels and albatross and have shown the potential for huge reductions in their bycatch. For example, reducing discharge to sump water resulted in a significant reduction of all seabird species numbers, with the small albatross group and smaller procellarids were reduced to less than 5% of the numbers that were within the sweep area when unprocessed discharge was released (Abraham *et al.*, 2009).

10.4 Monitoring of Bycatch Reduction Methods

10.4.1.1 Post implementation of the bycatch reduction measure, monitoring of the bycatch management measures will need to be undertaken to confirm efficacy and demonstrate that any commitments that may be provided in relation to compensation are being achieved. Whilst data collected as part of the UK BMP programme is useful to identify the initial scale of bycatch mortality, more targeted observations of the gillnet fleet operating in the vicinity of the bycatch reduction location decided is likely required. This is because the sample size from the UK BMP is low and incorporates observations of fishermen in other areas of the UK (potential to distort the estimations when extrapolated). Where undertaken, targeted sampling of vessels should seek to provide a higher sample size to ensure statistical power to make a meaningful assessment of pre- and post- bycatch reduction estimates.

10.4.1.2 Bycatch data is typically recorded using data collected by an observer onboard a vessel or by installing a camera system onboard which is later analysed by review of the recorded footage. Both systems may come with logistical challenges particularly where small vessels (under 10 m) may have limited space and facilities to support bycatch monitoring.

10.4.1.3 In addition, it would be useful to monitor weather conditions and turbidity, which have been reported anecdotally to affect bycatch. This may inform future adaptive measures that can be incorporated into any compensation measure. For example, certain bycatch reduction techniques may only be required during periods of poor weather when reduced visibility results in greater vulnerability of seabirds.

10.5 Summary

10.5.1.1 Although there are many potential gillnet bycatch reduction techniques, only a handful are suitable for guillemot and razorbill whilst also not impacting target catch and being economically viable. The most promising techniques identified are:

- Visual net modifications (reflective nets/high visibility nets)

- Net illumination[16]
- Acoustic deterrents (pingers)[17]
- Above water deterrents (reflective materials/ kites/ looming eyes buoy)

10.5.1.2 The LEB will be tested in a pilot study for bycatch reduction success as well as ensuring there are no negative implications to fisheries and non-target species. This is to ensure that variable factors do not impact the success of this compensation. Any improvements identified by the trial would be explored to improve the bycatch reduction techniques before widespread deployment – with potential development of the other short-listed techniques if the LEB was not deemed successful. To ensure the technology is successful in reducing bycatch, monitoring post-implementation will be important to estimate the success of the bycatch reduction techniques.

10.5.1.3 Although few studies have been conducted on gannets specifically, numerous trials have assessed the impacts of bycatch reduction techniques for other plunge/ surface diving seabirds (mainly shearwaters and petrels) across different fisheries with positive results. Therefore, it is highly likely that bycatch reduction techniques would greatly reduce the bycatch of gannet in UK fisheries.

10.5.1.4 As previous bycatch reduction techniques for seabirds have been up taken by the fishing industry, the Applicant is confident of the deployment of the static gillnet bycatch technique within the UK fishing fleet.

11 Bycatch Reduction as an Effective Compensation Measure

11.1 Size of Compensatory Population Required

11.1.1.1 The potential magnitude of the displacement mortality impact of Hornsea Four on the guillemot population of the FFC SPA is detailed in **B2.2: Report to Inform Appropriate Assessment**. If the aim of compensation is to fully offset this impact (remaining cognisant of other potential compensation measures proposed for guillemot and razorbill), then sufficient compensation should be provided to offer a corresponding increase in the population size via bycatch reduction.

11.2 Success of Bycatch Reduction

11.2.1.1 The scale of compensation for guillemot, razorbill, and gannet adults through the package of measures, including of bycatch reduction is dependent on the success of the bycatch reduction technique used. The level of reduction in bycatch is aimed to be identified through testing of the short-listed bycatch reduction measures identified in **Section 10** and outlined in the Bycatch Reduction Roadmap (**B2.8.2 Compensation measures for FFC SPA: Bycatch Reduction: Roadmap**). Thus, once the efficiency of bycatch reduction measures has been identified, the number of measures to be deployed will be calculated. Although more guillemot are bycaught in static nets compared to razorbill, bycatch reduction is still viable for razorbill compensation due to the extremely small number of razorbill that need compensating for.

11.3 Effects of bycatch reduction on the FFC SPA

11.3.1.1 Bycatch reduction is proposed to be completed within the English Channel due to the highest bycatch risk occurring in this area. The ICES division of the FFC SPA is estimated to have <0.5% of bycatch due to low gillnet fishing effort within this region. The Applicant therefore believes

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[16] Noting a not significant increase of non-target species (four individuals).

[17] Noting potential of marine mammal increase dependent on pinger frequency.

the wider UK guillemot and razorbill biogeographic populations will benefit greater by focusing on areas of higher bycatch.

11.3.1.2 Additionally, connectivity of guillemot and razorbill populations has been identified in Appendix A. Both winter dispersal and colony movement of juveniles contributes to the connectivity between UK populations, showing the importance of strengthening UK colonies to benefit the wider population.

11.3.1.3 As the highest potential bycatch occurs throughout the winter, this coincides with winter dispersal, with individuals from the FFC SPA (and other SPA colonies) being present in the English Channel (Appendix B: GIS Mapping). Therefore, focusing on the English Channel during the winter will benefit the FFC SPA colony as well as other SPA colonies. Moreover, the potential for juveniles to start breeding at non-natal colonies has been evidenced (Appendix A – Section 2 Philopatry), therefore, any increase to the UK guillemot (particularly the southern *albionis* race) and razorbill populations will in turn strengthen the integrity of the SPA network including FFC SPA.

12 Further Workstreams

12.1.1.1 The above sections have focused on reducing or eliminating bycatch via changes to fishing practices (deployment of bycatch reduction techniques). For guillemot and razorbill, the focused at this stage has been on gillnet reduction techniques due to the conclusions drawn from existing data which highlight bycatch risk to these large auk species from this prevalent fishing practice.

12.2 Guillemot and Razorbill

12.2.1.1 It is important to remain cognisant of the changing nature of the fishing industry (in terms of gear switching between seasons and years) and the potential contribution to bycatch totals from other fishing methods. For example, if the fishermen using the proposed bycatch reduction technique changes gear type, it is important that the Applicant stays aware of these changes to ensure the numbers of guillemot and razorbill not caught as bycatch do not fall below the levels of compensation required. If the level of static net effort reduces to a point that compensation cannot be met (or the bycatch reducing technique study is unsuccessful in reducing bycatch), then bycatch reduction in drift nets and/or midwater trawls will be explored. However, it should be noted that the potential number of fishing vessels needed for bycatch reduction for compensation is extremely low compared to the size of the UK fishing fleet, and therefore it is unlikely that there will be a time over the lifespan of Hornsea Four that there would not be enough static net vessels to compensate for guillemot and razorbill. The following sections provide a brief overview of drift nets and midwater trawls.

12.2.2 Drift Nets

12.2.2.1 As well as static nets, drift nets also have the potential to incidentally catch guillemot and razorbill. Drift nets are similar to static nets but kept afloat by buoys, instead of being attached to the substrate. Drift nets therefore have the same potential as static nets to incidentally catch seabirds.

12.2.2.2 Drift nets were identified by Coram *et al.* (2015) to catch both guillemot and razorbill as bycatch and have been estimated to annually catch 16 and 10 individuals respectively within the English Channel (ICES Divisions VIId and VIIe) (Section 6.3.3). The low rates of bycatch are due to the small amount of effort by drift net fisheries in the UK. However, fishing gear changes annually dependent on target catch therefore there is the potential for bycatch from drift nets to increase (if the fishing effort increases). It is therefore important to be aware of the potential for drift net bycatch during the lifespan of Hornsea Four.

12.2.3 Midwater Trawls

12.2.3.1 Trawling is a common fishing technique used worldwide due to its efficiency in capturing large numbers of fish. Trawl nets are designed to be towed by a boat through the water column.

12.2.3.2 Trawling results in bycaught of several taxa, including cetaceans, pinnipeds and seabirds, with trawling and tropical shrimp trawling accounting for 55% and 27% of all global discarded bycatch, respectively (Davies *et al.*, 2009; Eayrs, 2007). Longline and trawl fisheries are estimated to kill over 300,000 seabirds each year (BirdLife, 2021) with seabird bycatch in trawl fisheries being driven by the attraction of birds to foraging opportunities i.e., discarded waste such as offal, fish heads and tails or other non-commercial catch (Pierre *et al.*, 2010).

12.2.3.3 Seabirds are particularly vulnerable to larger mesh sizes of some trawl nets, particularly pelagic (120-800mm) (ACAP, 2016). The seabirds dive into the net entrance and then drown when shooting (launching) the net or are killed/ injured when the net is hauled onto the vessel. However, seabirds are also vulnerable to smaller mesh sizes (R. Wells from Parker, 2017). Seabirds may also be incidentally killed by warp strike, where birds collide with trawl warps, netsonde or paravane cables. If the warp hits the wing of a bird, it wraps around and the drag created by the forward motion of the vessel pulls the bird underwater, causing the bird to drown (BirdLife International and the ACAP, 2015).

12.2.3.4 Northridge *et al.* (2020) stated midwater trawlers catch guillemot and razorbill through evidence from the UK BMP. However, guillemot and razorbill are not thought to be affected by midwater trawls through warp strike or through diving into the nets due to not being attracted to vessels. Instead, it has been suggested that guillemot and razorbill are bycaught due to foraging within the same area of the vessel (Simon Northridge *pers. comm.*). The individuals will be caught whilst foraging and will ultimately be drowned within the catch prior to the net being hauled back onto the boat. As larger vessels pump the catch onto a separator then into cold water containers at a high speed, birds can easily be missed therefore bycatch counts would be inaccurate. This would be particularly apparent for guillemot and razorbill due to their small size (Simon Northridge *pers. comm.*). Due to this reason, it is likely that bycatch from midwater trawls is greatly underestimated and could be of concern for seabird populations.

12.3 Gannet

12.3.1.1 Similarly to guillemot and razorbill bycatch reduction, changes in fishing effort may impact bycatch compensation. As gannet have been identified to be impacted by multiple fishing gear, and there are proven technologies for both longline and midwater trawl bycatch reduction, this is unlikely to present barriers to gannet compensation. Moreover, the potential number of fishing vessels needed for bycatch reduction for compensation is extremely low compared to the size of the UK fishing fleet, and therefore it is unlikely that there will be a shortage of suitable vessels over the lifespan of Hornsea Four which can be used to compensate the small numbers of gannet.

12.4 Summary

12.4.1.1 As described in the Gannet, Guillemot and Razorbill Bycatch Reduction Roadmap (**B2.8.2 Compensation measures for FFC SPA: Bycatch Reduction: Roadmap**), bycatch reduction trials will be completed to understand the success of these techniques on guillemot and razorbill bycatch. In the possibility that the bycatch reduction techniques are unsuccessful for static gillnets, bycatch reduction for drift nets and/or midwater trawls will be explored.

12.4.1.2 Additionally, fishing effort changes annually, therefore to ensure bycatch reduction as compensation for the lifespan of the Hornsea Four offshore windfarm, it is important to be mindful of other fishing practices that cause gannet, guillemot and razorbill bycatch (e.g., if the drift net byelaw is lifted). Therefore, drift nets and/or midwater trawl bycatch reduction may be incorporated into adaptive management. Other adaptive management measures have been described in the Gannet, Guillemot and Razorbill Compensation Plan (**B2.8 FFC SPA: Gannet, Guillemot and Razorbill Compensation Plan**).

13 Conclusions

13.1.1.1 Based upon the evidence presented within this report, the following conclusions have been made:

- 1) Bycatch of guillemot and razorbill in static nets occurs in UK fisheries (updated estimates of 1,946 guillemot and 88 razorbill in 2018);
- 2) Guillemot and razorbill static net bycatch is highest by the coast, and decreases with increasing distance from shore;
- 3) Guillemot and razorbill static net bycatch in the UK is highest within the English Channel during winter, these areas have been labelled as “high risk zones”;
- 4) The estimated bycatch is underestimated within these “high risk zones”, this has been confirmed by information from a Cornish fisherman who stated to have caught 2-3 birds a day (which was lower than their average bird bycatch, with up to 20 birds bycaught per day);
- 5) There are many potential bycatch reduction techniques for guillemot and razorbill in static net fisheries, however some are unsuitable due to negative impacts on fisheries. The following techniques have the highest potential for reducing guillemot and razorbill bycatch:
    - Net illumination;
    - Net visibility;
    - Acoustic deterrents; and
    - Above water deterrents.

- 6) A pilot study will be conducted in winter 2021. The Applicant is confident in the success of the LEB as seabirds are deterred from a 50m radius, which is greater than the distance guillemot and razorbill can travel horizontally underwater. If this technique is unsuccessful, alternative techniques will be considered;
- 7) Gannet bycatch was estimated by Northridge *et al.* (2020) to be within the hundreds, mostly my longline fisheries. However, this did not include foreign fleet that fish in UK waters. Evidence from fisheries consultation identified bycatch of gannet within trawlers during the hauling of the net;
- 8) Bycatch reduction techniques have been identified for longline, static gillnet, and trawl fisheries with positive results from species with similar foraging ecology to gannet. Techniques used to deter individuals from warp lines (trawls) or reduce access to the hooks (longlines) reduce access to all seabirds and therefore would be a successful bycatch reduction technique for gannet; and
- 9) Previous bycatch reduction techniques have been up taken by the fishing industry therefore the Applicant is confident of the deployment of the static gillnet bycatch technique.

13.1.1.2 A bycatch reduction technique will be trialled in a pilot study to gain a better understanding of its success of bycatch reduction in guillemot and razorbill to ensure an accurate number of technologies can be deployed for compensation. This has been described in more detail in the Guillemot and Razorbill Predator Eradication Roadmap (**B2.8.4 Compensation measures**

for FFC SPA: Predator Eradication: Roadmap). If the trials are unsuccessful then alternative techniques will be considered and adaptive management will ensure guillemot and razorbill compensation.

13.1.1.3 The bycatch reduction techniques suitable for gannet have previously been trialled and tested, therefore, there is confidence in the success of bycatch reduction as a compensation measure for gannet. Further evaluations will determine the location for technique deployment.

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Appendix A : Guillemot and Razorbill: An Overview of Philopatry, Race and Connectivity

1 Document Background and Purpose

1.1.1.1 As part of the proposed compensation measures for guillemot and razorbill in regard to Hornsea Four, the Philopatry, Race, and Connectivity document has been produced to identify whether there is any connectivity between the Flamborough and Filey Coast SPA breeding population with the English Channel as part of the species biogeographic population. Philopatry identifies whether chicks return to their natal colony to breed, or breed elsewhere, whereas connectivity includes the dispersal during the winter season. Only race distribution was assessed for guillemot as only one razorbill race occurs within the UK.

2 Guillemot and Razorbill Connectivity

2.1 Philopatry

2.1.1.1 Philopatry is defined as the tendency of an animal to return to a particular area. However, when referring to seabirds, this definition has varied over time due to incorporating non-breeding season movements. It is therefore important to use adjectives to differentiate between the different uses of the term philopatry and avoid confusion (Table A 1).

Table A 1: The different uses of 'philopatry'.

Philopatry	Definition
Natal	Returning to the area the chick hatched from.
Colony	Returning to the colony the chick hatched from, but not necessarily near the location it hatched.
Breeding	Returning to the same breeding location after the first successful breed.
Wintering	Returning to the same migratory location during the winter period.

2.1.1.2 There are both advantages and disadvantages to seabirds in returning to the same location. Returning to the same site allows the individual to retain information on its environment, for example knowledge on prey, predators, and competitors (Coulson, 2016). However, if a population is increasing, all individuals staying within their natal colony will lead to pressures of overpopulation including competition for food and nesting sites (Coulson, 2016). Moreover, a high degree of natal philopatry will increase the likelihood of inbreeding which can lead to lower chances of breeding success (Greenwood, 1980). In addition to this, high levels of philopatry reduce gene flow, therefore making individual colonies more vulnerable to threats as beneficial mutations will not be shared throughout the population (Danckwerts *et al.*, (2021). Therefore, philopatry has its benefits, but it is also important for a proportion of the population to disperse to different locations to allow the population to thrive.

2.1.1.3 Dispersal within a colony is likely to be affected by environmental stability. If resources are abundant, most species tend to remain close to their natal area, whereas colonies under variable conditions on average disperse further (Steiner and Gaston, 2005). Likewise, as a population increases, competition for resources will also increase, therefore populations with high or increasing densities may be associated with high levels of dispersal (Greenwood, 1980; Matthysen, 2005). The degree of philopatry varies greatly between seabirds (Table A 2). Compared to kittiwakes, both guillemots and razorbills exhibit higher degrees of colony philopatry, particularly razorbills. Breeding philopatry was significantly high for all three species.

Table A 2: Degree of philopatry in three seabirds, guillemot, razorbill, and kittiwake.

Species	Latin Name	Degree of Colony Philopatry	Degree of Breeding Philopatry	References
Guillemot	*Uria aalge*	42-58%	>99%	Swann and Ramsay, 1983; Lyngs, 1993; Harris *et al.*, 1996
Razorbill	*Alca torda*	83%	>99%	Lavers *et al.*, 2007; Coulson, 2016
Kittiwake	*Rissa tridactyla*	11%	>95%	Horswill and Robinson, 2015; Coulson, 2016

2.1.1.4 However, Coulson (2016) has suggested that these studies may have overestimated the degree of philopatry due to biases of focusing on the natal colonies when resighting individuals. He stated that the majority of individuals returning to the natal site will be found and counted, whereas those who move away have a greater chance of being missed, leading to a biased percentage leaning heavily towards high philopatry. This has been supported by Harris *et al.* (1996) who stated a bias in their results due to the ability to recover individuals that moved to other colonies.

2.1.1.5 Moreover, Coulson (2016) also stated: "The expression of philopatry is probably variable within a species and is influenced by environmental conditions and population pressures and so should not be considered a constant for individual species." Therefore, colonies of the same species will have varying degrees of philopatry and should be expressed individually, taking into account environmental stability and competition within a population.

2.1.2 Guillemot

2.1.2.1 As shown in Table A 2, adult guillemots display a high degree of breeding philopatry, once they first start to breed, they repeatedly return to the same nesting site each year (Lyngs, 1993; Harris *et al.*, 1996; Halley *et al.*, 2007). It is therefore very unlikely that a breeding adult will disperse to a different breeding colony. Guillemots also display a relatively high degree of colony philopatry, with a significant number of birds returning to the colony in which they were born for the breeding season than if randomly distributed (42% Harris *et al.*, 1996; 57% Halley *et al.*, 2007). However, Harris *et al.* (1996) stated in their paper that the estimate was most likely an overestimation. This was due to the probability of all individuals that returned to the natal colony being accounted for, whereas not all those who dispersed would have been recovered.

2.1.2.2 Nevertheless, even if philopatry is as high as studies have suggested, emigration and immigration of juveniles occurs between colonies with ~50% of guillemots recruiting at non-natal colonies (Harris *et al.*, 1996; Knox, 2012). Lyngs (1993) and Olsson *et al.*, (2000) both suggested that Baltic guillemots breed away from the natal colony fairly regularly, with individuals breeding at colonies up to 780km away from their natal site. In addition to this, some colonies have increased at a faster rate than the populations fundamental increase rate, therefore indicating net migration occurring (Hudson, 1985; Lyngs, 1985).

2.1.2.3 A high degree of philopatry would inhibit gene flow between colonies, causing genetic differences between the populations. Therefore, genetic differentiation could potentially be studied to analyse the degree of philopatry between populations. Studies analysing the genetic differentiation of Atlantic guillemots have come to a variety of conclusions. Whilst some studies have demonstrated a low level of genetic differentiation between colonies (Atlantic, Moum and Árnason, 2001; north-eastern Atlantic, Cadiou *et al.*, 2004; north

Atlantic, Riffaut *et al.*, 2005), others have suggested differences with latitude (Friesen *et al.*, 1996) or across the Atlantic basin (Morris-Pocock *et al.*, 2008). As the former studies were unable to determine genetic differences, and the latter suggested isolation by distance, it is more than likely there is a high degree of interbreeding between surrounding colonies. Therefore, there is no abrupt genetic change between colonies, rather changes occurring over a large spatial cline. This genetic exchange can also be supported by the distribution of the bridled morph (white ring around the eye with a white stripe) as the bridling is genetically determined (Harris *et al.*, 1996). Although there is some clumping of individuals with the bridled morph, there is a gradual increase of the morph found with latitude (JNCC, 2020a). This evidence emphasizes that there is some philopatry observed in guillemots, however, it is not high enough to inhibited inter-colony movement of juveniles.

2.1.3 Razorbill

2.1.3.1 Razorbills are very similar to guillemots in terms of breeding site fidelity, once a bird has reared a successful chick, it will continue returning to the same breeding location (97% of adults - Lavers *et al.*, 2007). However, razorbills have a recorded colony philopatry double that of guillemots (Table A 2; Lavers *et al.*, 2007). Despite this, there are records of razorbill dispersal. Prior to 2004, no razorbills were known to breed on Petit Manan Island or Seal Island (Canada) (Lavers *et al.*, 2007). By 2006, both islands had been colonised by nearby colonies (Lavers *et al.*, 2007). Therefore, the accuracy of the degree of philopatry needs to be reassessed. The extremely high degree of philopatry may have been due to data bias (and therefore overestimation, Section 2.1; Coulson, 2016). Moreover, as stated in Section 2.1, different colonies exhibited different degrees of philopatry (Coulson, 2016). Therefore, the lack of research on razorbill breeding dispersal may lead to a biased view as there is no comparison between a variety of colonies.

2.1.3.2 In terms of genetic diversity, diversity in razorbills is higher than for guillemots, with genetic variations between colonies (Moum and Árnason, 2001). This agrees with the higher degree of philopatry as it suggests a restriction in gene flow. However, there has not been many genetic studies on razorbills therefore it is difficult to state with certainty how accurate the results are as they cannot be compared. A study by Barrett *et al.*, (1997) investigated the morphological differences between different colonies of razorbill. They found that razorbill size increased in latitude from the south-west to north-east of the species range (with the exception of Iceland and Britain which are not significantly different in size). A similar study on Brünnich's guillemots, *Uria lomvia*, by Gaston *et al.*, (1984) speculated differences were due to restricted gene flow between colonies. Therefore, the findings of Barrett *et al.*, (1997) could potentially imply high philopatry and limited gene flow. Nevertheless, there is overlap of razorbill size across the cline therefore again supporting the idea that there is some gene flow to surrounding colonies despite the high philopatry (Barrett *et al.*, 1997).

2.2 Guillemot and Razorbill Dispersal

2.2.1.1 Many organisms have evolved to undergo seasonal migrations as a strategy to maximise fitness in a seasonal environment (Alerstam *et al.*, 2003). These movements to non-breeding grounds allow organisms to avoid unfavourable climatic conditions whilst exploiting seasonal peaks in prey abundance (Philips *et al.*, 2017). Migrations can differ greatly between species, some individuals travel to the same wintering area each year, whereas others do not (Greenwood, 1980). Moreover, differences occur between age and sex within species, however, this also varies from species to species (Greenwood, 1980; Alerstam *et al.*, 2003).

2.2.1.2 The following sections detail the phenology of both guillemot and razorbill breeding in the UK and describe the movements of both species at sea during the non-breeding season. This information will provide a basis for understanding the connectivity of large breeding colonies (with particular reference to Flamborough and Filey Coast SPA (FFC SPA and the wider biogeographic population)) and potential locations of compensatory measures. However, there is a lack of data for the winter dispersal of both guillemot and razorbill, with most data recorded from ringing.

2.2.2 Guillemot

2.2.2.1 In the UK, it is estimated that there are currently 950,000 breeding guillemot pairs, (RSPB, 2021a). During the breeding season (March - July) guillemots breed in tightly packed colonies of many tens of thousands of individuals on steep ledges and cliffs (Sweet, 2008; JNCC, 2020a; Wildlife Trust, 2021). Breeding colonies in the UK are most notably located in Scotland although they can be found all around the UK and Ireland, with the exception of south-east England from Flamborough to the Isle of Wight (Figure A 1A) (Sweet, 2008; Natural England, 2020). Although no breeding colonies are established along the south-east English coastline, outside of the breeding season guillemots disperse from their breeding grounds and can be seen all around the UK (Figure A 1B; Sweet, 2008) (see Appendix B for at sea spatial distribution). The majority of individuals travel south over the winter, but some have been recorded moving further north than their breeding colony (Figure A 2A). Juvenile birds travel further distances and have been recorded from Portugal to north Norway, whereas adults mostly stay within UK waters (Swann and Ramsay, 1983; Furness, 2015).

2.2.2.2 As juveniles, guillemots visit other colonies, particularly within the third/fourth year (Halley and Harris, 1993; Knox, 2012). This increase of inter-colony movement around this age is potentially linked to the juvenile searching for future nesting locations. Although there is no exact distance calculated, juveniles have been documented breeding 780km away from their natal colony (Lyngs, 1993). This could potentially identify the connectivity between colonies and explain the high degree of gene flow mentioned in Section 2.1.

2.2.3 Razorbill

2.2.3.1 There are currently an estimated 130,000 breeding pairs of razorbill in the UK (RSPB, 2021b). In common with guillemots, razorbills nest on steep ledges and cliffs and therefore exhibit a similar distribution around the UK (Figure A 1B). During the breeding season they breed around the coast of the UK (mostly in Scotland) with a lack of breeding colonies between the Humber and the Isle of Wight (RSPB, 2021b). Moreover, winter dispersal of razorbills is also very similar to guillemots. Figure A 3B represents the estimated winter dispersal for UK razorbills, however, a lot less is known about razorbill winter dispersal as there has yet to be published winter geolocator tagging (currently in press Lila Buckingham *pers. comm.*). The majority of individuals move south, with a few from northern colonies dispersing north towards Norway. Lloyd (1974) identified different dispersive movements for different geographical locations. Colonies from the Irish Sea most frequently winter in the Irish Sea, the English Channel and the north of Bay of Biscay. Juveniles disperse further and there have been recoveries from west coast of Spain and Portugal from October onwards (Lloyd, 1974; Wright *et al.*, 2012). Juveniles from northern colonies mostly move south to winter with the birds from the Irish Sea colonies off Bay of Biscay, Iberia and North Africa (Lloyd, 1974). Adults are more inclined to stay within the North Sea, however some individuals have been recorded in the Bay of Biscay.

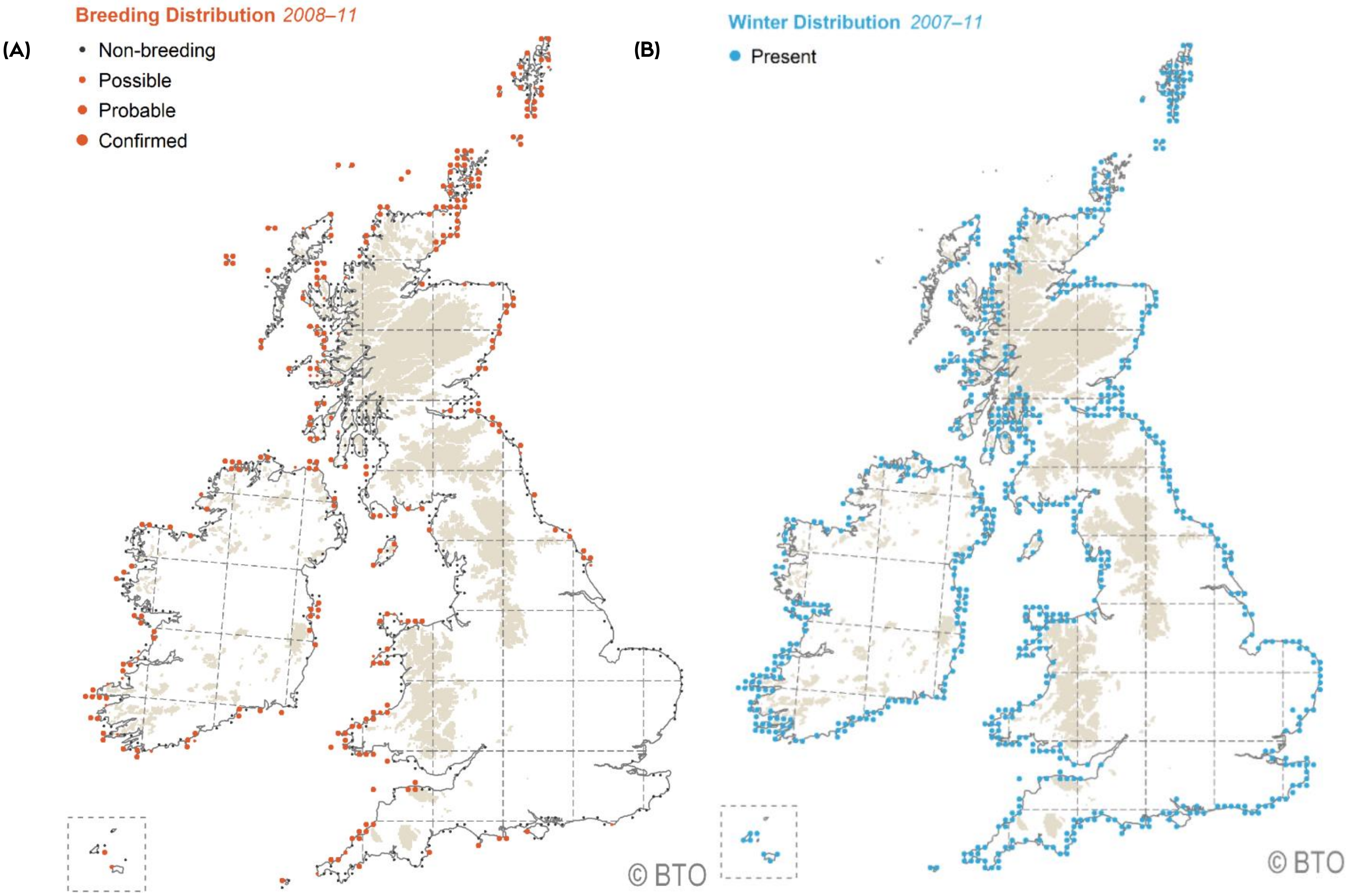

Figure A 1: Map of guillemot, *Uria aalge*, distribution in the UK and Ireland during the breeding season (A - left) and winter (B - right) (Bird Atlas, 2021a).

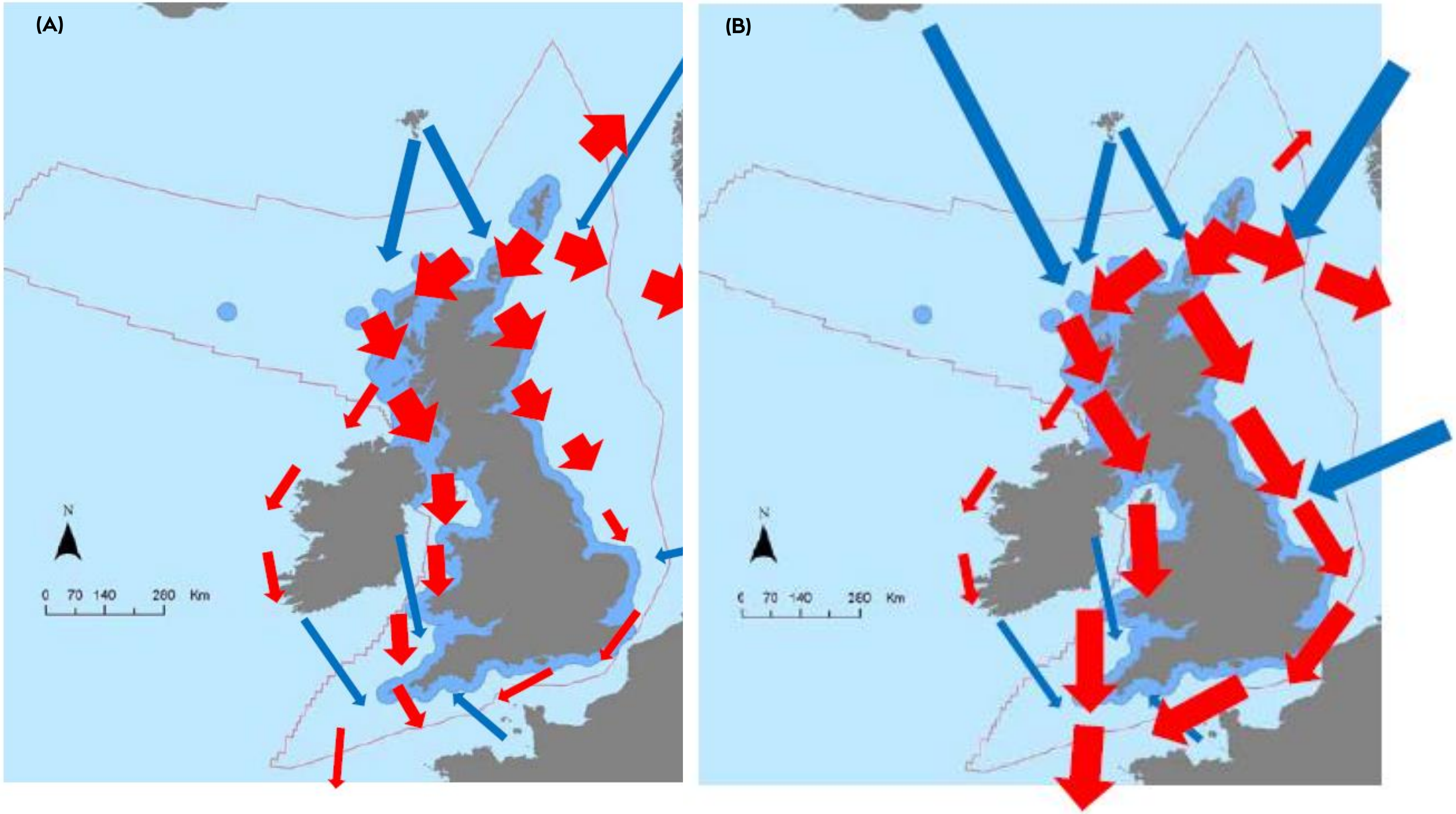

Figure A 2: Estimated winter dispersal of (A) guillemots, Uria aalge, and (B) razorbill, Alca torda. Red arrows represent UK colonies, blue arrows represent colonies from other countries (Furness, 2015).

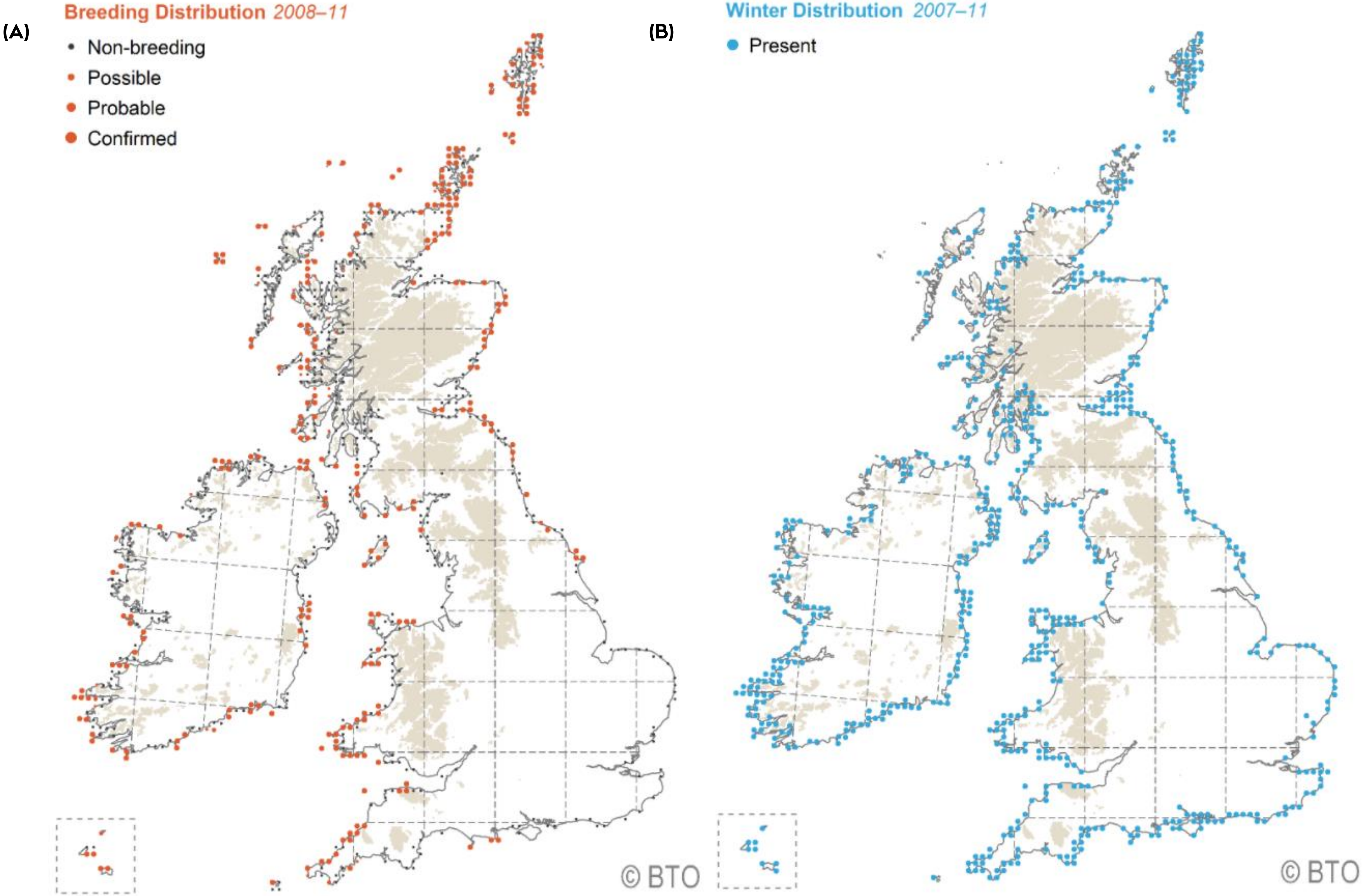

Figure A 3: Map of razorbill, *Alca torda*, distribution in the UK and Ireland during the breeding season (A - left) and winter (B - right) (Bird Atlas, 2021b).

2.2.4 Summary

2.2.4.1 Philopatry has been stated to be high within both guillemots and razorbills. However, the reliability of the data supporting this theory is being questioned due to biases within data collection (Harris *et al.*, 1996; Coulson, 2016). Recording tagged birds within auk colonies is difficult in any location due to breeding in high-density groups. It would be extremely difficult to search every potential colony that an individual may have dispersed to therefore recapture of all individuals will be impossible. The majority of studies focus more time and resources on the colony which was originally sampled therefore creating a bias towards high philopatry. Moreover, philopatry can vary greatly between colonies of the same species due to population pressure and environmental stability. Therefore, to get a precise estimate, the individual colony will need to be evaluated rather than relying on global estimates.

2.2.4.2 Both guillemots and razorbills exhibited genetic exchange between colonies due to inter-colony movement. Guillemots have been identified to be breeding up to 780km away from their natal site. Razorbills have also been known to breed away from their natal colonies, however the exact distance was not distinguished within the literature. Razorbills exhibited some evidence of restricted gene flow as there were some genetic differences between colonies within the Atlantic. Therefore, razorbills have a higher colony philopatry than guillemots. Nevertheless, as stated above, more research is needed in this area for accurate measurements.

3 Guillemot Race Distribution

3.1.1.1 During the first Hornsea Four compensation workshop (January 2021) Natural England questioned whether the race of guillemot breeding at FFC SPA will be the focus of compensation by the Project, or whether they will focus on other guillemot races. Razorbill have only two subspecies, Alca torda torda which is found in the Baltic and White Seas, Norway, Bear Island, Iceland, Greenland and eastern North America and Alca torda islandica which occurs throughout Ireland, Great Britain and north-western France, therefore, their distribution is not discussed further. The following Section of the report explores the different races of guillemot found throughout their range and discusses the likelihood of a particular race being the focus of the potential compensatory options currently under consideration.

3.2 Guillemot Races

3.2.1.1 There are several different subspecies (races) of the guillemot, however, the exact number has been widely debated. Knox (2012) states there are currently five distinct races each with their own species range (Table A 3). Races that are no longer recognised include: *spiloptera*, *intermedia*, *helgolandica* and *ibericus* (Knox, 2012).

Table A 3: Distinct subspecies of the guillemot.

Subspecies	Ocean Basin	Location
aalge	Atlantic	Eastern Canada Greenland Iceland Faeroes Scotland (north of 55°38'N) Baltic Norway (north of 69°N)
albionis	Atlantic	Britain (south of 55°38'N)

Subspecies	Ocean Basin	Location
		Ireland Helgoland Brittany Western Iberia
hyperborea	Atlantic	Norway (north of 69°N) Murmansk Bear Island Spitsbergen Novaya Zemlya
inornata	Pacific	North Pacific
californica	Pacific	California

3.3 Genetic Variation

3.3.1.1 Due to a lack of suitable breeding habitat in the Arctic, guillemot populations in the Pacific and Atlantic oceans have become genetically isolated and do not exhibit genetic exchange (Friesen *et al.*, 1996; Morris-Pocock et al., 2008). They have been separated for an extended period, most likely since the Pleistocene, causing inornate and californica to become genetically distinct from *aalge*, *albionis* and *hyperborea* (Friesen *et al.*, 1996).

3.3.1.2 Within ocean basins, genetic flow between the races is more complicated. As stated in Section 2, genetic exchange occurs between neighbouring colonies and this has led to a cline in genetic variation rather than distinct genetic differences between the subspecies. This suggests breeding occurs between neighbouring colonies, potentially even between individuals of different races. This can be evidenced through individuals being recorded breeding within another subspecies colony (Knox, 2012).

3.3.1.3 There is a possibility that in the future there will be significant genetic differentiation and even more subspecies. For example, guillemots have experienced range expansions through retreating glaciers, with those populations at the northern extent of the species range having yet to have a significant number of generations to establish a significant detectable genetic difference (Friesen *et al.*, 1996). It has therefore been suggested that factors other than genetics (i.e., location and morphology) should be considered when identifying subspecies (Harris *et al.*, 1996).

3.4 Morphological Variation

3.4.1.1 Guillemots range from 38-45cm in length with a 64-73cm wingspan (RSPB, 2021a). Adult guillemot plumage changes throughout the year. During the breeding season, the head to the lower neck are dark brown/black with a white under-belly (Sweet, 2008). Throughout the winter their plumage around their cheeks and eyes become white (Sweet, 2008). There is also a bridled morph which has a white ring around the eye with a white stripe (JNCC, 2020a).

3.4.1.2 The different races of guillemots exhibit morphological variations. Size and darkness of mantel both increase with latitude (Friesen *et al.*, 1996; Knox, 2012). These variations align with the findings of Friesen *et al.*, (1996) (latitudinal genetic differences). Morphology can be used to describe guillemot races in the Atlantic. The most northern subspecies (hyperborea) is the darkest and largest of the subspecies. Size and darkness then decrease with latitude with *aalge* and *albionis* successively (Knox, 2012). The occurrence of the bridled morph increases with latitude, therefore is likely to be more common amongst hyperborea and *aalge* than *albionis*, however it cannot be used for identification purposes as it has been documented in all Atlantic subspecies (Friesen *et al.*, 1996; Knox, 2012; Furness *et al.*, 2015; JNCC,2020a). Moreover, streaking and spotting on the underbelly increase with latitude (Knox, 2012). However, this is highly variable therefore also cannot be used for identification.

3.5 UK Colonies

3.5.1 Race Distribution

3.5.1.1 *Aalge* and *albionis* are found in separate regions of the UK (Table A 4, see Table A 5 for morphological differences). *Aalge* is the more northern race; it is found only in Scotland and Northumbria (north of 55°38′N). *Albionis* is mostly located on the coasts of Ireland, England and Wales, with the exception of southern Scotland (south of 55°38′N) (Furness, 2015; AEWA, 2019). The FFC SPA is therefore within the *albionis* subspecies range. However, guillemots ringed as chicks within the *albionis* range have been recorded breeding within *aalge* ranges and vice versa (Knox, 2012). Therefore, although there are definitive subspecies ranges, colonies surrounding the race range boundaries 55°38′N there will be an overlap in guillemot races (Furness, 2015).

Table A 4: Subspecies of the guillemot throughout the UK and Ireland. Taken from AEWA (2019).

	aalge	*albionis*
UK: Scotland (N, W & E)	*aalge*	
UK: Scotland (S)		*albionis*
UK: England (Northumbria)	*aalge*	
UK: England (minus Northumbria)		*albionis*
UK: Wales		*albionis*
UK: Northern Ireland		*albionis*
Ireland		*albionis*

3.5.1.2 Guillemots within SPAs have been mapped in Figure A 4 with the subspecies within the SPA network during the breeding season identified. Figure A 4 shows a clear divide between the north and south of the UK between races, this shows the same pattern as described in Table 4. Nevertheless, as both races have been recorded breeding within colonies of the other race, the figure identifies areas that may contain breeding populations of both aalge and albionis. Due to lack of data this represents an estimate rather than an exact location of subspecies overlap. Sightings mapped on Avibase (2021) differ slightly to those. *Aalge* sightings align with the subspecies ranges present in the north, east and west of Scotland as well as Northumbria. *Albionis* on the other hand has been recorded outside of the subspecies range, on the east of Scotland. This is most probably due to dispersal of chicks near the edges of the subspecies boundary as described in Section 3.2 or potentially due to the difficulty of identifying subspecies within the field (JNCC, 2021a).

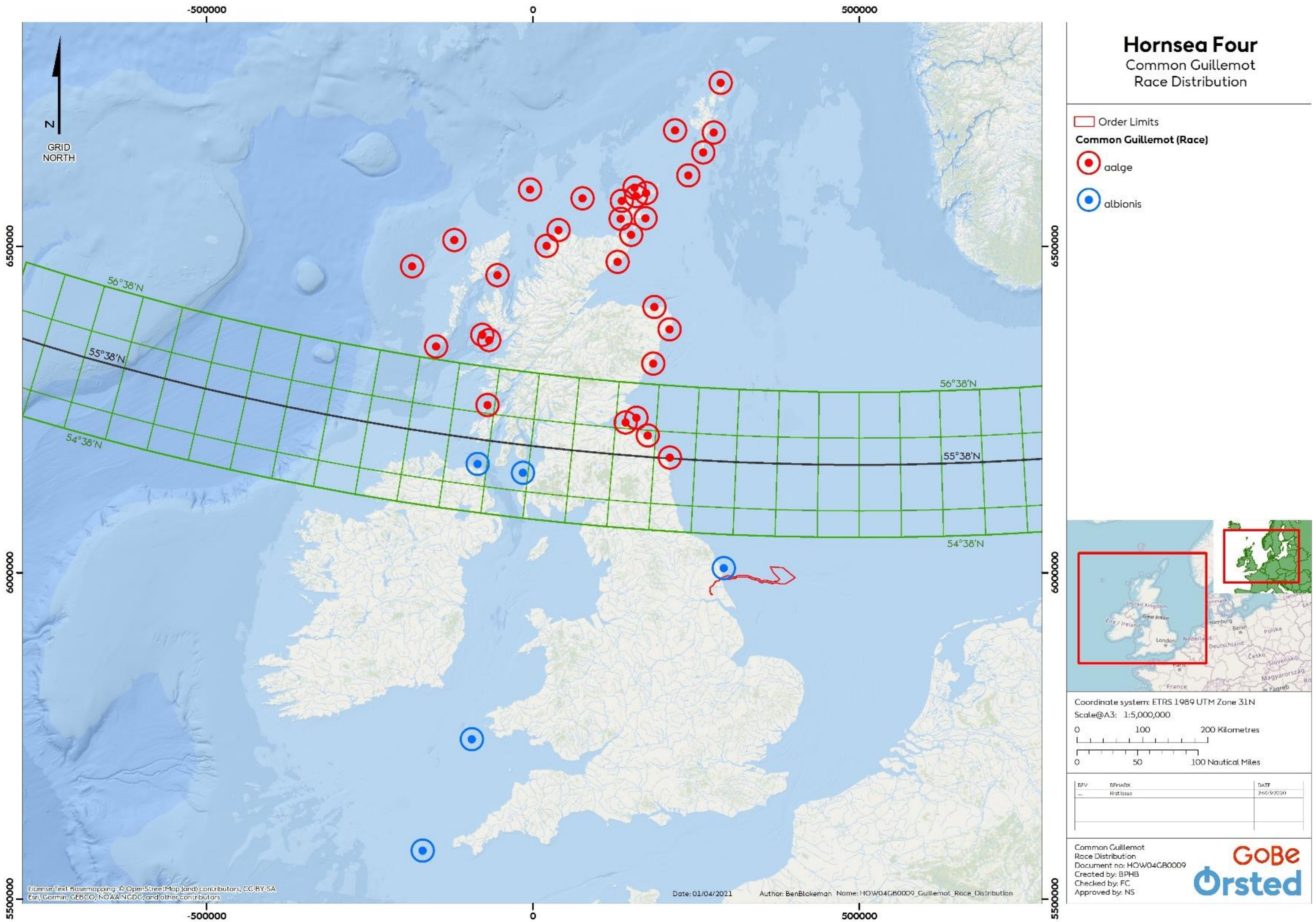

Figure A 4: UK guillemot Special Protection Areas identified as the northern *albionis* race and the southern *aalge* race. The black line identifies the latitudinal separation between the two races (north/ south of 55°38'N) with the green hashed area identifying areas with both races.

3.5.1.3 Outside the breeding season, both *aalge* and *albionis* can travel great distances away from their breeding colonies, ringed individuals from UK colonies have been recorded travelling 700km (Mead, 1974). Nevertheless, many individuals of both *aalge* and *albionis* remain in the north of the UK (750,000 *aalge*, 20,000 *albionis*) (Furness, 2015). Immature birds spend the winter significantly further away than adults, with first-year birds travelling the greatest distances (Birkhead, 1974; Mead, 1974). They spend the majority of winter out at sea. During this period even the most northern UK guillemot colonies intermix with the species ranges of those in the south. Figure A 5 displays winter dispersal of aalge guillemots from colonies in the north of Scotland. Both colonies exhibited southern dispersal into albionis subspecies range. As the most northern colonies travel the furthest distances during the winter dispersal, both races will spend the winter in intermixed groups (Furness, 2015). Despite this, guillemot dispersal is greatly dependent on prey availability (and therefore potentially governed in the future by climate related prey shifts), therefore any changes in prey abundance will likely affect future dispersal (Furness, 2015).

3.5.2 Race Morphology

3.5.2.1 The races of guillemot found in the UK, *aalge* and *albionis*, can be identified via morphological variations described above. The two main identifiable variations are plumage colour, and size (Table A 5). *Aalge* is both larger and darker than its counterpart *albionis*.

Table A 5: Morphological differences between guillemot subspecies *Uria aalge aalge* and *Uria aalge albionis*.

	aalge	***albionis***
Plumage *(Wildlife Trust, 2021)*	Black	Dark brown
Wingsize (mm) *(Cramp, 1985)*	204 (male) 206 (female)	196 (male) 195 (female)

3.6 Summary

3.6.1.1 The guillemot is a widely distributed seabird of the auk family. Despite their circumpolar distribution, Pacific and Atlantic colonies are genetically distinct and do not interbreed. Within ocean basins, although subspecies can be identified morphologically, they are not genetically distinct. This is potentially due to inter-breeding between colonies or a lack of a significant number of generations since the most recent northern range expansion to establish a significant detectable genetic difference. Subspecies should therefore be identified by size, plumage colour, as well as specific subspecies ranges rather than genetics.

3.6.1.2 Out of the five currently accepted guillemot races, two have breeding colonies in the UK and Ireland, *Uria aalge aalge* and Uria aalge albionis. Aalge is the more northern race and is located on Scottish and north-east English coasts (north of 55°38'N) during the breeding season. Albionis breeds on the Scottish (south of 55°38'N), Irish, Welsh, and English coastlines (with the exception of Northumbria and the south-east coast). The two races can be differentiated via morphological variations; *aalge* is both darker and larger than *albionis*.

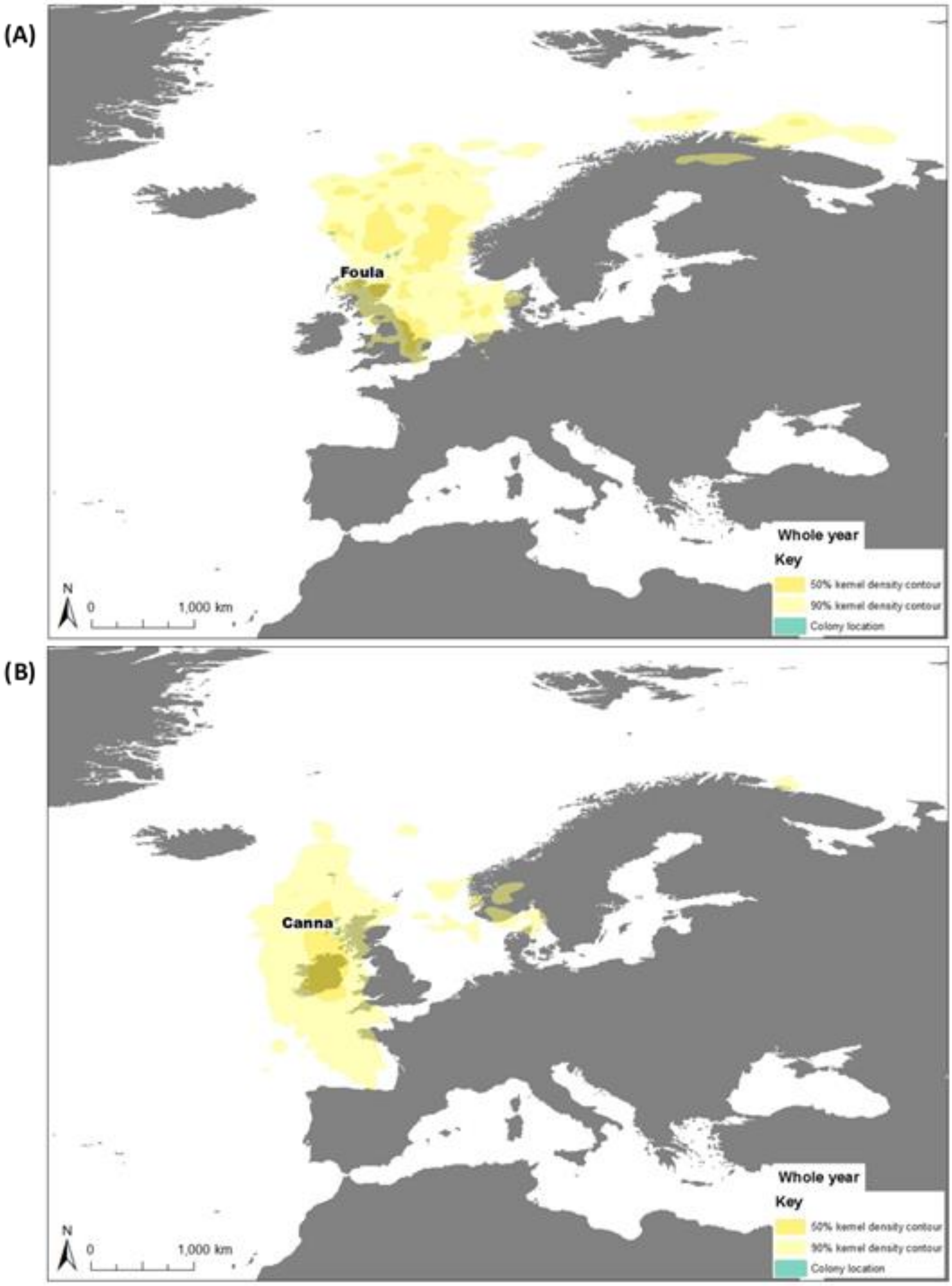

Figure A 5: Winter dispersal of two guillemot, Uria aalge, colonies in northern Scotland: (A) Foula (B) Canna. Maps derived from MacArthur Green (2019).

3.6.1.3 During the winter, guillemots disperse away from the breeding colony. Northern *aalge* populations travel the furthest distances, integrating with the southern *albionis* colonies. There are consequently no distinct winter dispersal locations for either race, rather both races will be recorded within the Irish Sea, Bay of Biscay, and the North Sea. Aalge have also been spotted travelling across the Baltic Sea to the waters north of Norway. The individuals travelling furthest are typically juveniles, with adults usually spending the winters in UK waters. While guillemot subspecies colonies are spatially distinct during the breeding season, there is no distinct separation over the winter.

4 Case Study: Flamborough and Filey Coast Special Protection Area

4.1 Seabird Colonies

4.1.1.1 The Flamborough and Filey Coast Special Protection Area (SPA) (UK9006101) is located on the east coast of England on the boarder of east and north Yorkshire (Natural England, 2020). The SPA encompasses 8039.6 hectares and comprises of two Sites of Special Scientific Interest (SSSI): Filey Brigg and Flamborough Head (Natural England, 2020). The SPA supports the largest kittiwake colony in the UK, the largest guillemot and razorbill colonies in England, and the only mainland gannetry in England, >200,000 seabirds during the breeding season (Natural England, 2020). Moreover, the FFC SPA is the most southerly large cliff-nesting seabird colony on the North Sea coast (Aitken *et al.*,2017). Guillemot and razorbill breeding at the FFC SPA are part of the *Uria aalge albionis* and *Alca torda islandica* biogeographic populations for guillemot and razorbill respectively[18][19]. Both biogeographic population ranges extend from the FFC SPA (and wider North Sea) down into and beyond the English Channel to encompass both southern breeding colonies and wintering

4.1.1.2 Although total UK guillemot population increased by only 1% between the 2000 seabird census and 2018, the population within the FFC SPA has increased by 81% (JNCC, 2020a; JNCC, 2020b). The breeding population within the FFC SPA has been increasing at a similar rate since the 1970s, with currently just over 60,000 breeding pairs (Figure A 6A, Aitken et al., 2017). In 2017, the mean productivity of guillemots in FFC SPA was 0.59, the lowest productivity observed since observations began in 2009 due to predation on eggs by carrion crows (Aitken *et al.* 2017). One site had a productivity of only 0.16 due to this predation.

4.1.1.3 The total UK razorbill increase from the 2000 seabird census has been 33%, compared to the 228% increase of population within the FFC SPA, double the increase of any other UK SPA (JNCC, 2020b; JNCC, 2020c). In common with guillemots, the colony has increased since the 1970s, most recently recorded as ~20,000 breeding pairs (Figure A 6B; Aitken *et al.*, 2017). However, there was a lull in the 2000 census with no increase in individuals. Despite this, the population then increased significantly. The 2017 mean productivity for the FFC SPA was below average at 0.56 (0.65 average 1986-2005) (Aitken *et al.*, 2017). The lowest productivity was measured at three sites within the Grandstand (0.15, 0.32, 0.37) (Aitken *et al.*, 2017). These are sites where predation of eggs by carrion crows is common (Aitken *et al.*, 2017).

4.2 Guillemot and Razorbill Connectivity

4.2.1.1 The dispersal and connectivity of guillemots and razorbills from the colonies within the FFC SPA is difficult to quantify due to the lack studies from these colonies. The following analysis is therefore speculative from literature analysis and studies of nearby colonies.

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[18] https://www.unep-aewa.org/sites/default/files/document/aewa_tc15_14_delineation_biogeographic_populcations_common_murre_Rev1.pdf

[19] https://www.unep-aewa.org/sites/default/files/document/aewa_tc15_11_delineation_biogeographic_populations_razorbill_en.pdf

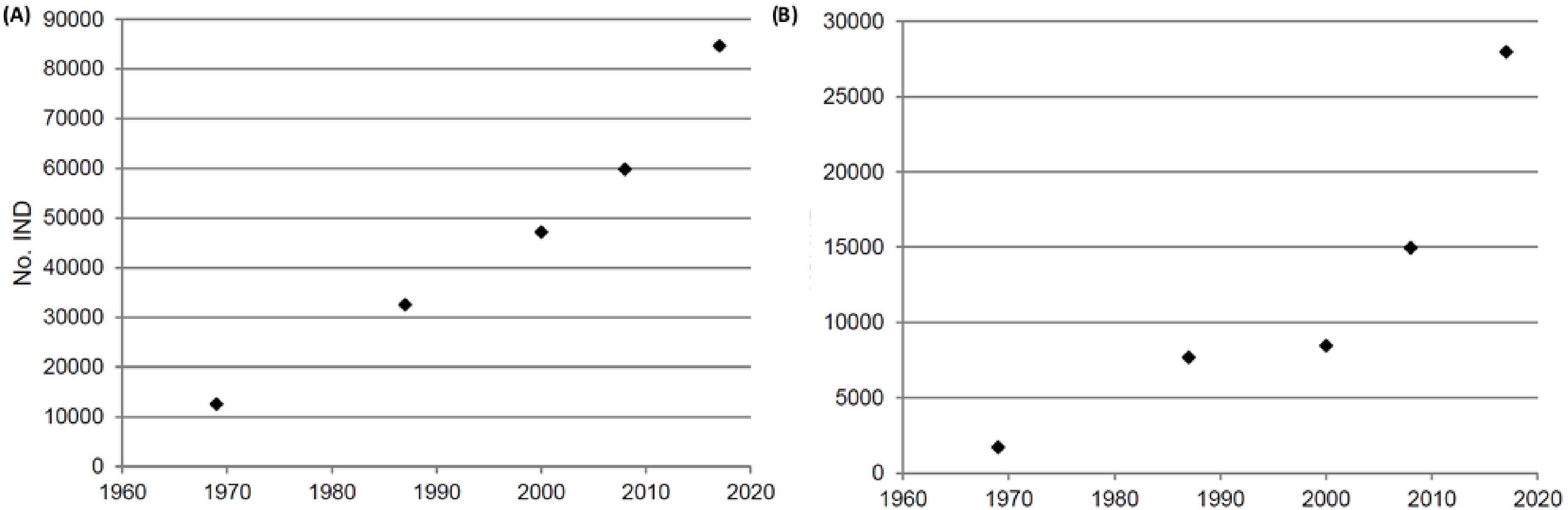

Figure A 6: Trends in (A) guillemot and (B) razorbill breeding population within the Flamborough Head and Bempton Cliffs SPA (1969-2017). Figure taken from (Aitken *et al.*,2017). No IND = numbers of individuals.

4.2.2 Philopatry

4.2.2.1 As described in detail in Section 2.1, both guillemots and razorbills have a high degree of philopatry (particularly razorbills), however, both species display inter-colony movement with first-time breeders breeding away from their natal colony (Lyngs, 1995; Lavers *et al.*, 2007). Therefore, there is potential for both species within the FFC SPA to exhibit colony movement to other UK colonies (potentially even outside of the UK).

4.2.2.2 The potential of this inter-colony movement is higher due to guillemot and razorbill populations within the FFC SPA increasing (Figure A 6). As an increasing population is linked with increased dispersal, it is likely that the juveniles will exhibit net-migration to other colonies to avoid high levels of competition. Colonies in south-west England, particular some location is Cornwall, are also reported to be rapidly increasing (JNCC *pers. comm.*[20]). There is potential for density caused emigration from these southern colonies. As there are limited suitable breeding grounds between the southwest and Flamborough, there is the potential for these colonies to directly interact with each other. However, analysis would be needed to confirm this.

4.2.3 Non-breeding season Movements

4.2.3.1 Mead (1974) collated winter distribution of UK guillemots and razorbills through analysing ringing data. Mead separated the UK colonies by location within the UK, focusing on the Irish Sea colonies independently to the colonies in the north and east of the UK. Both guillemot and razorbill colonies from the north and east coast show similar winter dispersal across the North Sea to Norway, including as far as the north of Norway as well as dispersing south through the English Channel (Figure A 7, Figure A 8). Those individuals travelling through the English Channel were immature (some adult razorbills), the distance travelled increased with decreasing age (Mead, 1974). Further studies have confirmed this analysis (Birkhead, 1974; Lloyd, 1974; Swann and Ramsay, 1983; Lyngs, 1993; Wright *et al.,* 2012).

4.2.3.2 Harris *et al.*, (2015) used kernel densities to identify winter distribution hotspots of guillemots from colonies on the Isle of May, Scotland (north of the FFC SPA). The majority of individuals stayed within the North Sea, most likely adults as they are more inclined to stay closer to the breeding colony during the winter dispersal. A 75% kernel density identified birds moving into the English Channel and a 50% density identified individuals moving fully through the channel as well as individuals off the coast of Norway.

4.2.3.3 A report by Macarthur Green (2019) tagged razorbills from two colonies in east Scotland (Whinnyfold and East Caithness). The winter distribution for the two colonies had slight differences. Whinnyfold dispersed to the southern North Sea and remained within a relatively small area whereas birds from East Caithness dispersed over a larger area of the North Sea, Scandinavian coast, and some in the Irish Sea. This shows that even colonies from close locations can have a variable distribution therefore to get an exact distribution of the FFC SPA razorbill winter dispersal more research is needed on this specific colony.

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[20] Southwest Marine Ecosystems Webinar, 11th March 2021. ‘Seabird Count: taking stock of the South-West’s breeding seabirds’, Daisy Burnell, JNCC.

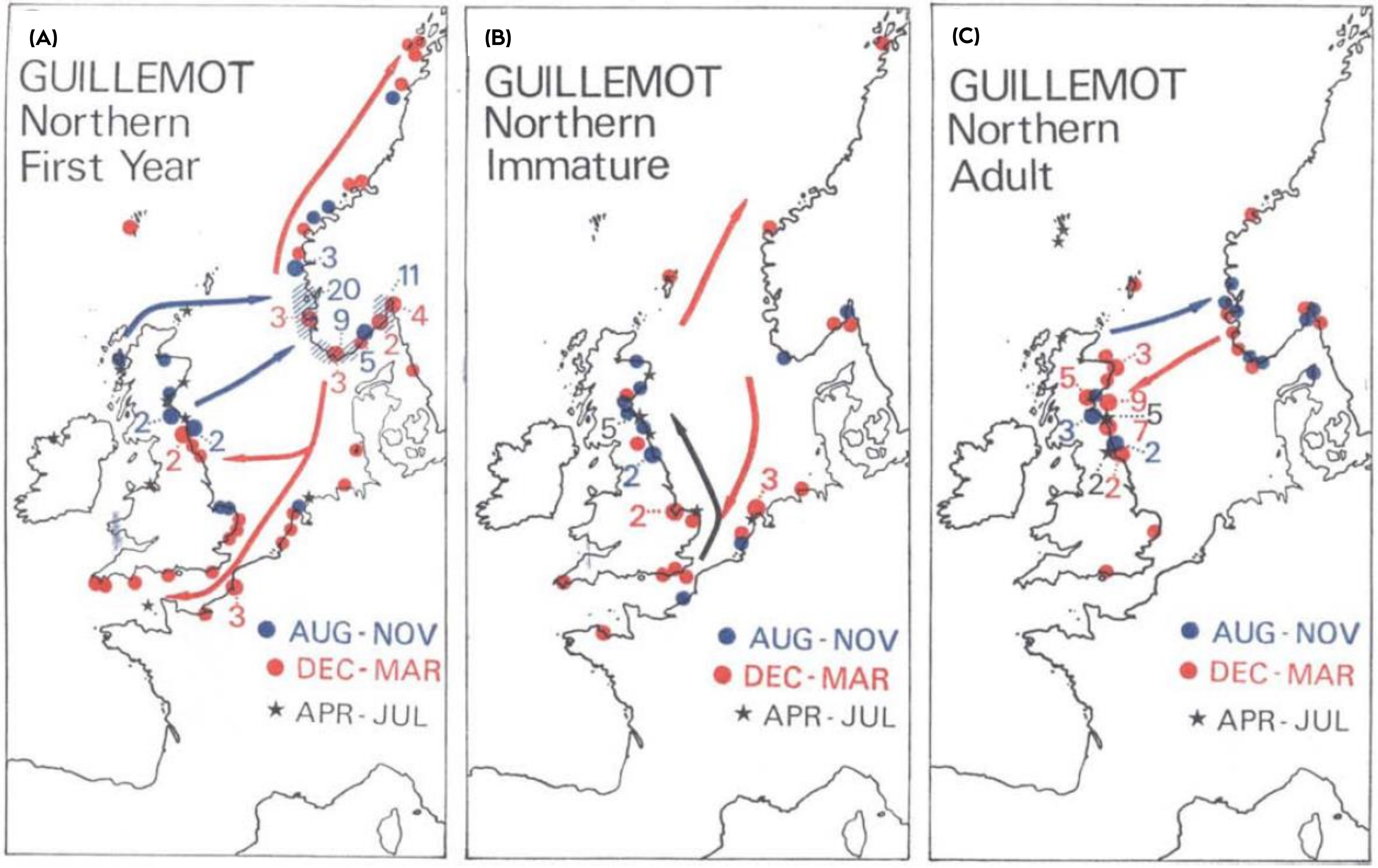

Figure A 7: Locations of guillemot from northern Britain (Scotland and North-East England) colonies outside of the breeding season. Blue = August to November, red = December - March. Each figure represents a different age class: (A) first year chicks, (B) two-to-four-year immatures, and (C) five plus year adults. Figure derived from Mead (1974).

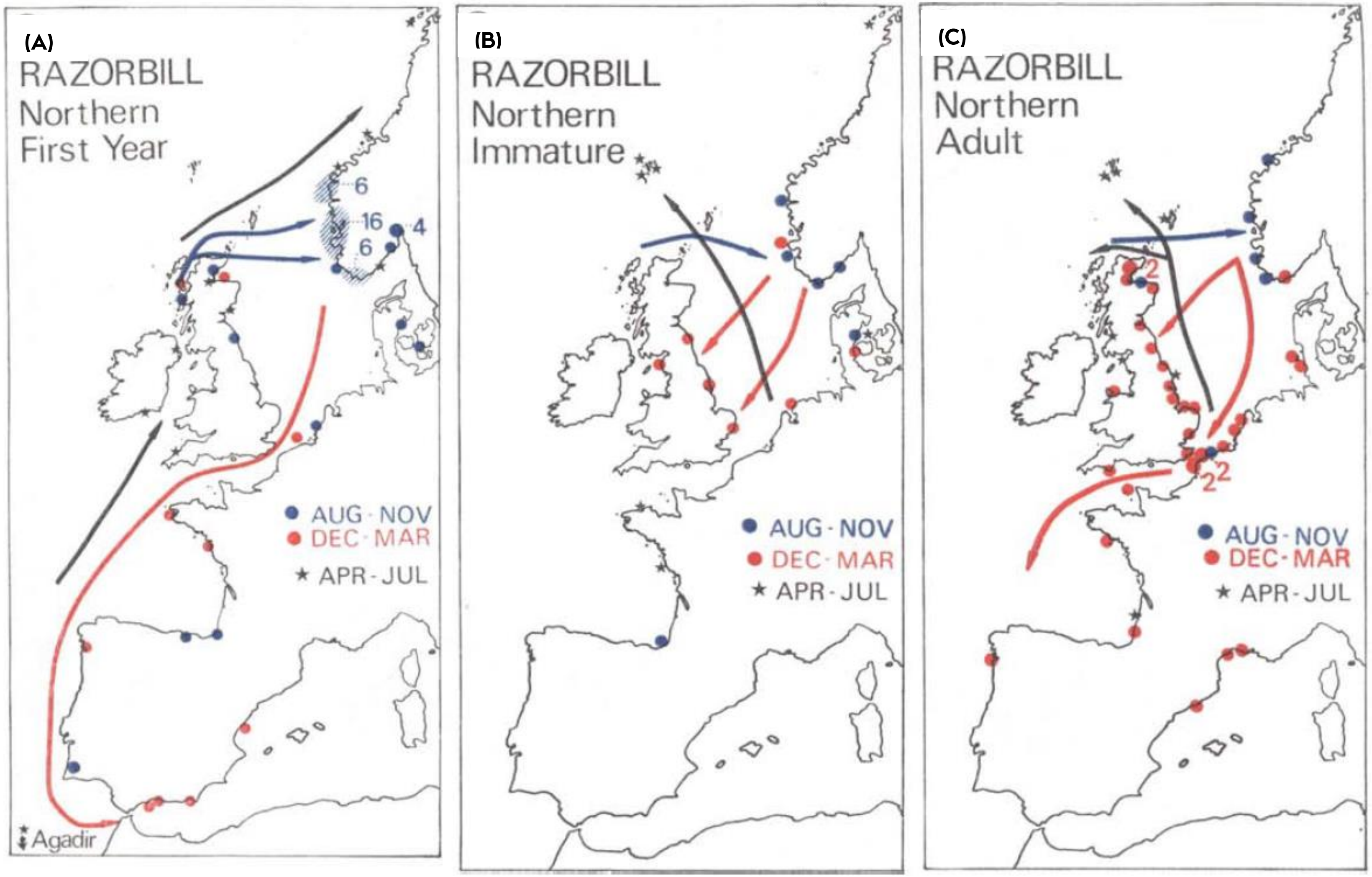

Figure A 8: Locations of razorbill, from northern Britain (Scotland and North-East England) colonies outside of the breeding season. Blue = August to November, red = December - March. Each figure represents a different age class: (A) first year chicks, (B) two-to-four-year immatures, and (C) five plus year adults. Figure derived from Mead (1974).

4.2.4 Non-breeding Season Movements: Ringing Recovery Data

4.2.4.1 The Ringing Scheme in Britain began in 1909 and is currently run by the British Trust for Ornithology (BTO) with the aim to understand how populations change in order to inform effective conservation policies. Alongside the actual ringing of birds, ringing recoveries, defined as individuals recaptured away from their site of ringing or reports of dead individuals with rings (Walker *et al.*, 2013), are reported to the BTO and this information can be used to inform a number of questions including species connectivity between different areas of the UK and further afield. Ringing recoveries depends on the chance a bird will die and the chance it will be found and reported. Currently, only one in 50 ringed birds is found dead and the recovery rate will vary from species to species.

4.2.4.2 Movements of razorbill and guillemot are complex and wide-ranging and are largely dependent on three main factors; time of the year; age of the bird and colony from which the individual originates (Mead, 1974). An analysis was undertaken by Mead (1974) on ringing of auks in Britain and Ireland and found that although relatively large numbers of auks had been rung, very little ringing recoveries had been recorded. This is as a consequence that ring recovery reports for auks depends on the death of the birds as ringers are unable to trap and handle auks (Mead, 1974). Therefore, although areas may not have any ringing recovery records, this does not mean there are no guillemot and razorbill in these areas.

4.2.4.3 Although there is limited ringing recovery data for guillemot and razorbill, it still provides some insight into the dispersion of the two species and shows where there is definite connectivity between sites in the UK and further afield for these species.

Methodology

4.2.4.4 Ringing recovery data for guillemot and razorbill rung in the east coast of England (Farne Islands to Norfolk) and recovered elsewhere in the UK and Europe was requested from BTO in order to investigate connectivity between sites within the UK and Channel Islands.

4.2.4.5 The BTO Ringing Scheme is funded by a partnership of the British Trust for Ornithology, the Joint Nature Conservation Committee (on behalf of: Natural England, Natural Resources Wales and Scottish Natural Heritage and the Department of the Environment Northern Ireland), The National Parks and Wildlife Service (Ireland) and the ringers themselves.

4.2.4.6 Data was received on the 22nd of June 2021 and the following analysis was conducted (it should be noted that BTO had no input into the analysis undertaken in this report). Analysis on ringing recoveries in Cornwall and the Channel Islands (including recoveries within France) which were originally rung at English east coast sites was undertaken to establish if there is any connectivity between guillemots and razorbills between these locations. Further analysis was undertaken to determine whether any ringing recoveries within the east coast of England came from Cornwall or within proximity of the Channel Islands.

Results

4.2.4.7 In total, only 164 guillemots and 63 razorbill were rung within the northeast of England from 2002 to 2020, demonstrating that there is little data potentially available for these species. There is a total of 82 ringing recoveries of guillemot in Europe from individuals that have been rung between the Farne Islands and Norfolk, dating back as early as 1918 and a total of 46 ringing recoveries between Farne Islands and Norfolk (36 guillemot and 10 razorbill) that have been rung from elsewhere in the UK or Europe. The locations of these ringing recoveries can be seen in Figure A 9 and Figure A 10.

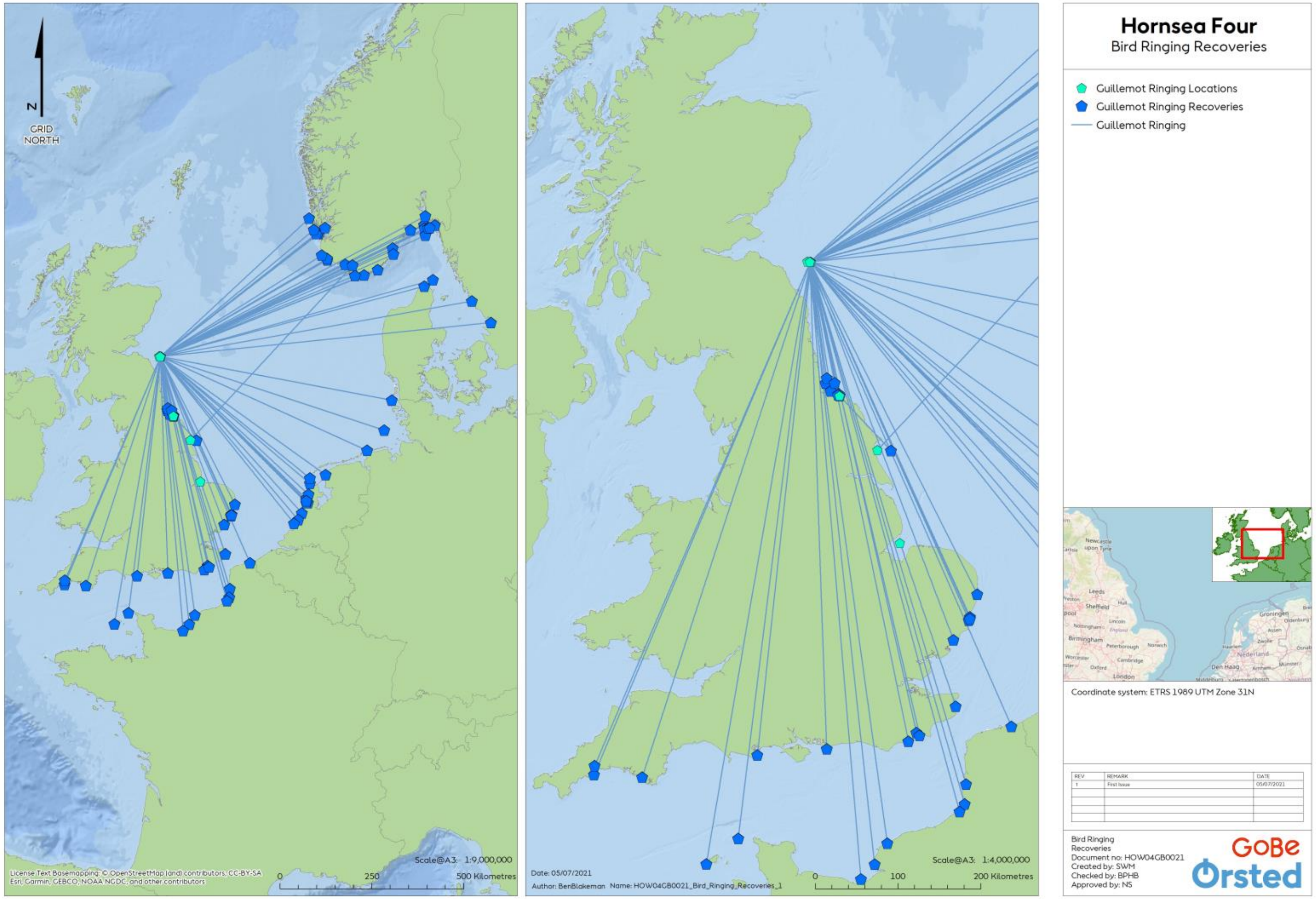

Figure A 9: Guillemot tagged between the Farne Islands and Norfolk. Distribution of where there have been identified.

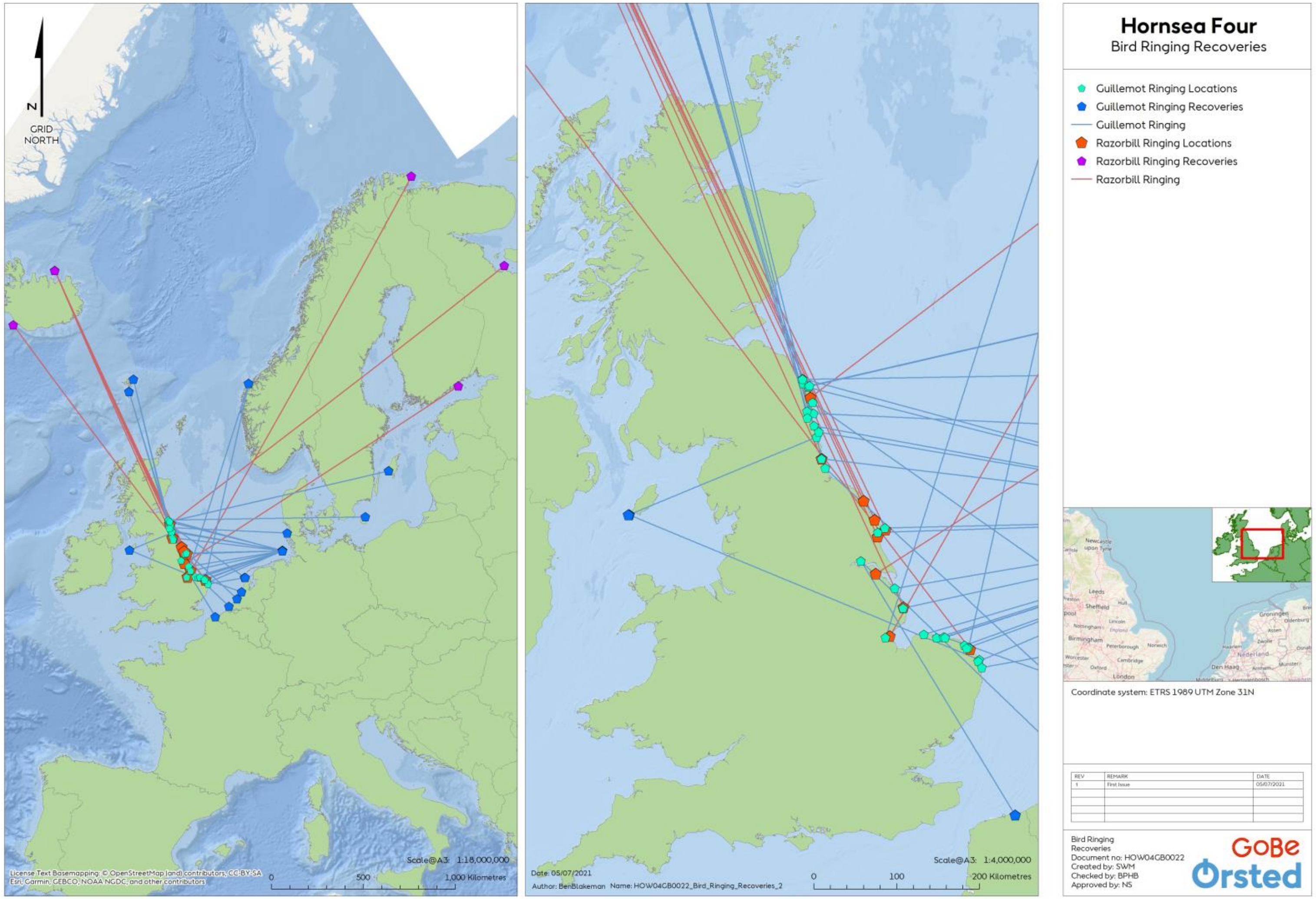

Figure A 10: Tagged guillemot identified between the Farne Islands and Norfolk that had been tagged elsewhere.

Conclusion

4.2.4.8 Despite there being limited data for guillemot and razorbill ringing recoveries, the ringing recovery data from BTO shows that there is connectivity between the east coast of England and the wider east Atlantic populations. Birds have both been tagged in northeast England and resighted elsewhere, as well as birds resighted in the northeast that were tagged elsewhere. There is connectivity from east coast birds across the North Sea, through the English Channel, as well as birds travelling from as far as Iceland, Norway, and Finland into the North Sea. These examples provide evidence of the distances both guillemot and razorbill can travel, showing the connectivity of guillemot and razorbill population and therefore the connectivity of the UK SPA network. Such movements conform with the species wider biogeographic ranges and include the likely locations of potential compensatory measures for the Hornsea Four projects for both species.

4.2.5 Guillemot Race Distribution

4.2.5.1 The guillemot breeding season at the FFC SPA is typically between April to August (Natural England, 2020). Nesting birds are distributed throughout the SPA, apart from the coastal cliffs south of Flamborough Head, with concentrations found on the highest ledges at Bempton Cliffs and around Breil Newk (Natural England, 2020). The breeding guillemot colony within the FFC SPA is of the southern *albionis* race. This is the largest English guillemot colony, supporting >80,000 breeding guillemot adults (15.6% of the southern *albionis* biogeographical population (Natural England, 2020)). Outside of the breeding season, guillemots of the *aalge* race have been recorded off the Flamborough coast while traveling south from their breeding colonies (Figure A 7).

4.2.5.2 As it has been shown, guillemots exhibit regular colony exchange, it is more than likely that emigration and immigration occur between the colony within the FFC SPA and other guillemot colonies. Emigration occurs at a greater rate when a population is increasing. As *albionis* colonies in the FFC SPA as well as along the south coast are increasing, there is a chance that colony exchange is occurring. However, more research is needed in this area to understand its importance for the FFC SPA colonies.

4.2.5.3 According to the “Managing Natura 2000 sites: The provisions of Article 6 of the ‘Habitats’ Directive 92/43/EEC”[21], with regard to a plan or project, ‘compensation should refer to the site’s conservation objectives and to the habitats and species negatively affected in comparable proportions in terms of number and status. At the same time the role played by the site concerned in relation to the bio-geographical distribution has to be replaced adequately’.

4.2.5.4 ‘The compensatory measures under Article 6(4) must address all issues, be they technical, legal or financial, needed to offset the negative effects of a plan or project and to maintain the overall coherence of the Natura 2000 network’ and include ‘clear objectives and target values according to the site’s conservation objectives’ and ‘description of the compensatory measures, accompanied by a scientifically robust explanation of how they will effectively compensate for the negative effects of the plan or project on the species and habitats affected in light of the site’s conservation objectives, and how they will ensure that the overall coherence of Natura 2000 is protected’.

4.2.5.5 Guillemots (*Uria albionis*) are a qualifying feature of the FFC SPA during the breeding season. Each summer, the SPA supports around >80,000 breeding guillemot adults which is around 15.6% of the southern *albionis* biogeographical population (Natural England, 2020). The conservation objectives for this site[22] are to ensure that the ‘integrity of the site is

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[21] “Managing Natura 2000 sites: The provisions of Article 6 of the ‘Habitats’ Directive 92/43/EEC”: ART. 6 INTERPRETATION GUIDE (europa.eu)

[22] Flamborough and Filey Coast SPA Conservation Objectives: Marine site detail (naturalengland.org.uk)

maintained or restored as appropriate, and that the site contributes to achieving the aims of the Wild Birds Directive, by maintaining and restoring:

- The extent and distribution of the habitats of the qualifying features;
- The structure and function of the habitats of the qualifying features;
- Supporting processes on which the habitats of the qualifying features rely;
- The populations of each of the qualifying features; and
- The distribution of qualifying features within the site.

4.2.5.6 The Supplementary Advice on Conservation Objectives (SACOs)[23] provides further detailed information to help achieve the conservations objectives and includes which attributes should be maintained and restored. The SACOs for guillemot include 'maintain the size of the breeding population at a level which is above 41,607 breeding pairs' during the breeding season, 'this will sustain the site's population and contribute to a viable local, national and bio-geographic population'.

4.2.5.7 To conclude, the SPA conservation objectives require the maintenance and restoration of the bio-geographic population of guillemots at this site, with this bio-geographic population being the southern subspecies Uria aalge albionis. Therefore, it may be expected that the compensation plan for guillemots should focus on the southern subspecies with the chosen area of compensation being 'within the same biogeographical region or within the same range, migration route or wintering area for bird species' in order to be in-line with guidance from "Managing Natura 2000 sites: The provisions of Article 6 of the 'Habitats' Directive 92/43/EEC".

5 Summary

5.1.1.1 Both the guillemot and razorbill colonies within the Flamborough and Filey Coast SPA are increasing at potentially faster rates than other UK colonies. Despite the occurrence of colony philopatry, these population expansions increase the likelihood of colony exchange with other populations. Throughout the winter, juveniles of both guillemots and razorbills travel great distances, with many moving through the English Channel. Adults are more inclined to stay within the North Sea, however, some have also been identified travelling through the Channel (Figure A 7; Figure A 8).

5.1.1.2 The guillemot breeding colony is of the race *albionis* and is the largest guillemot colony in England. The FFC SPA supports >80,000 breeding guillemot adults, 15.6% of the southern *albionis* biogeographical population. The colony is highly successful, more than doubling in size since 2000. There is a possibility that the breeding population at FFC SPA is made from both individuals from the colony and other individuals who emigrated from elsewhere. To understand the important of immigration/emigration for the Flamborough and Filey coast colonies, more research will need to be done in this area.

5.1.1.3 Both guillemots and razorbill display similar characteristics with breeding and winter dispersal. They both breed on steep ledges and cliffs around the coasts of the UK and Ireland, with the exception of south-east England from Flamborough to the Isle of Wight. During the winter period, both species are frequent around the whole of the UK and Ireland. The majority of individuals disperse south, with immatures travelling a significantly further distance than adults who remain predominantly near the colony. The long distances travelled by juveniles of both species during the winter dispersal could potentially linked to the juvenile searching for future nesting locations.

5.1.1.4 The evidence within this report provides evidence for the connectivity between UK guillemot

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[23] Flamborough and Filey Coast SPA Supplementary Advice on Conservation Objectives: https://designatedsites.naturalengland.org.uk/Marine/SupAdvice.aspx?SiteCode=UK9006101&SiteName=flamb&SiteNameDisplay=Flamborough+and+Filey+Coast+SPA&countyCode=&responsiblePerson=&SeaArea=&IFCAArea=&NumMarineSeasonality=4,4,4

and razorbill populations, through both the winter dispersal and dispersal of juveniles that breed away from their natal colony. The UK guillemot and razorbill populations are therefore connected, so a benefit to a colony within each species biogeographic population range will help strengthen the wider population and improve the status of UK guillemot and razorbill.

6 Consideration of EU Compensation Guidance

6.1.1.1 FFC SPA qualifies under the EU Habitats Directive (1) and, by virtue of Article 7 of that Directive, also the Wild Birds Directive (2) (the Nature Directives):

- 1) Council Directive 92/43 /EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (OJ L 206/7 22.7.1992) (the Habitats Directive).
- 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 20/7 26.1.2010) (the Birds Directive).

6.1.1.2 "Managing Natura 2000 sites: The provisions of Article 6 of the 'Habitats' Directive 92/43/EEC" states that compensation should be located in areas where they will be most effective at maintaining 'the overall coherence of the Natura 2000 network'. For sites designated under the Habitats Directive the areas selected for compensation must 'be within the same biogeographical region' in the Member State concerned. Whereas sites designated under the Birds Directive must be 'within the same range, migration route or wintering area for bird species' in the Member State concerned.

6.1.1.3 As guillemot and razorbill are both qualifying features under the Birds Directive (2009/147/EC), compensation must be 'within the same range, migration route or wintering area for bird species'[24]. Based on the current locations being considered for compensatory measures, this requirement will be adhered to as demonstrated in Figure A 7 and Figure A 8 (winter dispersal of guillemot and razorbill through the English Channel). In addition to this, the southern guillemot *albionis* race is being targeted within the proposed measures.

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[24] "Managing Natura 2000 sites: The provisions of Article 6 of the 'Habitats' Directive 92/43/EEC": ART. 6 INTERPRETATION GUIDE (europa.eu)

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Appendix B : GIS Mapping

1 Methods

1.1.1.1 Monthly densities of guillemot and razorbill have been estimated at a 10km resolution by Waggitt *et al.*, (2019). 2.68 million km of aerial and vessel survey data were collected from 1980 to 2018. The data was then collated and standardised to account for variations in survey techniques. Variations were first estimated using detection function models then adjustments were made to account for these. Biases that may cause variations have been summarised in Table B 1.

Table B 1: Biases derived from survey sampling (Waggitt *et al.*, 2019).

Bias	Description
Perception Bias	Undetected animals due to observer's visibility being compromised e.g., high sea state.
Availability Bias	Undetected animals due to animals being out of sight e.g., diving.
Response Bias	Animals' reaction to the presence of the platform. Can increase or decrease the likelihood of sightings depending on the animal's response e.g., disturbed by the platform (decrease) or approach the platform (increase).

1.1.1.2 Waggitt *et al.* (2019) modelled the sightings against environmental characteristics (annual temperature, annual temperature variance, depth, fronts, regional temperature, seabed roughness) as well as the proximity to land, proximity to the breeding colony and the point of the breeding cycle. Relationships between these factors were identified and used to estimate the seabird densities at monthly scales around the UK.

2 Results

2.1.1.1 Monthly distribution densities of guillemot (Figure B 1; Figure B 2; Figure B 3) and razorbill (Figure B 4; Figure B 5; Figure B 6have been mapped around the UK. Guillemot cover a greater area offshore throughout the year when compared to razorbill.

2.1.1.2 From April to July, both guillemot and razorbill are located tightly around their colonies. This is expected as aligns with the known breeding season when adults are nesting onshore. Outside of the breeding season, both species move further offshore, then start moving south post September. By December both species are located offshore around all UK coasts.

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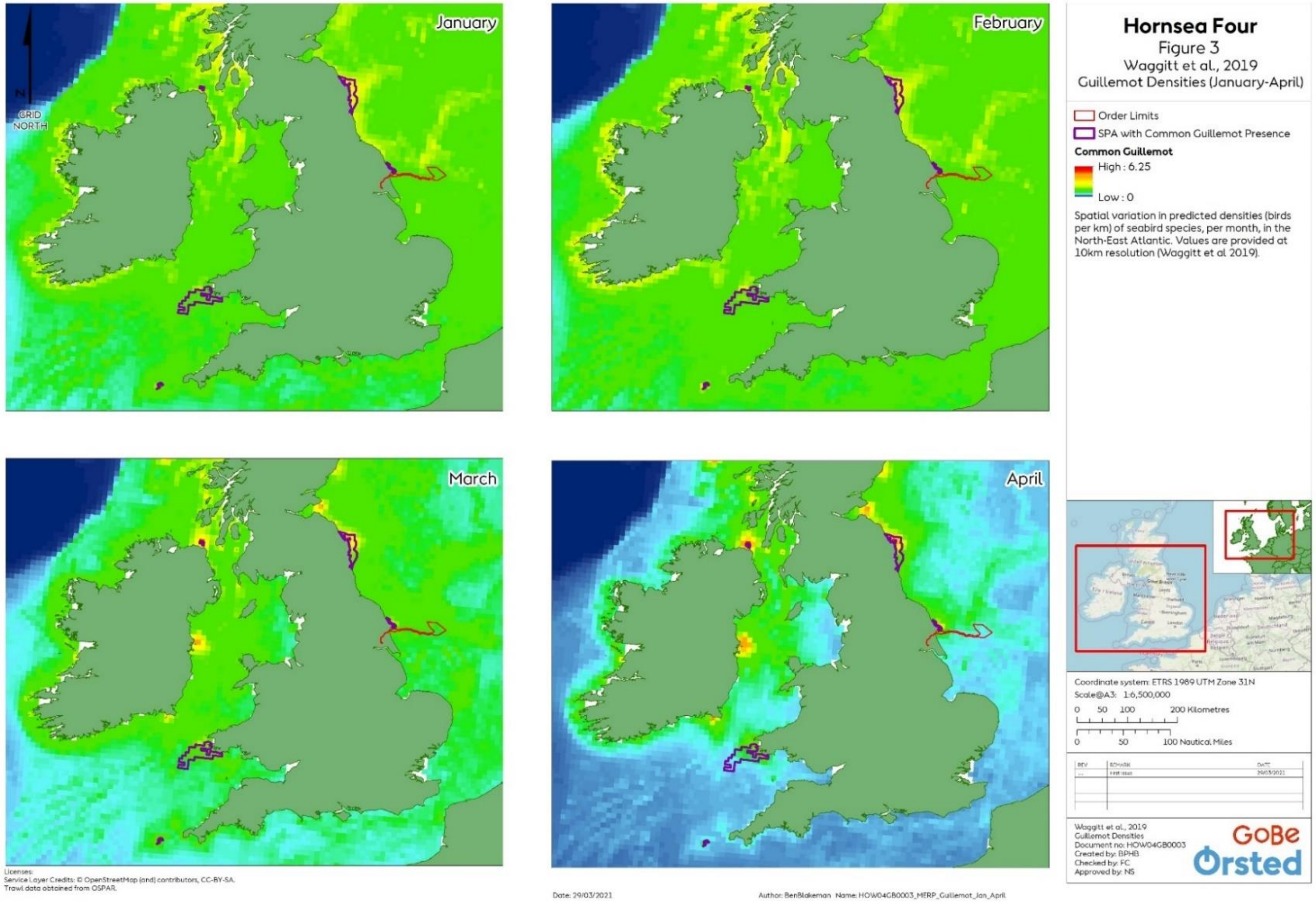


Figure B 1: Guillemot density from January to April. Red represents the highest densities and green represents the lowest. Data derived from Waggitt *et al.*,(2019).

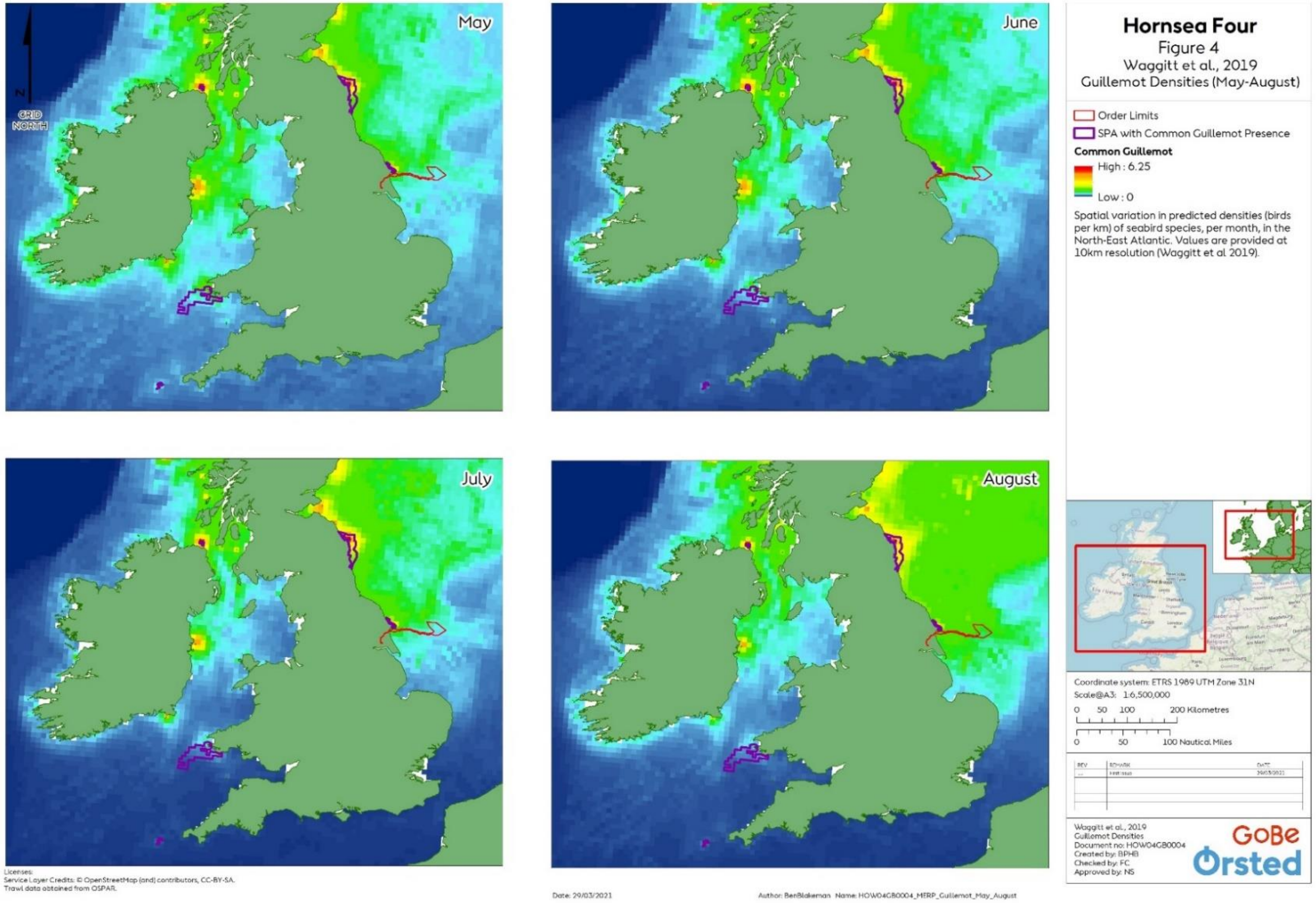


Figure B 2: Guillemot densities from May to August. Red represents the highest densities and green represents the lowest. Data derived from Waggitt *et al.*, (2019).

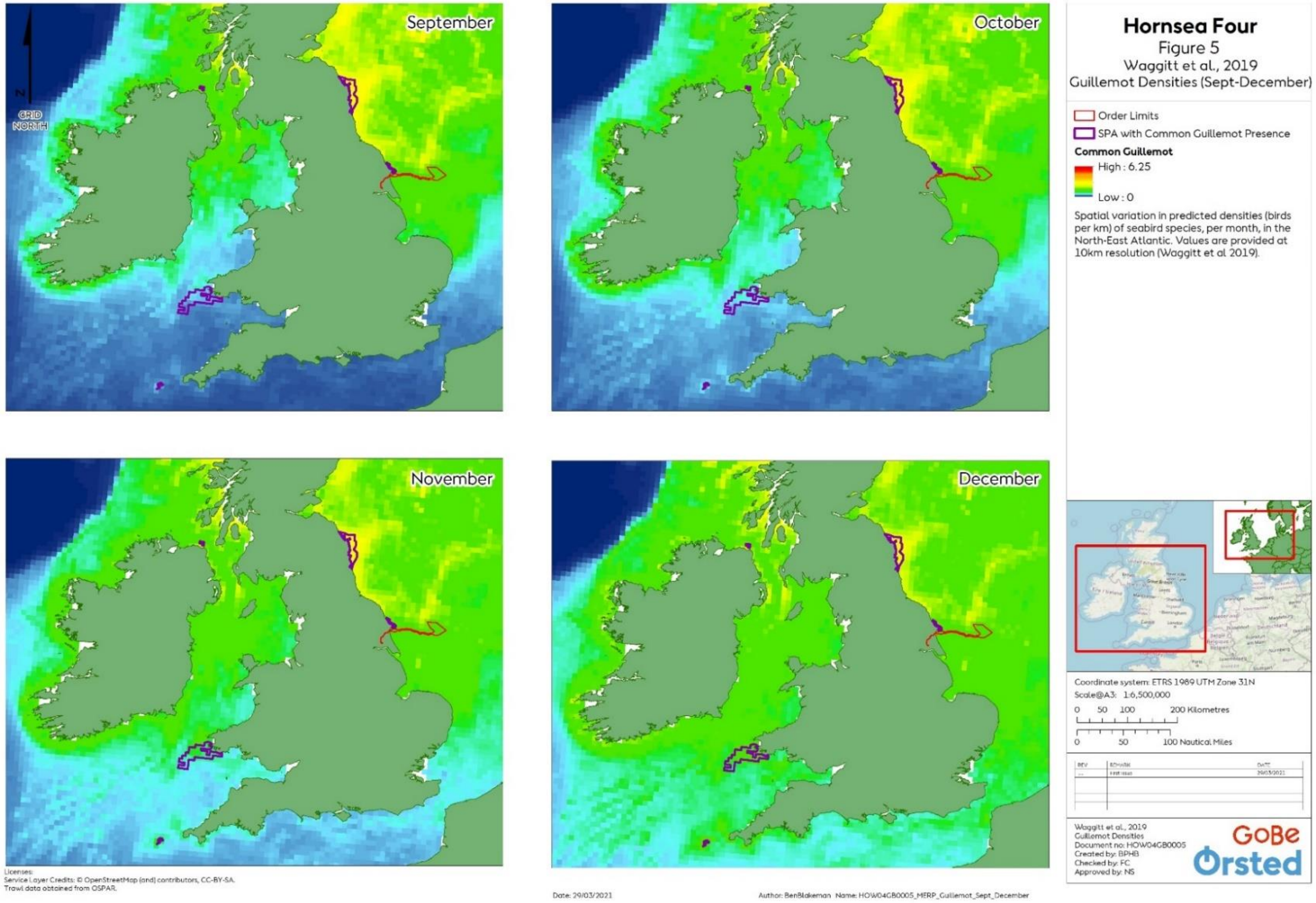


Figure B 3: Guillemot densities from May to August. Red represents the highest densities and green represents the lowest. Data derived from Waggitt *et al.,* (2019).

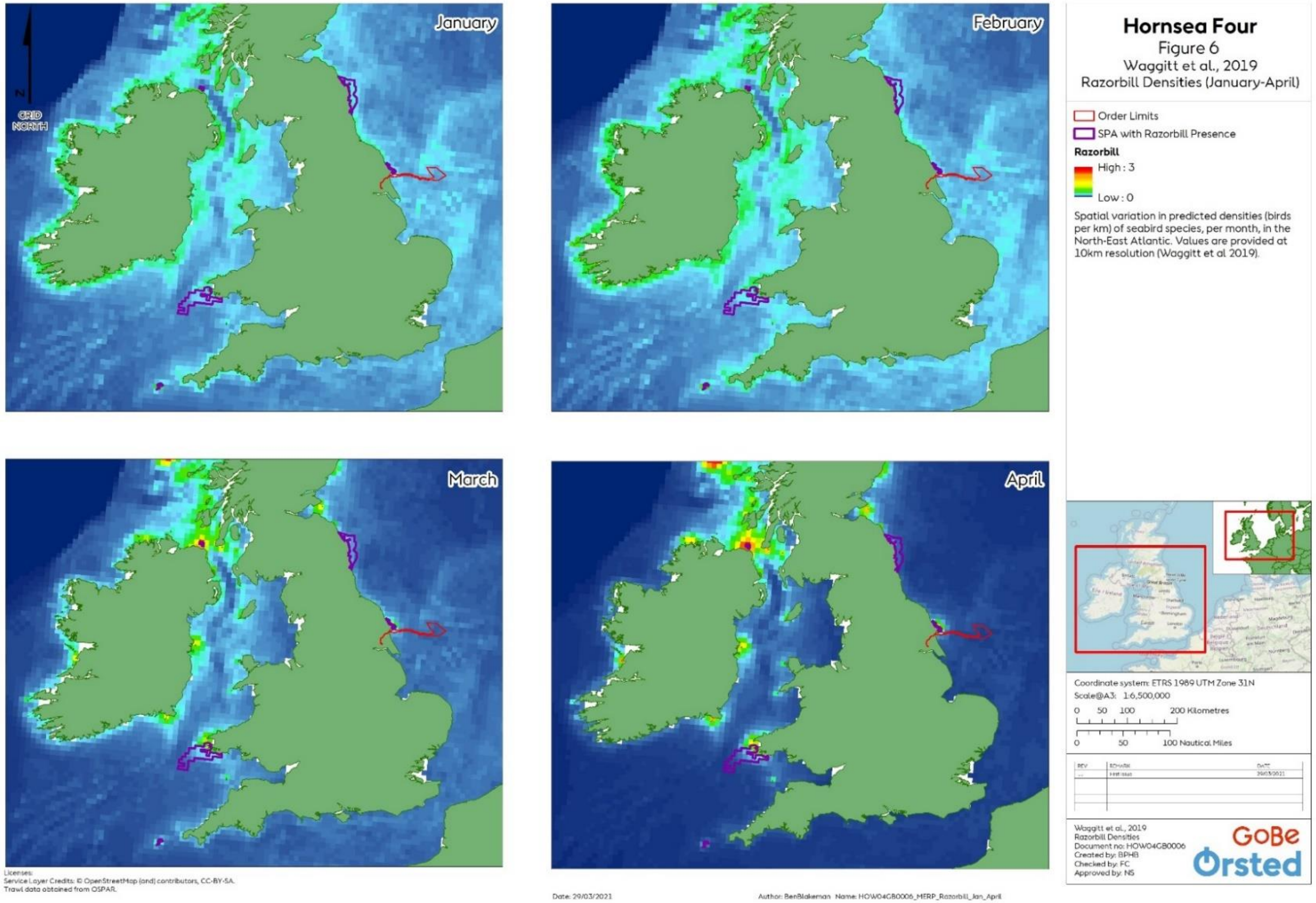


Figure B 4: Razorbill densities from January to April. Red represents the highest densities and green represents the lowest. Data derived from Waggitt *et al.*, (2019).

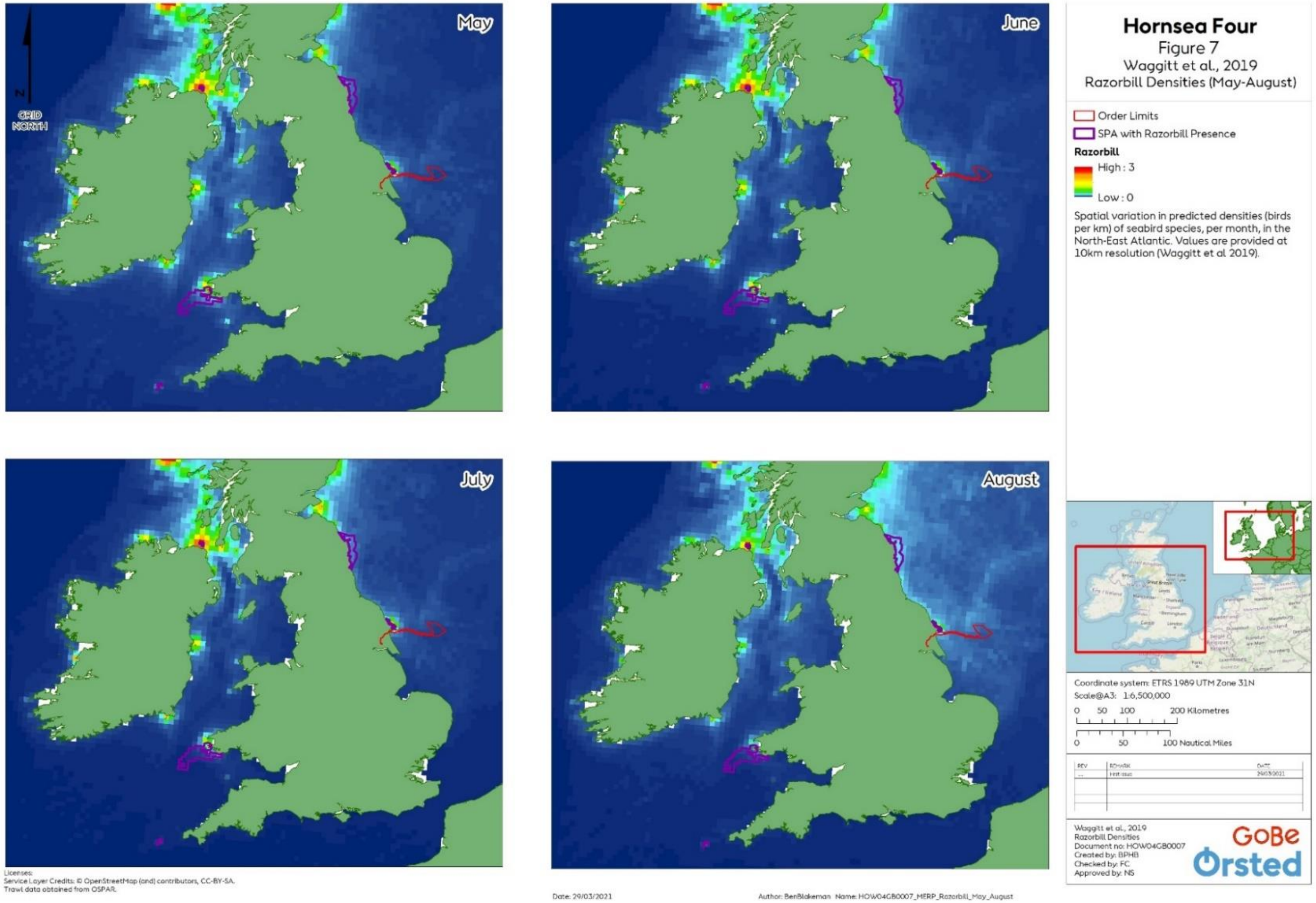
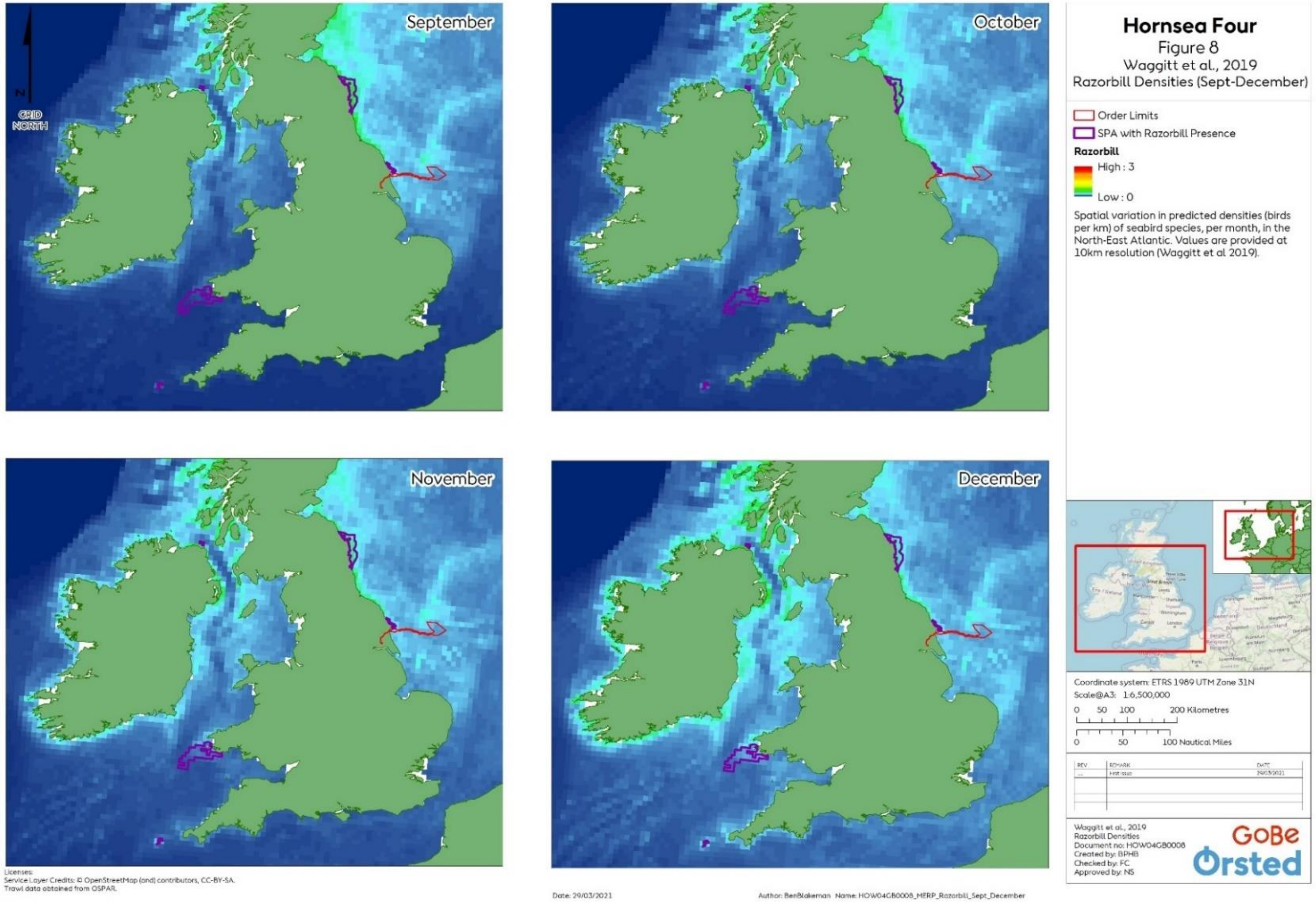


Figure B 5: Razorbill densities from May to August. Red represents the highest densities and green represents the lowest. Data derived from Waggitt *et al.*, (2019).



Hornsea Four
Figure 8
Waggitt et al., 2019
Razorbill Densities (Sept-December)

Spatial variation in predicted densities (birds per km) of seabird species, per month, in the North-East Atlantic. Values are provided at 10km resolution (Waggitt et al 2019).

Coordinate system: ETRS 1989 UTM Zone 31N
Scale@A3: 1:6,500,000

REV	REMARK	DATE
...	First issue	29/03/2021

Waggitt et al., 2019
Razorbill Densities
Document no: HOW04GB0008
Created by: BPHB
Checked by: FC
Approved by: NS

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Trawl data obtained from OSPAR.

Date: 29/03/2021 Author: BenBlakeman Name: HOW04GB0008_MERP_Razorbill_Sept_December

Figure B 6: Razorbill densities from September to December. Red represents the highest densities and green represents the lowest. Data derived from Waggitt *et al.,* (2019).

Appendix C : Guillemot and Razorbill Gillnet Bycatch Reduction Review

1 Introduction

1.1.1.1 The Applicant has identified gillnet fisheries as a potentially major cause of large auk bycatch in the UK (see Bycatch Reduction Evidence Report (**B2.8.1 Compensation measures for FFC SPA: Bycatch Reduction: Ecological Evidence**)). In order to successfully reduce bycatch numbers and act as compensation, a successful technique to reduce bycatch needs to be identified. Within the Bycatch Reduction Evidence Report (Section 10: Bycatch Reduction Techniques Review), an overview of the long-listed gillnet bycatch reduction techniques was listed, however, was not listed in depth in order to be concise. The purpose of this appendix is to explore the evidence base available for potential guillemot and razorbill bycatch reduction methods in the UK in detail (long-list - Table C 1). This document also quantifies the success of each method including examples of previous trials and experiments and their impacts on bycatch and target catch rates.

2 Long-list of bycatch reduction methods

2.1.1.1 Table C 1 presents a long-list of potential gillnet fisheries bycatch methods for seabirds discussed in Wiedenfeld *et al*. (2015), Parker (2017) and other potential technologies.

Table C 1: Potential bycatch reduction methods in gillnet fisheries.

Thematic Category	Bycatch reduction method	Section of this document which contain further information
Net illumination	Light sticks on nets	3
	Lights of different colours (LEDs or UV)	3
Visual net modifications	Reflective nets/ materials in panels	5
	Mesh sizing	6
	Contrasting net panels/ rope in mesh	7
	Coloured/ high visibility nets/ materials	8 9
	Silhouettes or predator mimics placed in nets	10
	Moving/twisting elements or streamers	11
Above water methods Section	Net surface markers	12
	Kites or drones flown over net	12
	Raptor silhouettes	12
	Looming eyes buoy	13
Acoustic methods	Multi-frequency pingers	14
	Audio recordings of predators	N.A. data not available

Thematic Category	Bycatch reduction method	Section of this document which contain further information
Net type and setting	Low profile nets	15
	Tie downs to reduce profile of net	15 and 19
	Net height	16
	Depth at which net is set	16
	Hanging ratio	17
	Headline drops	N.A. data not available
	Net weights	19
	Altered float lines	19
Net operations	Adjust setting and hauling times	20
	Soak times	21
	Nocturnal setting	22
	Net sensors (alarm, light)	22
	Net-checking frequency	22
Operational fishing measures	Area and seasonal closures	23
	Gear-switching/ restrictions	24

3 Net Illumination

3.1 Bycatch reduction method and how it works

3.1.1.1 Two methods for net illumination have been suggested for their use as a bycatch reduction strategy in gillnet fisheries, namely, the use of light sticks (e.g., chemical light sticks) on nets and the use of LED or UV coloured lights (Wiedenfeld *et al.*, 2015). Net illumination in gillnets has been tested in numerous studies, at multiple locations worldwide for its effects on reducing bycatch for species including marine mammals, turtles and seabirds.

3.1.1.2 Chemical light sticks have been used in fishing practices for luring fish (e.g., swordfish) with a higher catch rate of swordfish recorded when attaching light sticks to the branchlines of longlines (Freeman, 1989; Ito *et al.*, 1998; Bigelow *et al.*, 1999; Witzell, 1999; Hazin *et al.*, 2002, 2005; Tüzen *et al.*, 2013). However, they have also been shown to potentially reduce bycatch of species such as sea turtles by 60% whilst having no significant impact on target catch and catch value (Wang *et al.*, 2010).

3.1.1.3 Alternatively, the impacts of using LED or UV coloured lights have been tested in a number of studies for bycatch reduction of species including sea turtles and seabirds. Colour and light levels are chosen according to species (Patrick and Poulton, 2007; Wiedenfeld *et al.*, 2015) however little is known about what colours are best used for seabirds (Martin and Crawford, 2015).

3.1.1.4 Chemical light sticks are simpler and cheaper than LED lights, however, are not reusable and are limited to fisheries with short soak times due to their limited life of only a few hours (Patrick and Poulton, 2007). Compared to LED lights which can be expected to last approximately 3 years (Mangel, 2015) and require the replacement of batteries on a monthly basis (Wang *et al.*, 2010) or can be powered through remote power supply/ solar (Patrick and Poulton, 2007). UV lights have been trialled (Milliken and Wang, 2013; Mangel, 2015), however are unlikely to be useful for seabird bycatch rates as there is no evidence that amphibious bird species can see UV lights (Martin and Crawford, 2015).

3.1.1.5 Lights can be attached at intervals (e.g., every 10 metres) along the net's floatation line as a sensory cue in order to alert species to the presence of fishing gear in the water (Mangel *et al.*, 2018; Bielli *et al.*, 2020). The use of lights has been tested on different types of gillnets including driftnets and bottom set nets with similar results of a decrease in sea turtle and seabird bycatch as a result of implementing this method (Mangel *et al.*, 2018; Bielli *et al.*, 2020). The results from these studies and other studies are described in further detail in Sections 3.2 and 3.3 of this report. Figure C 1 shows how an experiment was set up, conducted in small-scale fishing vessels in Peru between 2015 and 2018, using LED lights on driftnets versus a control net for assessing the impacts of illumination on bycatch.

3.2 Success from trials to date for chemical light sticks

3.2.1.1 There are limited studies conducted into the use of chemical light sticks to reduce bycatch in gillnet fisheries. Wang *et al.*, (2010) found that placing chemical light sticks every 5m along nets in nights trials in Mexican coastal fisheries did not impact the target catch rate but decreased sea turtle bycatch by 59%.

3.2.1.2 However, light sticks have a short lifespan, working for approximately 12 hours and are non-reusable (Ito *et al.*, 1998; Stone and Dixon, 2001; Poisson *et al.*, 2010). Chemical light stick litter is considered the largest source of plastic waste from underwater fishing lights (Nguyen and Winger, 2018), with thousands being discarded into the ocean each day. For example, approximately 7,000 discarded light sticks were collected within 90km of the northern coast of Bahia State, Brazil (Oliveira *et al.*, 2014). This constitutes a potential toxicant to marine flora and fauna (Poisson *et al.*, 2010) and therefore using light sticks within fishing operations could contribute to the risk of plastic waste. This ultimately has negative consequences on the environment and human health as evidence has shown that many animals, including seabirds, whales and turtles die as a result of plastic pollution (Nguyen and Winger, 2018).

3.3 Success from trials to date for coloured LED or UV lights

3.3.1.1 Martin and Crawford (2015) reviewed seabird perceptual and sensory capability to identify potential bycatch reduction methods in gillnet fisheries. The majority of gillnet-susceptible birds are likely to be visually guided foragers, therefore based on Martin and Crawford (2015) analysis, birds whilst underwater are most likely to detect visual alerts such as lights and highly visible netting. Therefore, visual deterrents such as these are a potential means to reduce seabird bycatch (Melvin *et al.*, 1999; Mangel *et al.*, 2018).

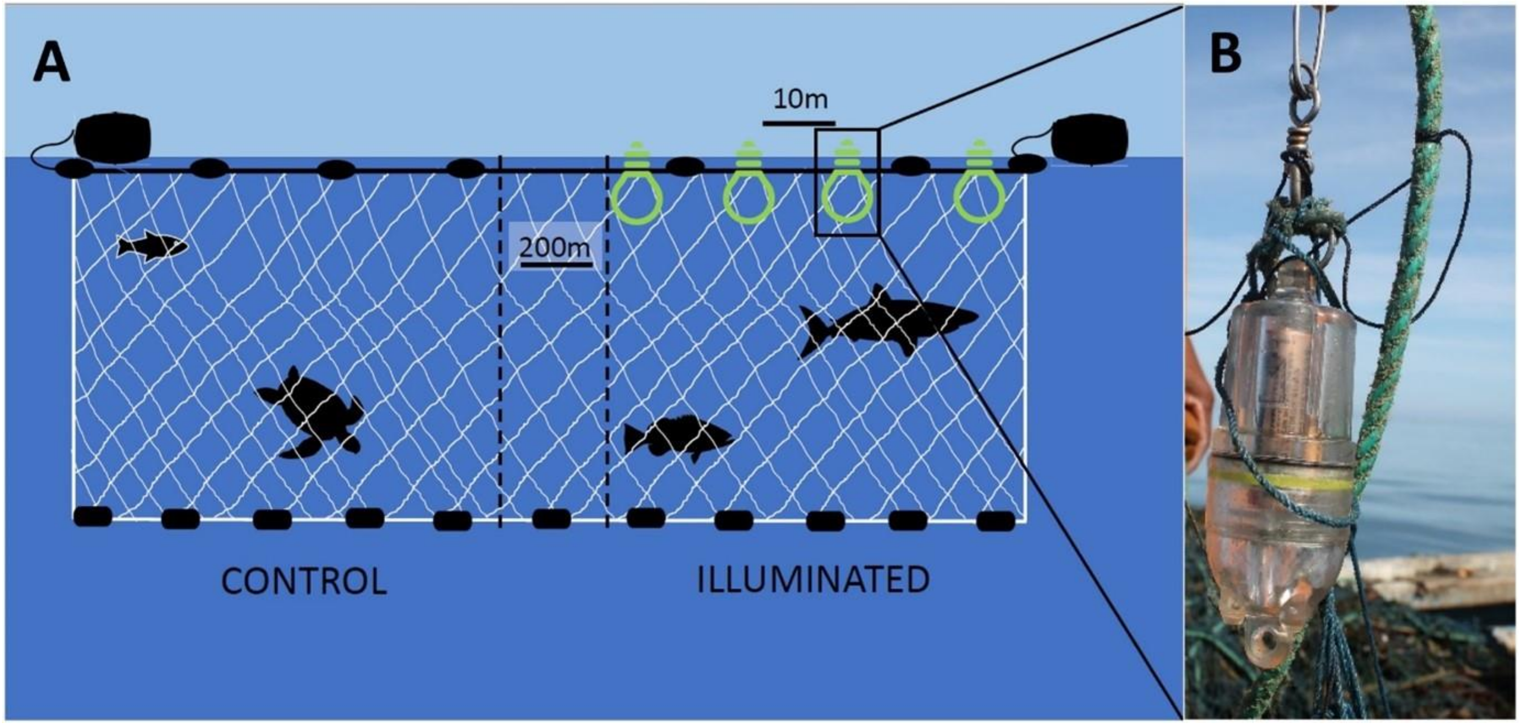

Figure C 1: Experimental design using driftnets undertaken between 2015 and 2018 in small-scale fisheries in Peru: paired control and illuminated nets (A) and an example of LED used in the experiment (B) (image taken from Bielli *et al.*, 2020).

3.3.2 Bottom set gillnet illumination experiment, Peru

3.3.2.1 Mangel *et al.* (2018) conducted gillnet bycatch reduction experiments in small-scale fisheries in Sechura Bay, Peru from 2011 to 2013. The experiment compared 114 pairs of control and illuminated bottom set gillnets, where the latter were equipped with green LEDs placed every 10m along the float line. Nets were deployed in the late afternoon and retrieved the following morning. Results showed that illuminated nets caused a decline in bycatch rate of guanay cormorants of 85.1% compared to the control.

3.3.2.2 Despite the large decrease in cormorant bycatch, the study recorded an increase in the numbers of Peruvian Boobies caught in illuminated nets, however this number was very small (four individuals) therefore no conclusions could be drawn on this in the analysis.

3.3.2.3 At the same fishery, a previous study has been conducted by Ortiz *et al.* (2016), finding that net illumination reduced green sea turtle bycatch by 63.9%. This study also measured the catch per unit effort of the fisheries target catch, namely, guitarfish, flounders and rays, finding that using illuminated lights had no impact on their catch rate.

3.3.3 Driftnet illumination experiment, Peru

3.3.3.1 Bielli *et al.* (2020) conducted a study between 2015 and 2018 with Peruvian NGO ProDelphinus, deploying LEDs on the float lines of paired gillnets (control vs illuminated) during 864 fishing sets on small-scale vessels departing from three Peruvian ports. Their study showed that target fisheries species catch per unit effort was not negatively impacted by the use of LEDs.

3.3.3.2 Where seabirds were bycaught, this consisted predominately of the following species; white-chinned petrel, Humboldt penguins and pink-footed shearwaters. This bycatch occurred in driftnets, with no interaction recorded with bottom set nets during this trial. Seabird entanglement was rare (99% of sets had zero seabirds recorded) so no conclusions could be drawn on the effects of net illumination on seabird bycatch rates. However, mean nominal bycatch per unit effort was calculated and showed a decrease in seabird bycatch of 84.0% when nets included LED lights. This result is similar to that found by Mangel *et al.* (2018) for bottom set gillnets.

3.3.4 Gillnet fisheries experiment, Baltic Sea

3.3.4.1 Field *et al.* (2019) conducted an experiment using high contrast panels and lights on gillnet fisheries in the Baltic Sea. Alongside the use of constant green battery-powered LED lights (model YML-1000, YM Fishing, Korea), they also recorded the impact flashing white battery-powered LED lights (Fishtek, Devon, UK) had on seabird bycatch. Figure C 2 shows the setup of these nets.

3.3.4.2 The experiment consisted of each treatment net being paired with an identical control net. The study was conducted in relatively turbid coastal fisheries, where visibility is likely to be limited for foraging animals. Constant green lights were tested in the Polish Baltic during the winter fishing season of 2016 and 2017, whilst the flashing white lights were tested in the eastern Baltic off of the coast of Lithuania during the winter of 2017/18 only.

3.3.4.3 Results showed that constant green net lights had no impact on the fish catch in this area. The total bird bycatch was 98 birds in 78 net deployments, with the majority of these being long-tailed ducks. Similar numbers of birds were caught in the control and illuminated nets therefore, green lights had no significant effect on bycatch during this experiment.

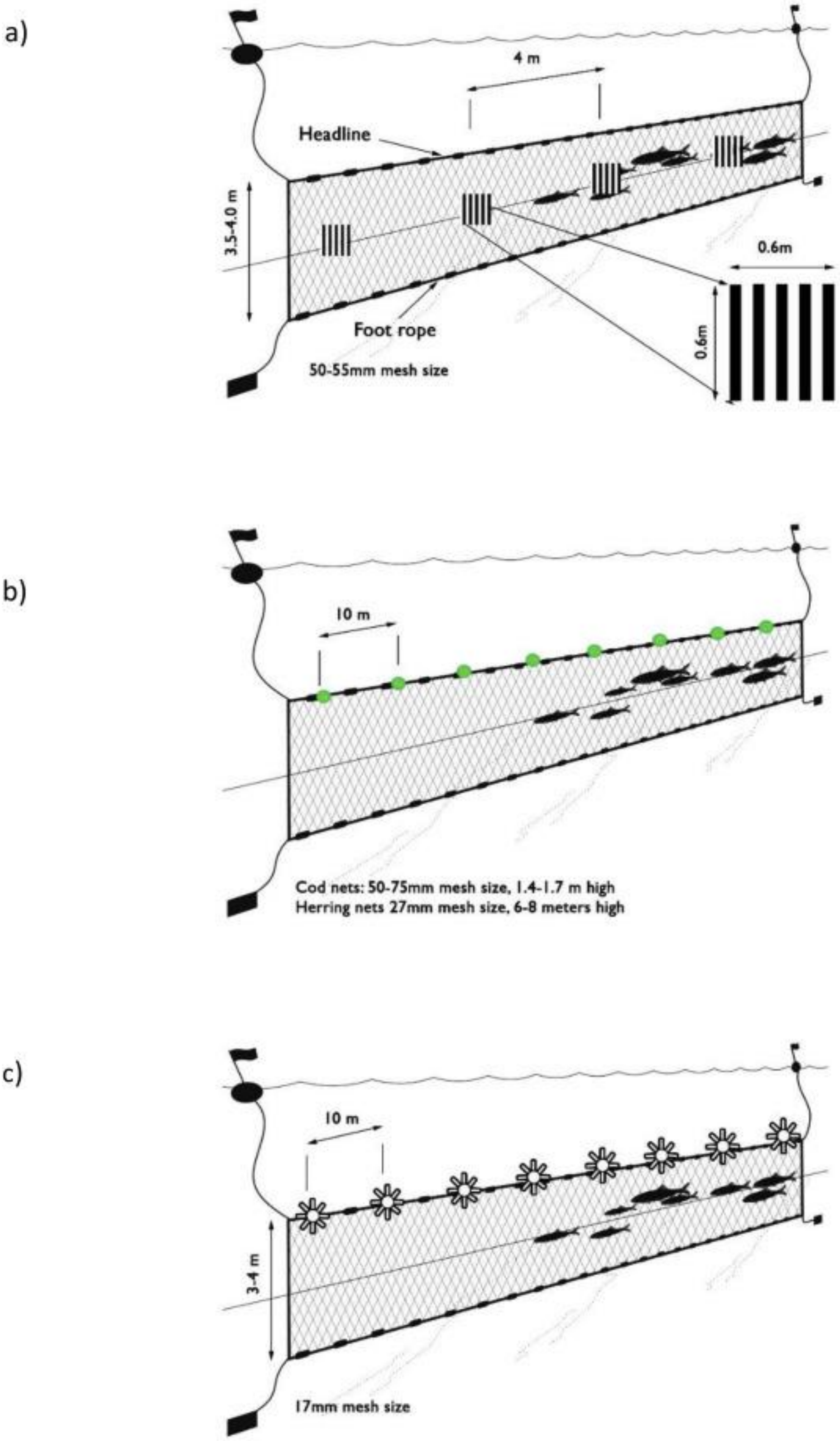

Figure C 2: Bycatch reduction measures trialled in the Baltic Sea. a) Contrasting panel used in Lithuanian bycatch reduction trails. Panels measured 0.60 x 0.60 m and were attached every 4m along each net, equidistant from the head and bottom lines; b) Green constant lights used in Polish trials, every 10m along the headline; c) Flashing white lights, used in Lithuanian waters, every 10m along the headline (taken from Field *et al.*, 2019).

3.3.4.4 Flashing white net lights were tested in smaller mesh smelt nets during 39 deployments. Fish catch with the presence of white lights showed a mean change of 10.4% between illuminated and control nets, however, was not statistically significant. The total bird bycatch was 50 birds, with the majority being long-tailed ducks. There was an increase in bycatch of all birds whilst using flashing white lights on nets indicating that these had negative impacts on bird bycatch.

3.3.4.5 Overall, neither of the most commonly caught species in the Baltic Sea region, namely, long-tailed ducks and velvet scoters, were deterred from nets using constant green or flashing white lights. Although use of lights in this bycatch reduction experiment was unsuccessful, here the deterrents were tested predominately on sea ducks which primarily exploit tactile information to detect benthic prey in waters of low visibility (Madge and Burn, 1988; Livezey, 1995). Mangel *et al*. (2018) and Bielli *et al*. (2020), however tested deterrents on visual pursuit predators (e.g., cormorants and penguins) which may be more applicable to the behaviour exhibited by guillemot and razorbills.

3.4 Conclusion of trials

3.4.1.1 There are currently no studies of the use of light sticks on seabird populations. Whereas for LED lights, there were a number of studies conducted on differing seabird species and locations. These studies found mixed results. Although these studies do not directly measure the applicability of using illuminated nets as a bycatch reduction method for guillemot or razorbill, the studies on using LED lights show that there is a potential to decrease pursuit diver bycatch, whereas sea ducks appear to be unaffected by lights. All of the studies above, with the exception of using white flashing lights by Field *et al*. (2019), show that target fish catch is not significantly impacted by using lights.

3.4.1.2 The reason for the decrease in bycatch of pursuit divers is likely to simply be that net illumination increases the visual signature of the gillnets, therefore allowing seabirds to better avoid them and reduce entanglement rates (Melvin *et al*., 1999; Trippel *et al*., 2003; Martin and Crawford, 2015). This method has also been shown to reduce bycatch across multiple species, therefore could derive multiple benefits, not only for auks, but at a multi-taxa level and across a range of fisheries at a reduced cost and eased implementation (Bielli *et al*., 2020). However, it must be noted that lights are unlikely to help reduce seabird bycatch during the daytime at surface-set nets (Parker, 2017) as light levels are already high, therefore, this technique may be location and fishery type dependent and it must be considered that lights may impact the retinas of species and the impacts of using lights on the surrounding ecosystem is largely unknown.

3.5 Effects of using light sources on species

3.5.1.1 Although the use of light sources has been demonstrated to reduce bycatch across multiple taxa, their use may affect the adaptation of the vertebrate retina to ambient light levels (Martin and Crawford, 2015). When foraging in dark conditions (i.e., at night or at depth) the retina has a high degree of dark adaptation. The eye takes a relatively long period to readapt to ambient light levels (Warrant, 2008) and when it is not properly adjusted, the eye will have lower resolving power. Exposure to illuminated nets in dark conditions may therefore produce a rapid reversal in the adaptation of the retina, resulting in longer term impairment. This in turn is likely to decrease the probability that parts of the net not illuminated will be less visible, which could negatively impact bycatch rates for non-illuminated nets.

3.6 Practicality and availability of trialling in the UK

3.6.1.1 Previous trials have found that disposable chemical light sticks cost between $0.10-1.00 per stick (Wang *et al*., 2010; Wiedenfeld *et al*., 2015) and require replacing every 24 hours.

Whereas using LED lights may be a relatively easy method of bycatch reduction to implement at a reduced cost compared to other methods (Bielli *et al.*, 2020). The lights used in the study by Ortiz *et al.* (2016) were approximately $10 per LED, to initially equip a 2km length gillnet would therefore cost around $2,000 for LEDs spaced 10m apart. Comparing this to pingers which would cost approximately $2,600 to cover the same area (spaced 100m at $130 per pinger). This cost could be further reduced in fisheries where the optimal spacing between lights is higher (e.g., 15m in Virgili *et al.*, 2018).

3.6.1.2 In the UK, FishTek Marine produce net lights that are compact (165mm x 47mm x 37mm) and lightweight with an in-water weight of just 25g. The NetLight devices have a guaranteed depth rating of over 1,200 metres and are designed to provide 500-800 hours of light. These qualities will allow ease of use by fishermen, therefore may be feasible for large scale deployment as a compensation measure.

3.7 Conclusion

3.7.1.1 The use of chemical light sticks on nets is impractical. They require replacement every 24 hours, therefore would be ineffective on nets with longer soak times and result in the disposal of large amounts of plastic waste. The use of chemical light sticks therefore, is not recommended to be taken through to trialling stages.

3.7.1.2 The use of LEDs on nets has been shown to be effective at reducing bycatch of pursuit divers in bottom set gillnet fisheries (Mangel et al., 2018), whilst also maintaining catch of target fish species. Once attached to nets, limited effort would be required by fishermen as battery life is long lasting. The method is available to be trialled through Fishtek Marine in the UK, therefore this technique will be trialled for its effects on guillemot and razorbill bycatch in static gillnet fisheries.

4 Visual Net Modifications

4.1.1.1 The materials used in nets has been shown to be an important factor for regulating bycatch (Österblom *et al.*, 2002). The introduction of inconspicuous monofilament nylon nets for fishing has led to a significant increase in seabird mortality (Evans and Nettleship, 1985; DeGange *et al.*, 1993) and may be as a result of the *alcid* family being visual predators (Gaston and Jones, 1998).

4.1.1.2 Therefore, multiple bycatch reduction methods of visual net modifications have been proposed in order to make nets more conspicuous in order to reduce bycatch in gillnet fisheries. These methods include; use of reflective material, changing of mesh sizes, contrasting net panels and coloured nets (Wiedenfeld *et al.*, 2015). The following describes how each of these methods, and other visual net modifications may be incorporated into fishing practices.

5 Visual net modifications: Reflective material

5.1 Bycatch reduction method and how it works

5.1.1.1 Two differing techniques of using reflective material to reduce bycatch in gillnet fisheries have been proposed; use of reflective netting and use of reflective material woven into panels (Wiedenfeld *et al.*, 2015).

5.1.1.2 Nets with better sound reflectiveness to target marine mammal bycatch were developed in 1999 (King and Holy, 2003). This has since been developed so that monofilament nets can be treated with barium sulphate. This results in nets being a dyed pale blue colour making them less transparent and stiffer than monofilament nylon nets (Trippel *et al.*, 2003). Although this method was developed in order to make nets more acoustically reflective for marine mammals, studies have found it also reduces seabird bycatch, as it is likely to increase the visibility of the netting (Trippel *et al.*, 2003).

5.2 Success from trials to date

5.2.1 Demersal gillnet fisheries experiment, Canada

5.2.1.1 Between July to September 1998 and 2000, an experiment was conducted on eight commercial demersal gillnet fisheries on the east coast of Canada (Trippel *et al*. 2003) in a region with previous high incidental catches of harbour porpoise (Trippel *et al.*, 1996). The experiment was conducted using two types of nylon monofilament gillnet, one of which was used as a control with strands made of 100% nylon and the other of which the strands contained fine barium sulphate particles and was dyed pale blue to mask the white opaque colour. Each gillnet string was roughly 300m long and 4m deep with a stretched mesh size of 15cm and were set at 100m depth.

5.2.1.2 Results showed that there was no difference between the control and experimental reflective nets in the catches of commercial fish species, namely, cod, pollock, haddock and spiny dogfish.

5.2.1.3 Although the experiment was to predominately study the effects of reflective nets on the bycatch of harbour porpoise, results found that there was an 80% reduction in shearwater bycatch in reflective strings (Trippel *et al.*, 2003). The impacts of reduced seabird bycatch is likely to be as a result of the stiffness (Koschinski and Strempel, 2012) or increased visibility of the blue opaque net (Lythgoe, 1979) rather than the acoustic reflectively of the nets.

5.2.2 Franciscana bycatch experiment, Argentina

5.2.2.1 Experimental trials were conducted in a gillnet fishery in Buenos Aires, Argentina (Bordino *et al.*, 2013). The experiment used monofilament nylon material to construct webbing for three types of gillnets; control, reflective and stiff, manufactured in China. Each net consisted of two 50m panels of 140mm stretched mesh nylon monofilament net with a rigged height of 3.5m. The trials included three fishing boats, equal number of strings of each net type were deployed per trip with nets set 100 to 300m apart.

5.2.2.2 Results showed there was no difference in the bycatch rates of franciscana or of the target fish catches among the three net types. Although no bycatch was reduced, this experiment further supports Trippel *et al.* (2003) that reflective nets do not impact target fish catch.

5.3 Conclusion

5.3.1.1 There is limited research of the effects of reflective netting for reducing seabird bycatch, with only one research study, which showed successful results, having been conducted on seabirds, and two experiments showing that the use of reflective nets do not change target fish catch. Further research may be needed on their effects to seabird bycatch before being used on a large scale (Koschinski and Strempel, 2012).

5.3.1.2 As the use of reflective nets is a visual technique to reducing seabird bycatch, it is unlikely to be successful in deeper waters. Net colour is unlikely to be useful for fisheries where nets are set at night or in demersal nets at depths below the photic zone, as colour vision is not possible in low light, therefore Martin and Crawford (2015) concluded that there is unlikely to be any advantage of including colour into netting as light levels are likely to be very low in fisheries. Therefore, this method will not be taken forward to trialling as it may only be useful in limited fishery types.

6 Visual net modifications: Mesh sizing

6.1 Bycatch reduction method and how it works

6.1.1.1 Mesh size and depth have been shown to be important factors for changes in bycatch rates across numerous taxa (Pechham *et al.*, 2007; Žydelis *et al.*, 2009; Orphanides, 2010; Cosgrove *et al.*, 2016). Larger mesh sizing has been linked to increased rates of bycatch for species of turtle (Murray, 2009), cetacean (Orphanides, 2010) and seabird (Dagys and Žydelis, 2002). However, for harbour porpoise (Orphanides, 2010) and species of seabird (Ainley *et al.*, 1981) bycatch rates may decline again once the mesh size exceeds a certain threshold. Considering that different sized mesh are used to target different fish species, it is therefore unsurprising that the mesh size would also impact non-target species (Luck *et al.*, 2019).

6.1.1.2 A guillemot head on average measures 35mm in diameter (Oldén *et al.*, 1988) with observer data and fisher reports suggesting that bird captures are lower in smaller meshes (finer than 35mm; Stempniewicz, 1994) and increasing mesh sizes from 25 to 60mm increases bird capture rates dramatically (Dagys and Žydelis, 2002). Therefore, in the salmon gillnets, cod gillnets and set gillnets for flounder and turbot in Swedish fisheries (Högberg, 1993) pose major threat to guillemot populations (Österblom *et al.*, 2002) due to netting mesh sizes used and this is likely to be the case elsewhere globally.

6.1.1.3 It is therefore proposed that changing mesh sizes may change the impacts to seabird bycatch.

6.2 Success from trials to date

6.2.1 Bycatch of seabirds in bottom set gillnet fisheries, Norway

6.2.1.1 A study conducted by Bærum *et al.* (2019) presented seabird bycatch data from a 10-year time-series (2006-2015) of fisheries data from small-vessels fishing with gillnets designed to fish close to the sea bottom (however, could be set closer to the surface with the use of buoys) along the Norwegian coast. High rates of incidental bycatch were recorded with estimated annual bycatch of between 1,580 and 11,500 birds in this fishery. 43% of the bycatch comprised of surface-feeding seabirds such as northern fulmar, with the highest number of diving seabirds caught being guillemot and the third numerous being razorbill.

6.2.1.2 For both surface feeding and diving seabirds, there was no clear effect of mesh size on bycatch. Therefore, no evidence to support changing mesh sizes as a possible seabird bycatch reduction approach from this study.

6.2.2 Lithuanian waterbird bycatch, 2001-2002

6.2.2.1 Seabird bycatch have been shown to be impacted by mesh sizing in studies (e.g., Žydelis *et al.*, 2009). Steller's Eider, red-throated diver and black-throated divers were found to be the most threatened species to inshore gillnet fisheries in Lithuanian coastal waters with larger mesh sizes, particularly salmon nets (>60mm mesh size) posing the greatest threat to wintering birds (Dagys and Žydelis, 2002).

6.2.2.2 Dagys and Žydelis (2002) studied the effect of mesh sizes on wintering birds using three mesh sizes; 1,825mm, 5,060mm, >60mm. Gillnets with the smallest mesh size had an entanglement rate of 0.35, medium mesh; 0.62 entanglement rate and the largest mesh size having a rate of 1.8 birds/1,000 net meter days. Therefore, the largest mesh size (>60mm) were almost three times more effective at catching birds than medium-sized mesh and more than five times more effective than nets with small-sized mesh.

6.2.2.3 Salmon nets (>60mm) were found to have greatest impacts on seabird bycatch, therefore restrictions (e.g., seasonal or spatial) would be beneficial to minimise the threat posed by these nets for the most vulnerable species. However, restrictions should be specific enough to not cause a considerable decrease in fisherman profits.

6.3 Conclusion

6.3.1.1 The example given of Lithuanian fisheries, alongside research conducted in Latvia (Urtans and Priedneiks, 2000) and the USA (Bianchi, 2002) found that smaller mesh sizes reduced seabird bycatch and may therefore indicate that smaller mesh sizes are likely to be more visible to seabirds (Quayle, 2015). Although there are numerous studies demonstrating the impacts of mesh size on bycatch of seabird species, there are limited fisheries globally that have actually implemented this method for reducing bycatch. There is at least one area known to regulate mesh size to minimise turtle bycatch (Murray, 2009), however there are a number of reasons why this is often not a feasible bycatch reduction option:

- Changes to mesh sizes may reduce bycatch of the target vulnerable species, however, may shift the affect to other species making them more susceptible to being bycaught (Northridge *et al.*, 2016);
- Mesh size changes may result in the retention of undersized fish (Northridge *et al.*, 2016) which could result in negative ecological consequences; and
- May reduce the catch of target fisheries species (Northridge *et al.*, 2016).

6.3.1.2 As a widespread measure it is unlikely to reduce bycatch of species whilst also maintaining commercial levels of fish catch and if enforced, in some fisheries, could result in spatial or seasonal closures or restrictions (Northridge *et al.*, 2016). The effects of closures and restrictions are further explored in Section 23. Although this method may reduce seabird bycatch, it would likely negatively impact fishermen efforts and catch and may increase bycatch of other species. Therefore, changing mesh size does not meet the criteria outlined by O'Keefe *et al.* (2012) for successful bycatch reduction techniques so will not be taken forward to trialling stage.

7 Visual net modifications: Contrasting net panels

7.1 Bycatch reduction method and how it works

7.1.1.1 Martin and Crawford (2015) propose the use of contrasting net panels 'warning panels' in the surface of gillnets. In order to increase visibility of netting to seabirds at range of light levels without causing negative implications to species retina or without reducing target fish catch rate, warning stimuli need to be relatively large and/or have high internal contrast (Martin and Shaw, 2010; Summers and Dugan, 2001). High contrast grating stimulus panel, such as equally spaced black and white stripes, that meet a 100 min of arc threshold will be visible from a distance of 2m. The stripes or the squares of the chequerboard pattern should have a 60mm width and the whole panel should contain at least 10 stripes/ 100 squares. This is demonstrated in Figure C 3.

7.1.1.2 Although this may seem highly conspicuous in daylight to humans, 60mm is relatively small compared to many fish prey of auks and other seabirds. Therefore, this design contains the basic spatial element of the smaller kinds of prey that these birds take. These panels would be well spaced and are not likely to disproportionately reduce the catch of fish by more than the surface area taken up by the panels (≈2.5%).

7.1.1.3 For larger fish, such as tuna, panels would be detectable and could therefore, warn off this species from being caught in nets. This may be especially problematic in gillnet fisheries that target species such as tuna. However, results from tests are needed in order to assess the impact that this bycatch reduction design has on target fish catch and bycatch species.

7.1.1.4 Studies are currently still underway in Chile (Bielli *et al.*, 2020) to test the Martin and Crawford (2015) warning panel design specification. However other studies have been conducted using similar warning panel specifications elsewhere (e.g., Field *et al.*, 2019).

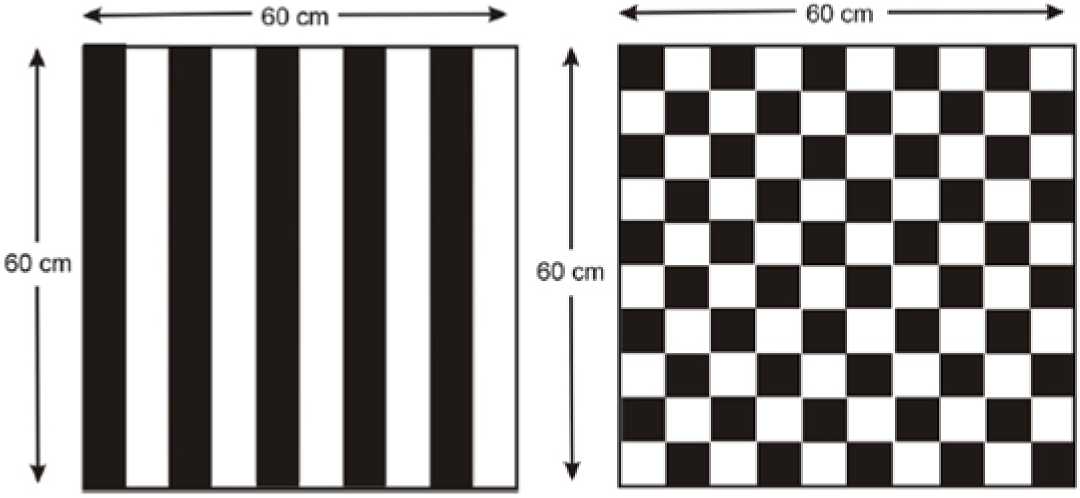

Figure C 3: Examples of a grating and chequerboard patterns of high contrast recommended for use as stimulus warning panels. The overall dimensions are indicated, the dimension of individual elements, stripe widths and sides of squares are 6cm (taken from Martin and Crawford, 2015).

7.2 Success from trials to date

7.2.1 Warning panels in gillnet fisheries, Baltic Sea

7.2.1.1 Field *et al.* (2019) conducted net panel trials in the winters of 2015/ 2016 and 2016/17 in a cod fishery off of the west coast of Lithuania and Curonian Spit. Paired tests were conducted in multiple monofilament nylon gillnets. The paired tests consisted of one control and one experiment net using the high visibility net panel design in Martin and Crawford (2015). Panels measured 0.6mx0.6m and were composed of oriented alternate black and white stripes made of nylon attached every 4m along the net and centrally in the vertical plane (Martin and Crawford, 2015).

7.2.1.2 151 experimental net deployments resulted in 129 birds being caught, 74 in the control sets and 56 in the experimental sets. Results showed that significantly contrasting net panels had no effect on target fish catch but also were not an effective means of reducing current bycatch rate, with long-tailed duck bycatch increasing when net panels were deployed.

7.2.1.3 Melvin *et al.* (1999) found that using high visibility meshing reduced seabird, including guillemot, bycatch rates in Puget Sound. The trials conducted in the Baltic Sea were in relatively turbid coastal fisheries, similar to that of Puget Sound, where visibility for foraging animals is likely to be limited. However, this study was different in that it was focused on bottom-set gillnet fisheries and their interactions with sea ducks, rather than driftnets and diver species as was Melvin *et al.* (1999). Therefore, this may explain why the results during this study do not confirm that increased net visibility results in lower bird bycatch.

7.2.2 Warning panels in gillnet fisheries, Portugal

7.2.2.1 Trials were carried out in autumn/winter 2016-17 when bycatch of auks is most critical in this area in small-scale fisheries using primarily single panel gillnets rather than trammels (Almeida *et al.*, 2017). Each vessel deployed one set of nets with panels and one control set per trip. Panels followed the striped specifications laid out by Martin and Crawford (2015) and were attached centrally on the net every 4 metres.

7.2.2.2 Results showed that contrasting net panels did not significantly change the volume of fish catch compared to the control gillnets, therefore this study provides evidence that this bycatch reduction technique would not negatively impact fisheries catches.

7.2.2.3 Although razorbill are reported as bycatch in Portuguese gillnet fisheries (Oliveira *et al.*, 2015; Vingada *et al.*, 2012; Teixeira, 1986; Granadeiro *et al.*, 1997), no birds were caught in the control or experimental sets therefore, no conclusions can be made here on the impacts of warning panels on razorbill bycatch (Almeida *et al.*, 2017).

7.2.2.4 This study was conducted on a small scale therefore results should be taken with caution.

7.3 Conclusion

7.3.1.1 There are currently limited studies assessing the effects of using contrasting net panels as a bycatch reduction technique in order to reduce seabird bycatch. Preliminary tests of Martin and Crawford (2015) warning panel design in 2015/16 in Lithuania showed that numbers of birds caught were lower in nets with panels, however this was not a statistically significant decrease (Almeida *et al.*, 2017). Studies in the Baltic since this have not shown there to be any decrease in bycatch in netting with warning panels, therefore suggesting this technique is unlikely to be an effective means of reducing current bycatch rates (Tarzia *et al.*, 2017). However, both studies showed that the warning panels did not impact target fish catch.

7.3.1.2 With limited studies conducted on this method and the results of the Baltic Sea study being predominately relatable to sea ducks rather than pursuit diving auk species, further trials are needed in order to confirm the likely impact this bycatch reduction technique will have on reducing a range of seabird bycatch.

7.3.1.3 The use of visual net modifications, excluding lights, may only be useful in surface gillnet fisheries as light levels in fisheries are likely to be very low and therefore use of net colours and contrasting panels may not be detected by seabirds (Martin and Crawford, 2015). Therefore, this method will not be taken forward to trialling as it may only be useful in limited fishery types.

8 Visual net modifications: High visibility netting

8.1 Bycatch reduction method and how it works

8.1.1.1 Research into the use of high visibility netting as a bycatch reduction approach has been ongoing over the past few decades. Successful bycatch reduction of seabirds, including guillemot, have been recorded using high visibility sections of netting as early as Melvin *et al.* (1999).

8.1.1.2 The design of this bycatch reduction technique is based on the observation that the majority of bycatch occurred in the upper sections of the nets. This is particularly apparent when large numbers of auks drift towards nets via ocean currents and become startled by the float line and therefore dive in response (Melvin *et al.*, 1999). Therefore, by having more visible material in the upper meshes/ leader section of the net, it is hoped that auks will not dive in response and instead fly or jump in order to avoid the float line.

8.2 Success from trials to date

8.2.1 Impact of contrasting mesh panels on guillemot bycatch, Puget Sound

8.2.1.1 Melvin *et al.* (1999) examined the use of highly visible netting in the upper net, pingers, abundance-based fishery openings and time-of-day restrictions on bycatch of guillemot and Rhinoceros auklets in a salmon gillnet fishery in Puget Sound, Washington. The study was conducted between July and August, 1996 throughout normal fishing hours. In total 17 trips were completed, totalling 642 sets. Each trip included approximately one dawn, one dusk and three daytime sets.

8.2.1.2 Drift gillnets in Washington commercial salmon fisheries are made from single or multistrand monofilament nylon (approximately 0.5mm diameter) and appears almost invisible underwater. We compared traditional monofilament nets to two mesh panel treatments: 1) a monofilament net with the upper 20 meshes replaced with 127-mm white multifilament, nylon seine twine (1.8m of the upper net). 2) A monofilament net with the upper 50 meshes replaced with 127 mm white multifilament nylon seine twine (4.6m of the upper net) (Figure C 4).

8.2.1.3 From the 642 sets, 13,118 sockeye salmon, 258 guillemot, and 85 rhinoceros auklets were caught. Results showed that guillemot bycatch was reduced by 40% and 45% in the 50-mesh and 20-mesh trials, respectively, whereas bycatch of rhinoceros auklet was reduced only in the 50-mesh trials by 42%. These trends match the results from the preliminary work in 1995 (Melvin and Conquest, 1996). These studies show that nets modified with high contrasting panels can reduce seabird bycatch. However, this study also recorded a reduced rate of sockeye catch by more than half in the 50-mesh trial.

8.2.1.4 Fisheries are often quota driven rather than time. Therefore, if equipment that reduces bycatch is used, but results in a reduced catch rate of target species, fisheries will continue to fish for longer until quota is reached. This additional time will result in additional bycatches, assuming no gear will completely eliminate bycatch. Therefore, bycatch as a result may not overall decrease.

8.2.1.5 In comparison, the 20-mesh visible panel trials were similar at reducing bycatch of guillemot, whilst also maintaining fishing efficiency for sockeye. Figure C 5 below shows these results. This study therefore shows that thick white mesh panels incorporated into nets have been successful for reducing auk bycatch in drifting gillnets, it also found that the greatest single reduction in seabird bycatch (43%) can be achieved by limiting fishery openings to periods of high salmon abundance as this reduces the effort required to meet quota. Combining this with 20-mesh contrasting panels during periods of high fish abundance have the potential to reduce seabird bycatch by up to 70-75%.

8.2.1.6 These experiments resulted in the 20 mesh panel nets being legally mandated in the salmon driftnet fishery at Puget Sound (Washington Department for Fish and Wildlife, 2015).

8.2.1.7 Similar nets were trailed in the bottom-set Baltic cod gillnet fishery in Lithuania, in 2014. However, the study was small and there appeared to be no significant difference in bycatch levels (Almeida *et al.*, 2017).

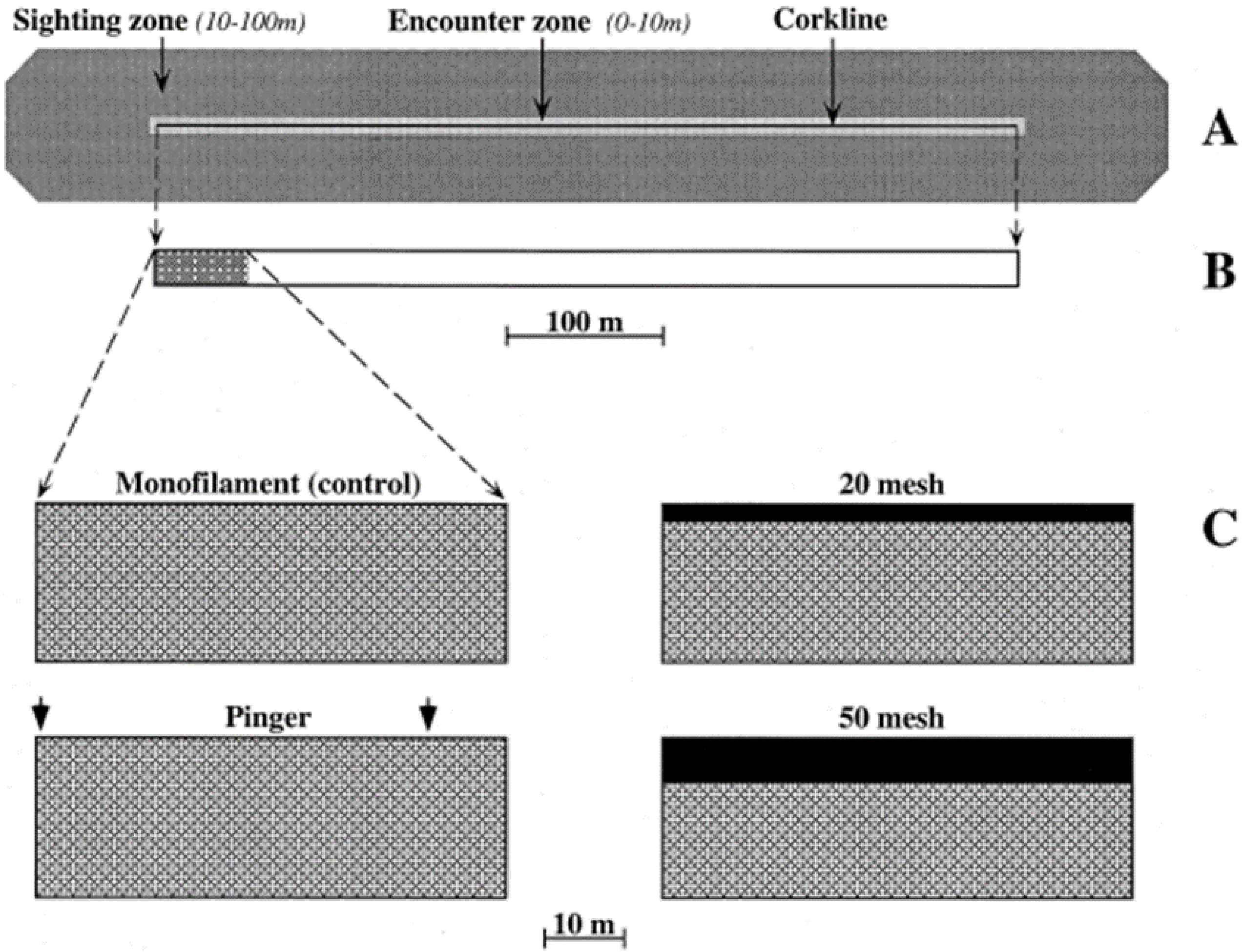

Figure C 4: Scale illustration of the drift gillnets used in this study: (a) to-scale overview (i.e., surface of the water) of the net (corkline) and surrounding seabird observation zones (encounter and sighting) (see text for complete descriptions); (b) to- scale elevation (i.e., underwater at 90o) view of the net; (c) expanded elevation view of the experiment setups: monofilament control, visual alerts (20- and 50-mesh), and acoustic alerts (pingers). Each net was a single treatment (taken from Melvin *et al.*, 1999).

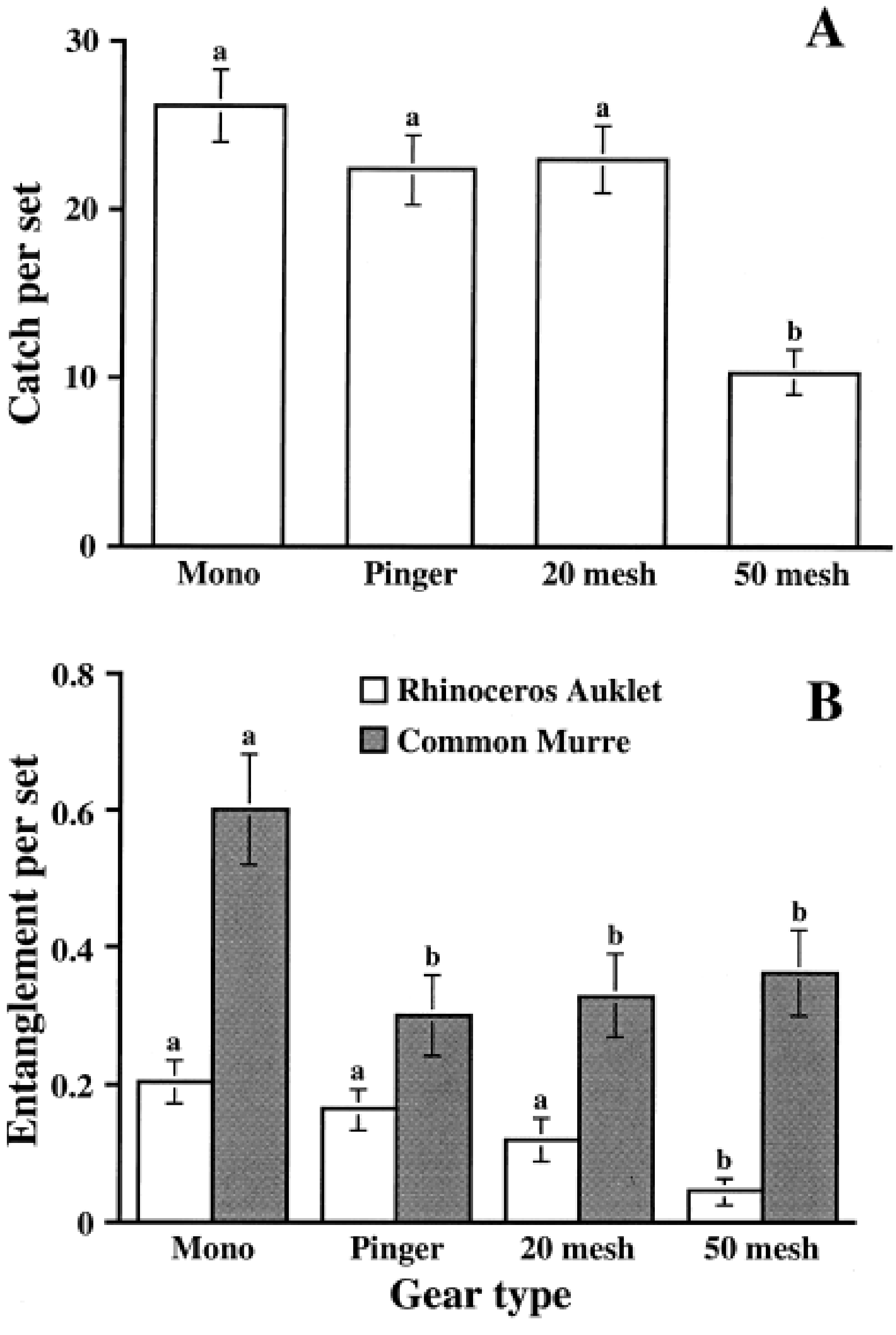

Figure C 5: Effect of gear modification on mean salmon catch and seabird entanglement per set: (a) sockeye salmon and (b) seabirds. Within-species significant differences as calculated by post hoc contrasts (at least *p* < 0.05) are indicated by lowercase letters. Error bars are standard errors (taken from Melvin *et al.*, 1999).

8.2.2 Net panels in Salmon fisheries, Flamborough and Filey Coast

8.2.2.1 In 2010 a byelaw was passed on small-scale fishing boats using J-shaped gillnets in order to catch salmon and trout. The law stipulates that netsmen must:

- Release birds that get caught in the nets as soon as possible with minimal injury; and
- During the month of June;
    - Remove nets from the water from 9pm to 5am;
    - Tailpiece of net must be made out of high visibility, multifilament nylon and attached to the headpiece;
    - If the net is made from monofilament it must not exceed 70 metres in length; and
    - A net must not be left unattended in the water at any time.

8.2.2.2 If it becomes apparent that significant numbers of birds are being caught in the net, then steps should be taken to reduce this. These include (but not limited to);

- Implementing the steps above outside the month of June;
- Increase visibility of the net;
- Reset net in a different configuration;
- Reset net in a different location;
- Remove net temporarily; and
- Shooting and hauling the net.

8.2.2.3 The high visibility multifilament 'corline' netting is made from a dark coloured material and is used in the leader straight section of the J-shaped net (Figure C 6). The material is thought to make the net more visible underwater and therefore reduces bycatch. However, it is believed that it does not adversely impact the fish catch as netsmen have reported that it funnels fish into the curved monofilament end and potentially actually increases the fish catches.

8.2.2.4 Since the introduction of the byelaw in 2010, bycatch levels have declined and remained low with the exception of a rise in 2011, when increased numbers of seabirds were recorded foraging in the bay (Figure C 7).

8.2.2.5 Although it is apparent that the byelaw has led to the decrease in seabird bycatch, the relative importance that each measure (net attendance, modification of nets and temporal closures) has on this decrease and how these interact with other factors (e.g., weather, breeding population per year) is unknown due to no direct comparisons between modified and non-modified netting. Therefore, this report cannot evaluate the successfulness that introducing high visibility netting has to reducing bycatch. However, fishermen have reported that fewer birds are caught in the leader section compared to the curved section, therefore it may help to reduce bycatch. Also, due to there being no reported decrease in fish catch, it can be assumed this method has no negative implications on the fishing practices in this area.

Figure C 6: Corline netting (left) and monofilament (right) (taken from Quayle, 2015).

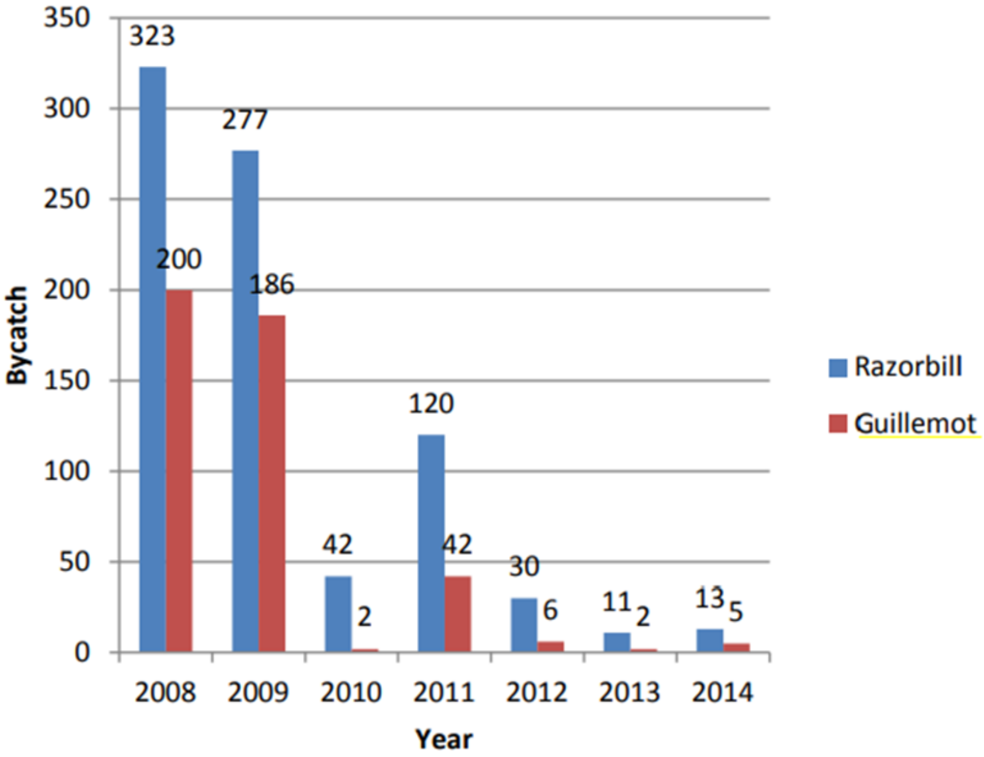

Figure C 7: Filey Bay season bycatch 2008-14. Figures for 2008 and 2009 were collated by ECON; monitoring discovered that all bycatch was not reported so figures were scaled based on recordings from other observers – averages are shown here. The monitoring period in 2008 and 2009 was longer extending into September. Figures from 2014 show bycatch from three days a week of monitoring only. It should be noted that the fishing season extends into August when Wold Ecology monitoring (2010-14) had ceased (taken from Quayle, 2015).

8.3 Conclusion

8.3.1.1 This method has been shown to be successful at reducing bycatch rates by Melvin *et al.* (1999) in a drift-net fishery and likely to have positively impacted bycatch rates by Quayle (2015), with both techniques showing no impacts to target catch, however other bottom set fisheries found no significant difference in bycatch levels (Almeida *et al.*, 2017). This method has been proven to reduce guillemot bycatch (Melvin *et al.*, 1999), without also decreasing fish catch rates, however no studies have been conducted into the effect on razorbill bycatch.

8.3.1.2 When light levels are poor, coloured nets are less effective, in a bottom-set cod gillnet fishery, white meshes in the upper 10% and 25% appear to have no effect on bird captures (Crawford, 2015). In order for this method to be successful light is needed for the white or coloured nets to be seen, therefore, this method is unlikely to be useful for use during night or in deep water fisheries (Trippel *et al.*, 2003; Žydelis *et al.*, 2013; Martin and Crawford, 2015) and success will be location dependent.

8.3.1.3 This method has been trialled in Filey Bay and therefore, may be available to trial elsewhere in the UK to gain quantifiable results. However, as the technique relies on visual capabilities of guillemot and razorbill and Martin and Crawford (2015) state that low light levels are likely in fisheries, it is unlikely that this bycatch reduction technique will be useful in a range of gillnet types, therefore, this method will not be taken through to trialling stage.

9 Visual net modifications: Coloured netting

9.1 Bycatch reduction method and how it works

9.1.1.1 Net colour is another potential bycatch reduction option, there are again limited studies investigating the use of coloured nets in reducing seabird bycatch. However, Martin and Crawford (2015) conclude there is unlikely to be any advantage of including an element of colour into netting as at low light levels, seabird visual systems are not capable of colour vision.

9.2 Success from trials to date

9.2.1 Captive penguins, coloured netting experiment

9.2.1.1 One experiment has been conducted on the use of coloured nets as a seabird bycatch reduction technique. Hanamseth *et al.* (2017) conducted a study using little penguins from a zoo in Australia and involved a repeated-measures design where they were exposed to a number of experimental treatments (green, orange and clear mono-filament gillnet mimics) and a control without any gillnet mimic.

9.2.1.2 Green and clear colours were used to mimic what is currently widely used in gillnet fisheries globally, and orange was chosen as other marine vertebrates (e.g., northern right whale) have been shown to be able to detect this colour at significantly greater distances than green coloured ropes (Kraus *et al.*, 2014).

9.2.1.3 Results found that collision rates were lower when nets used orange monofilaments (5.5% of encounters resulted in collision) compared to clear and green gillnets (35.9% and 30.8%, respectively).

9.2.1.4 In most foraging conditions, gillnets are visible to diving birds only at close ranges (Martin and Crawford, 2015). The results from this experiment indicate that orange netting may be detected from a greater distance than green or clear gillnetting by little penguins. Alongside these results, little penguins continually attempted to swim through the clear and green monofilament lines after collision, showing that there is a behavioural cognitive failure in identifying the danger of a hazard (Martin and Crawford, 2015).

9.3 Conclusion

9.3.1.1 There are a number of studies conducted into the use of high visibility netting and warning panels with high contrasting black and white panels in order to reduce seabird bycatch, however there are fewer studies conducted into the use of coloured netting. The study conducted by Hanamseth *et al.* (2017) was undertaken as an experiment in captive conditions, where pool waters were clear and nets could be easily seen in the water column. This is 1) unlikely to represent true conditions of gillnet fisheries at sea and therefore the results in this experiment should be taken cautiously and 2) gives no indication of the impact that using coloured nets has on target catch species or the bycatch rates of other vulnerable species.

9.3.1.2 The colour preference experiments have shown that in shallow waters with high light levels, seabirds are able to identify fine colour differences, with Martin and Crawford (2015) stating that in these conditions, bycatch seabird species may be able to make fine colour discriminations throughout the visible spectrum between 400nm and 650 nm. This experiment is therefore likely to be more effective in shallow water fisheries where light levels are higher, rather than at greater depths.

9.3.1.3 Currently little is known about the colours that are visible to seabird species caught as bycatch (Martin and Crawford, 2015). However, net colour is unlikely to be useful for fisheries where nets are set at night or in demersal nets at depths below the photic zone, as colour vision is not possible in low light, therefore Martin and Crawford (2015) concluded that there is unlikely to be any advantage of including colour into netting as light levels are likely to be very low in fisheries. Therefore, this method will not be taken through to the next stage of trialling.

10 Visual net modifications: Predator mimics in netting

10.1 Bycatch reduction method and how it works

10.1.1.1 Predator models such as scarecrows, raptor models and cat silhouettes are commonly used techniques in order to deter bird species, however often with variable success (Marsh *et al.*, 1992). The successful implementation of predator mimic deterrent devices often entail extensive investigations and modifications, such as adding in motion or sounds to enhance realistic characteristics (Wang *et al.*, 2010).

10.1.1.2 There are limited studies done into the use of predator mimics inside of nets to reduce bycatch, with no known studies conducted on the use of this methods for seabirds. Captive reared loggerhead turtle observations showed that shark shapes trigger an escape response which suggested that these could be used as a sea turtle deterrent in nets (Higgins, 2006). Wang *et al.* (2010) adapted these deterrents into commercial bottom gill net fisheries by placing simple shark cut-outs, made from a PVC sheet and painted black every 10m along the net and found that bycatch rates of green turtles were reduced by 54% in nets using a shark mimic.

10.2 Success from trials to date

10.2.1.1 There are limited studies done into the use of predator mimics inside of nets to reduce bycatch, with no known studies conducted on the use of this method for seabirds.

10.2.2 Shark mimic impacts on turtles in bottom gillnets, Mexico

10.2.2.1 Wang *et al*. (2010) tested the effects of using shark mimics on the bycatch of turtles and target catches along the Pacific coast of Mexico between 2006 and 2009. Two sets of experiments were conducted, a bycatch experiment measuring the impacts of mimics on turtles at Punta Abreojos and an experiment in a commercial bottom-set gillnet fishery at Bahia de los Angeles measuring the impacts of mimics on target fisheries catch.

10.2.2.2 Bycatch experiments were conducted at Punta Abreojos during daylight hours and included experimental nets with simple cut-out shark shapes, painted black and placed at 10m intervals along the length of the gillnet, as well as control nets with no shark mimics. Each shark shape had a fork length of 150cm, were 1.9cm thick and were weighed down by a lead plate in order to ensure negative buoyancy.

10.2.2.3 In the bycatch experiments, the shapes were suspended 60cm below an orange float which was attached to the surface-set net by 1.5m of line. This allowed the shape to float and not become entangled in the net. The control net contained only the orange floats and were attached every 10m (Figure C 8).

10.2.2.4 Experiments in commercial bottom-set gillnet fisheries were conducted in order to quantify the effects of shark mimics on target fish catch rates and the catch value. In these experiments, the same shark shapes were used but were adapted to attached to bottom-set gillnets. Instead of attaching the shapes to floats, they were attached directly to the net float line every 10m. Again, control nets used did not have a shark shape attached.

10.2.2.5 A total of 14 trials were conducted to examine bycatch impacts with a total of 133 green sea turtles captured, 85 in the control nets and 48 in the experimental nets. This showed that the presence of shark shapes significantly reduced the mean catch rates of green turtles by 54%.

10.2.2.6 Comparing this to the target fish catch experiments, a total of 22 pairs of nets were deployed in the commercial fishery. During these experiments, no sea turtles interacted with either net type. However, target fish species reduced by 45% when using shark mimics and the mean catch value also decreased by 47%. These results are shown in the Figure C 9.

10.3 Conclusion

10.3.1.1 There is currently limited research into the use of predator mimics in nets, especially related to reducing impacts to seabirds. Wang *et al*. (2010) showed that using shark mimics, bycatch of turtles was reduced, however target species catch of fisheries and catch value also reduced by significant amounts.

10.3.1.2 Successful implementation of such deterrent devices therefore often entails extensive investigation and modification in order to increase its impact on bycatch whilst minimising its effects to fish catch. In this case, suggestions of exploiting the difference between the sensory systems of sea turtles and fish species may be able to improve the selectivity of bycatch strategies (Swimmer and Brill, 2006; Southwood *et al.*, 2008).

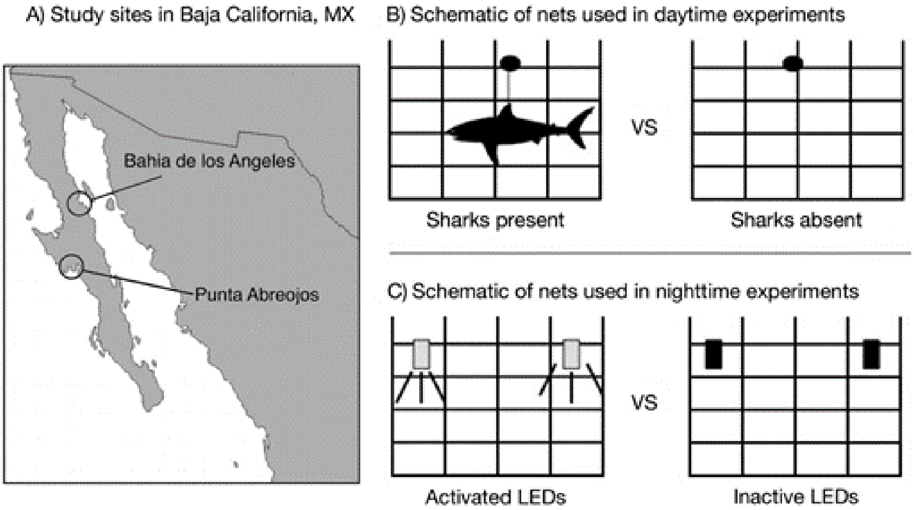

Figure C 8: (A) Study sites along the coast of Mexico's Baja California Peninsula. Experiments examining sea turtle catch rates were conducted in Punta Abreojos, while experiments examining target catch and catch values were conducted in a commercial bottom-set gill net fishery in Bahia de los Angeles, Mexico. (B) Schematic of experimental nets with shark shapes suspended nest to the nets from floats and control nets with only floats used in daytime studies. (C) Schematic of experimental nets with activated LED lights or lights sticks and control nets with inactive LED lights or light sticks used in nighttime studies (taken from Wang *et al.*, 2010).

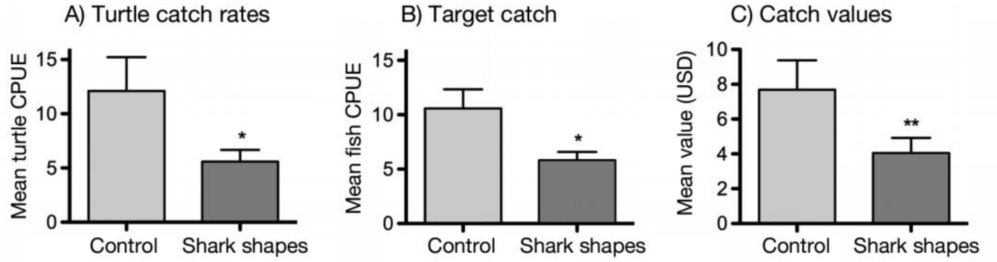

Figure C 9: Effects of deploying shark shapes on green sea turtle catch rates, target fish catch, and catch value using control nets versus experimental nets (with shark shapes). (A) Shark shapes resulted in a 53.9% reduction in the mean CPUE (catch per unit effort) from the control nets. (B) Mean CPUE of target fish was decreased by 45.0%. (C) Mean catch value (US$) decreased by 47.4%. *Indicates significant difference of $p < 0.05$ and ** of $p < 0.01$ (taken from Wang *et al.*, 2010).

10.3.1.3 Several commercially important pelagic fish species, such as tunas, filter out UV light (Fritsches *et al.*, 2000; Fritsches and Warrant, 2006), whereas evidence suggests that sea turtles can see into the UV spectrum (Witherington and Bjorndal, 1991; Fritsches and Warrant, 2006; Crognale and Eckert, 2007; Mathger *et al.*, 2007; Salmon and Wyneken, 2007; Wang and Swimmer, 2007). This difference could therefore, allow adaptions to the Wang *et al.* (2010) design to construct the shark mimic shapes out of transparent, UV-absorbent plastics, therefore turtles will be able to detect these but target fish species will not (Wang *et al.*, 2010). Currently there is limited research into the visual capabilities of seabirds, including guillemot and razorbill, and no evidence that they can see UV light, therefore, there is no evidence that this technique could work.

10.3.1.4 Using this method has shown to be effective at deterring bycatch, however it also decreases fish catch, therefore this method will not be taken through to trial stage.

11 Visual net modifications: Moving elements or streamers in netting

11.1.1.1 Streamers may be incorporated into netting and have the potential advantage of being readily visible due to their movement with water currents passing through. There are two basic types of streamers:

- Mesh streamers- where the width and length are similar sizes to mesh panels; and
- Ribbon streamers- these are narrow and much longer than the mesh size, attached or tied into the net.

11.1.1.2 Mesh streamers may be less likely to tangle either with one another or with the net, whereas ribbon streamers may be more visible and present more movement.

11.1.1.3 There are currently no studies looking into the use of streamers inside nets, therefore, no results can be drawn upon. As a result, this method will not be taken forward for trialling until more research on this technique has been conducted.

12 Above water methods (excluding Looming Eyes Buoy)

12.1 Bycatch reduction method and how it works

12.1.1.1 Bird scaring devices are commonly used techniques to deter birds. Attaching moving and/ or reflective materials to nets above water may increase visibility to seabirds and marine mammals and reduce species caught in gillnets (Parker, 2017).

12.1.1.2 Commonly tested bycatch reduction techniques include bird-scaring lines used in longline fisheries and net surface markers, whereas newer techniques may include use of kites or drones flown over nets and the use of raptor silhouettes. Another technique that has been used in Japanese fisheries is the use of reflective discs, however the results from this are inconclusive.

12.1.1.3 Net surface markers such as corks and floats may alert birds to the presence of nets, however they can also act as a barrier to some species, including auks (Melvin *et al.*, 1999). They may cause birds to dive rather than jump over nets therefore endangering them from being entangled in nets. At Filey Bay, as bycatch occurs lower down in the netting, it was deemed more effective to focus measures on increasing visibility in this area, rather than at the surface of the water (Quayle, 2015).

12.2 Success from trials to date

12.2.1.1 There are no studies conducted with quantifiable results on the use of above water visual deterrents as bycatch reduction strategies. However, techniques using reflective materials such as mirrors, compact discs (CDs) and tins are used globally in fisheries in order to scare off species such as cormorants.

12.2.1.2 Highly reflective CDs are hung on nets to deter seabirds from being caught in nets in the Japanese right-eye flounder fishery. This method is inexpensive, however the CDs may become easily tangled in the nets during setting and hauling. There is currently no conclusive evidence of this technique, therefore it is unknown whether this method reduces bycatch without impacting target fish catch (Wiedenfeld *et al.*, 2015). Similar methods have been used elsewhere globally, in eastern USA, where 8 out of 336 fish hatchery managers reported using tin reflectors, however 7 reported there had been no success in using this as a depredation control technique (Russell *et al.*, 2012). Compared to the use of hand-held mirrors in Israel, which have been reported as an effective scaring technique.

12.2.1.3 As with many other deterrent techniques, in Greece at Lake Kerkini, mirrors have been used in conjunction with audible deterrents (bells) and have been shown to be successful in deterring cormorants from sites close to the shore (Russell *et al.*, 2012).

12.3 Conclusion

12.3.1.1 The use of these above water techniques may be effective for surface feeders. However, for diving species, there is concern that visual cues on the water surface may cause some species to dive to avoid these markers, and ultimately put the species at more risk of being caught in nets (Melvin *et al.*, 1999). Currents may also change the behaviour and position of netting in the water column, where nets are set in high tidal areas, potentially reducing the efficacy of surface markers and making diving seabirds more vulnerable to net entanglement (Quayle, 2015). However, recent developments in above-water techniques using deterrents that can be seen at a further distance than diving species can travel horizontally whilst diving. This opens up the potential for above-water techniques to be used as a bycatch reduction strategy for bycatch of diving species, such as guillemot and razorbill, as well as surface feeders. Further information on this new above-water bycatch reduction technique can be found in 13.

13 Above water methods: Looming eyes buoy (LEB)

13.1 Bycatch reduction method and how it works

13.1.1.1 Previous bycatch reduction techniques for reducing seabird bycatch in gillnet fisheries largely focussed on using visible underwater methods. However, the results from these vary by location and target species with areas of high sediment load, for example the Baltic Sea, being unlikely to be able to utilise such methods as marine-adapted birds may experience reduced visual capacity in these waters (Martin and Crawford, 2015). Therefore, underwater deterrent techniques may not be effective at reducing seabird bycatch (Schnell, 2019). As such, it has been suggested to use above water deterring techniques instead in order to prevent birds from diving in areas of gillnets (Schnell, 2019).

13.1.1.2 Looming stimuli have been shown to trigger a collision-risk signal in avian brains (Wang and Frost, 1992; Sun and Frost, 1998), whilst conspicuous eyespots are more likely to evoke an aversive response in avian species than other stimuli (Stevens, 2005; Kodandaramaiah *et al.*, 2009; Blut *et al.*, 2012; Olofsson *et al.*, 2013; De Bona *et al.*, 2015). On land, the combination of these two visual stimuli has resulted in significant escape responses in several bird species (Hausberger *et al.*, 2018). Therefore, a prototype device has been developed using these features which sits on the ocean's surface with the aim to not only prevent them from diving near gillnets but also from entering the area at all in high-risk bycatch zones whilst minimising habituation.

13.1.1.3 In order to develop a successful prototype, it is important to understand the potential radius of the LEB. It was assumed that the horizontal distance that diving seabirds cover during a typical foraging dive would provide a maximum radius over which the device would need to be detected in order to provide an effective technique. Using GPS loggers and time-depth recorders at North Atlantic colonies (Wakefield *et al.*, 2017; Browning *et al.*, 2018), showed that guillemots, razorbills and shags rarely travelled over 50m horizontally in a single dive. Therefore, designing a prototype that limited dives within a 50m radius around gillnets could reduce the risk of seabird entanglement in gillnets.

13.1.1.4 The prototype was designed to be a contrasting black and white pattern, 200mm wide to ensure that it could be detected from a distance of at least 50m during relatively low light levels. The design was incorporated into a three-dimensional rotating device consisting of two panels simulating an eye pattern with the opposite face of each panel exhibiting a different size eye pattern, in order to create the 'looming' effect when the panels rotate (Figure C 10). As the device moves with the wind, the changes in natural wind will induce unpredictable movements and rotation speeds, therefore, intensifying behavioural responses and minimising chances of habituation (Gregor *et al.*, 2014; Schnell, 2019).

13.2 Success from trials to date

13.2.1 Non-commercial trials in the Baltic Sea

13.2.1.1 The use of LEBs has been trialled in the Baltic Sea in order to test whether birds would be significantly reduced in a radius of 50m around the device between February and April 2020. The trials were set up so that there were three LEBs aligned with an oblique angle from the coastline and spaced 100m apart in order to represent a 200m long gillnet with a control plot deployed 500m from the treatment plot (Rouxel *et al.*, 2021).

13.2.1.2 A total of 11,118 seabirds of 18 different species were recorded within the two experimental plots, 91.4% of which were long-tailed ducks. Due to the low numbers of other species, only long-tailed ducks were included in the statistical analysis. The results suggest that the LEB has the potential to reduce long-tailed duck numbers by 20-30% within a 50m radius of the device and therefore if deployed on gillnets could have a similar reduction rate.

13.2.1.3 There was no evidence that long-tailed ducks would continue to be displaced from the site after the device was removed, however there was some evidence to suggest habituation may occur over time. This could however be due to seasonal differences in the experiment.

13.2.1.4 Although this trial was carried out only on long-tailed ducks, the prototype developed may trigger escape or fear responses in other seabird species (Schiff *et al.*, 1962; Schiff, 1965; Schiff and Detwiler, 1979; Wang and Frost, 1992; King *et al.*, 1999; Carlile *et al.*, 2006). The LEB deters birds from a 50m radius, as guillemot or razorbill rarely travel 50m horizontally during a dive, there is confidence in the LEB as a bycatch reduction technique for guillemot and razorbill.

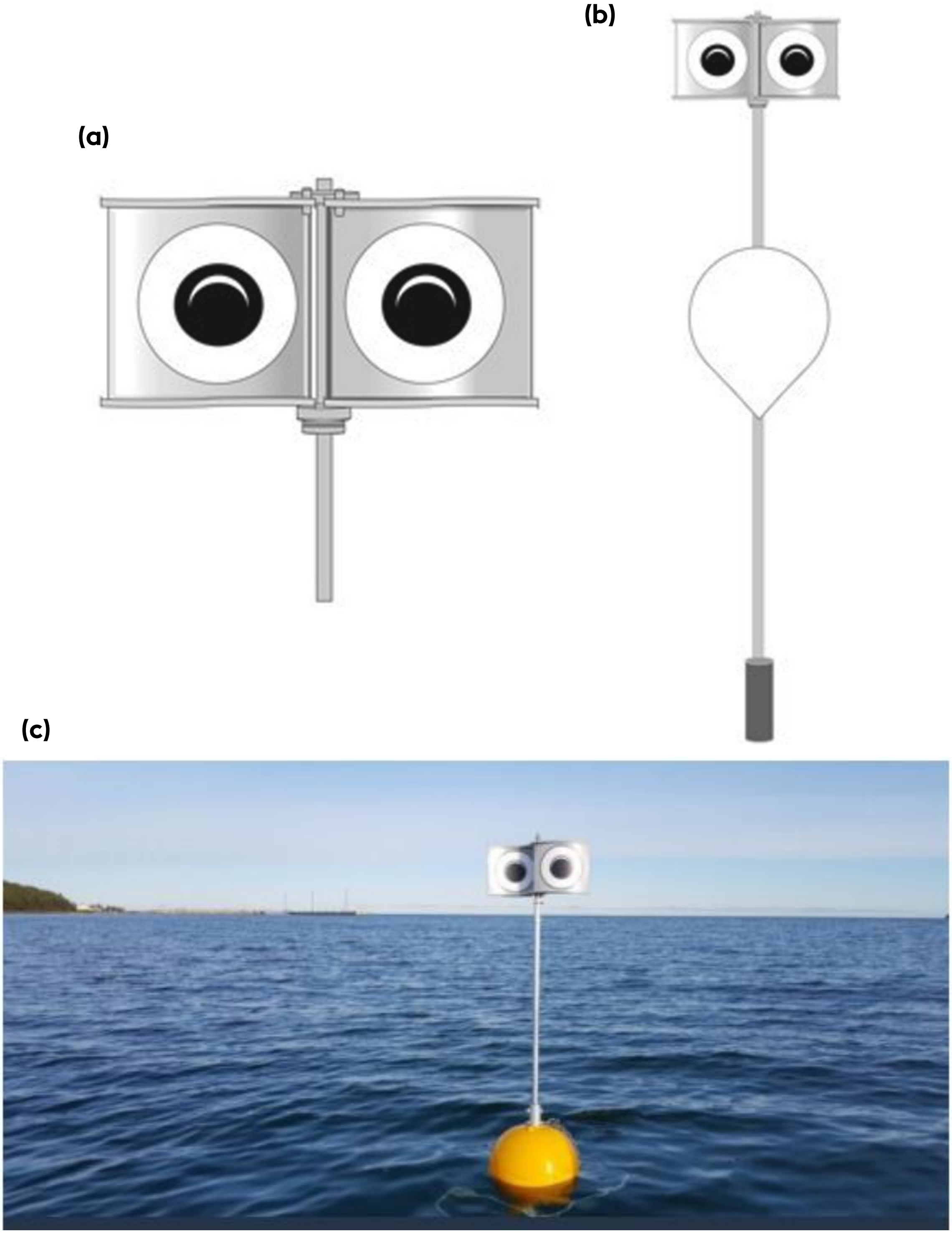

Figure C 10: (a) Looming eyes buoy (LEB) rotating unit with panels and eyes pattern; (b) unit fully assembled on pole buoy with counterweight (Rouxel *et al.*, 2021). (c) Example looming eyes buoy design (Source: BirdLife International).

13.3 Conclusion

13.3.1.1 The LEB is a method that could work across varying geographical locations, due to being an above water deterrent technique, to help reduce seabird bycatch. The results of the trial showed a decrease in bycatch rates, mainly linked to the deterrent causing a reduction of seabirds within the vicinity of the net. As guillemot or razorbill rarely travel 50m horizontally during a dive (and the LEB deters seabirds from a 50m radius), there is confidence in the LEB as a bycatch reduction technique for guillemot and razorbill. Moreover, although there was evidence of habituation within the experiment, the LEB was tested in a non-commercial fishery therefore the LEBs were in the same location throughout the trial. Whereas in a commercial fishery, the locations of the nets will change depending on multiple factors, including fish stocks and weather, therefore the likelihood of habituation is reduced in a commercial fishery. As such, this method will be taken forward to the next trial stage.

14 Acoustic deterrents: Pingers and AHDs

14.1 Bycatch reduction method and how it works

14.1.1.1 Acoustic deterrence devices, namely pingers and acoustic harassment devices (AHDs) have been suggested as potential seabird bycatch reduction techniques (Wiedenfeld *et al.*, 2015; Parker *et al.*, 2017). Pingers work in that they are small underwater devices that emit high-frequency sound pulses which are attached along nets in equal intervals such as every 50m (Melvin *et al.*, 1999) in order to alert an animal to the presence of the net (Figure C 11). Whereas AHDs emit underwater sounds of such high intensity (at least 200 dB re 1 μPa @ 1m) that they cause pain and/or alarm in some species.

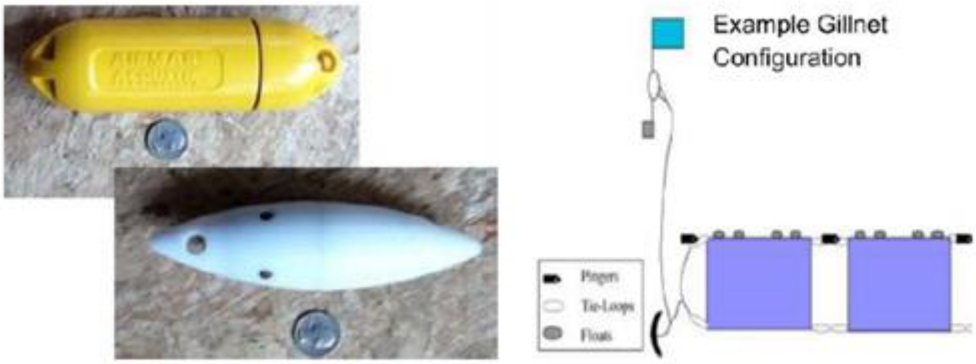

Figure C 11: Acoustic pingers (left) attached to tie-loops of gillnets (right) (taken from NMFS, 2013).

14.1.1.2 Pingers have been under development for marine mammal bycatch reduction since the 1970s (Guzzwell *et al.*, 1993) and have been tested on numerous species in numerous studies with successful results, such as harbour porpoise (e.g., Gearin *et al.*, 1994; Trippel *et al.*, 1999; Dawson *et al.*, 2012; Bjørge *et al.*, 2013). Currently there are two types of pinger using different source levels and frequencies that have been approved in EU waters; 1) a 10kHz pinger and 2) a variable ultrasonic frequency pinger. These pingers are mandatory for certain fishing vessels in parts of the Baltic Sea (Council of the European Union, 2004).

14.1.1.3 Pingers have been successful at reducing cetacean bycatch by approximately 90% without also reducing target catch rates (Kraus *et al.*, 1997; Trippel *et al.*, 1999; Larsen *et al.*, 2002). However, currently little is known about the subsurface hearing abilities in seabird species (Northridge *et al.*, 2016) and pingers may have limited use in reducing bycatch of seabirds as most birds are poor at detecting a sound's source (Martin and Crawford, 2015), as well as there being no evidence to show that birds are able to communicate or navigate using acoustic cues under water (Gridi-Papp and Narins, 2008). Pingers have however, been shown to be successful for guillemot in one study (Melvin *et al.*, 1999), in which the frequency of the pinger was changed from those used in mammal studies in order to better reflect frequencies at which seabirds may be deterred.

14.2 Success from trials to date

14.2.1 Impact of pingers on auks in Puget Sound

14.2.1.1 Melvin *et al.* (1999) conducted a series of experiments in Puget Sound, Washington salmon drift gillnet fisheries, using high visibility meshing and pingers. Information on the meshing can be found in Section 8.

14.2.1.2 The experiment was conducted in 1996 and consisted of 642 sets. The acoustic alerts were set up clipped along the corkline of each monofilament net every 50m, totalling 13 pingers per net. The pingers were set to emit a 1.5kHz frequency signal with a pulse width of 300ms (610%) every 4 seconds at 35-40 dB above background noise levels.

14.2.1.3 Results showed that pingers reduced guillemot bycatch rates by approximately 50% compared to traditional monofilament nets, similar to that of the 20-mesh net setup, however they had no significant effect on rhinoceros auklet bycatch. Results also found that pingers had no effect on the salmon catch rates.

14.2.2 Impact of using AHDs

14.2.2.1 AHDs have been primarily developed to deter marine mammals (Werner *et al.*, 2006) and have been developed primarily in aquaculture operations, therefore are untested for diving seabirds. However, this approach has had variable success. Werner *et al.* (2006) reviewed this method and concluded that AHDs may be harmful since they may exclude animals from important habitat and risk damaging an animal's hearing.

14.3 Impact on other non-target bycatch

14.3.1.1 Alongside deterring species that are vulnerable to bycatch from nets, they can also act as an alert to species such as bottlenose dolphin and some species of pinniped and attract them to the nets in search of food. This therefore increases their chance of being entangled in nets (Hamer *et al.*, 2011; Dawson *et al.*, 2012) and potentially increases the rate of depredation of catch from the nets (Kraus *et al.*, 1997; Melvin *et al.*, 2001a; Bordino *et al.*, 2002; Dawson *et al.*, 2012; Stansbury *et al.*, 2015). Examples of this have been shown such as Melvin *et al.* (2001a) observed greater abundance of seals at drift gillnets with pingers than those without.

14.4 Conclusion

14.4.1.1 Underwater hearing in birds is not currently well studied, with little known about species ability to locate sounds underwater (Martin and Crawford, 2015). Experiments such as Melvin *et al.* (1999), where pingers had significant impact on one species but not on another, suggests that there may be differences either in behavioural responses of birds to underwater signals or in their hearing abilities (Northridge *et al.*, 2016).

14.4.1.2 Therefore, pingers effectiveness for seabirds is inconclusive. Pingers that have been adjusted to frequencies used for seabirds have been shown to reduce bycatch of guillemot (Melvin *et al.*, 1999) but had no impact on rhinoceros auklet. These pinger frequencies increased seal presence (Melvin *et al.*, 1999), and using marine mammal frequencies have been shown to increase seabird bycatch rates by three-fold in salmon fisheries in Kodiak Island, Alaska

(Manly, 2007). Therefore, this approach may decrease guillemot bycatch in UK fisheries but may increase bycatch of other vulnerable species.

14.4.1.3 AHDs have limited research results, with studies conducted on their effects to seabirds, however they are likely to exclude species which will impact ecosystems and may cause harm to target and non-target species hearing.

14.4.1.4 Martin and Crawford (2015) do not recommend that the use of acoustic signals to warn animals about the presence of gillnets as positive results from studies such as Melvin *et al.* (1999) could be the result of neophobia rather than the direct avoidance of the pinger sounds.

14.4.1.5 This technique does not fulfil the criteria posed by O'Keefe *et al.* (2012) for a successful bycatch reduction measure as use of acoustic deterrents has the potential to increase the bycatch of other species. With currently little information on the hearing capabilities of guillemot and razorbill and the negative potential side effects of this technique, we will not be taking this technique forward through to the trialling stage.

15 Net type and setting: Low profile nets and tiedowns

15.1 Bycatch reduction method and how it works

15.1.1.1 Seabird captures have been observed to be higher in nets that have been set more loosely/ unstrained, such as those nets used in southern Baltic to capture flatfish or when storms have enabled nets to be become loose (Stempniewicz, 1994). Maintaining an upright, taut net in water with sufficient net tension that it does not loft when full of fish may minimise how much net there is horizontally and therefore reduce how much net there is available to capture birds (Figure C 12) (Montevecci in Wiedenfeld *et al.*, 2015).

15.1.1.2 Upright stand-up nets (without tiedowns) have been developed to reduce sea turtles and sturgeon bycatch and are being developed in Newfoundland, Canada for seabirds, however, have yet to be tested (Figure C 13).

15.2 Success from trials to date

15.2.1.1 Trials have not yet taken place of upright taut nets in reducing seabird bycatch, however, plans for testing of double-weighted lead lines in order to decrease lofting and therefore minimise seabird bycatch, particularly northern gannet have been discussed in Wiedenfeld *et al.*, (2015).

15.2.1.2 Other studies have tested the effects of stand-up gear without tiedowns and have found mixed results (NMFS, 2013). In North Carolina, USA this technique was found to reduce turtle bycatch in bottom set flounder fishery (Price and von Salisbury in Gilman *et al.*, 2010). However, in New Jersey monkfish fisheries found higher turtle and dolphin capture rates when testing this bycatch reduction method (Armstrong *et al.*, 2013; Wark *et al.*, 2013). It was found that in both of these studies, target fish species catch was significantly reduced in standup nets without tiedowns relative to control nets with tiedowns.

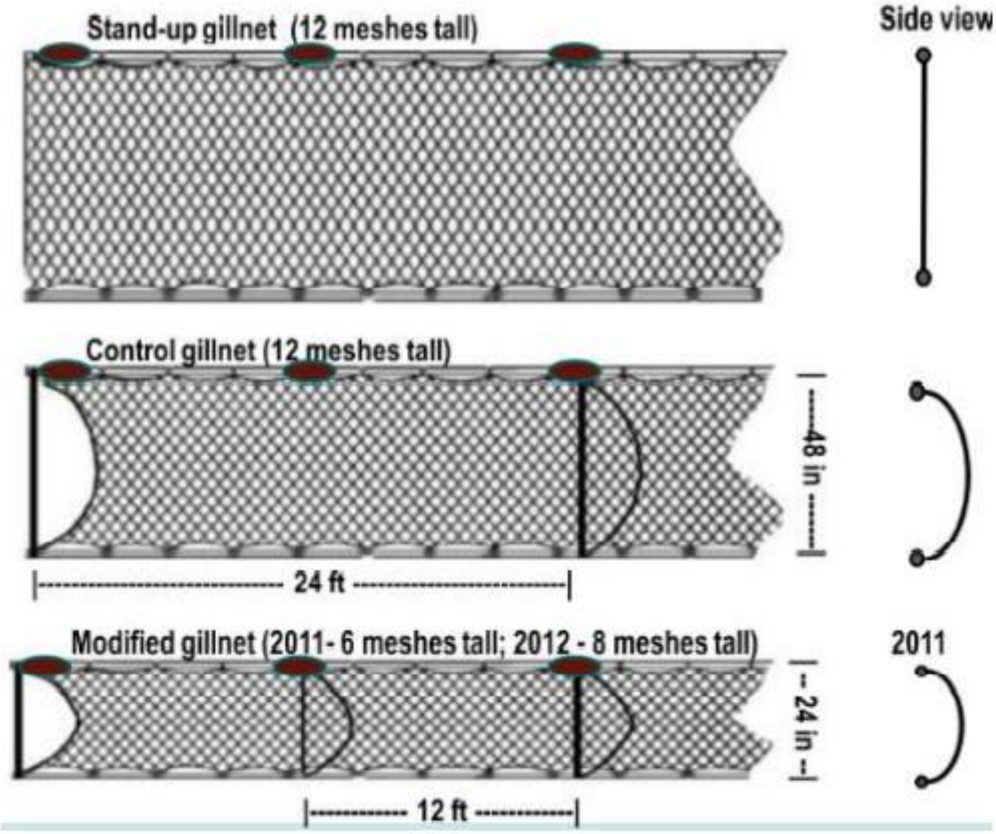

Figure C 12: Standup gillnet compared to standard net with tiedowns (taken from Wark *et al.*, 2013).

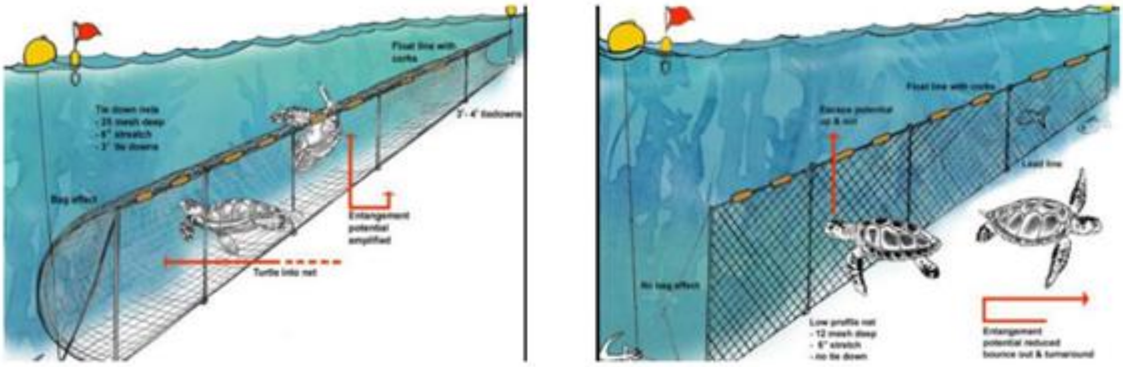

Figure C 13: Standard net with tie-downs (left) compared to low-profile standup net (right). (Image taken from Gilman *et al.*, 2010 and modified by Jeff Gearhart).

15.3 Conclusion

15.3.1.1 Although there are no tests that have been carried out on the impacts to seabird bycatch, other studies (Price and von Salisbury in Gilman *et al.*, 2010; Armstrong *et al.*, 2013; Wark *et al.*, 2013) have all demonstrated that the method negatively impacts target fish catch. As this does not fulfil the criteria set out by O'Keefe *et al.* (2012) for a successful bycatch reduction strategy, this method will not be taken forward into the trialling stage.

16 Net type and setting: Setting depths and net height

16.1 Bycatch reduction method and how it works

16.1.1.1 Studies have been conducted into the diving behaviours of seabirds and found that most diving birds prefer shallow waters with the majority of seabird bycatch occurring in depths less than 20m (Stempniewicz, 1994). The probability of catching non-target species also decreases with increasing water depth (Bellebaum *et al.*, 2013). Therefore, changing the depths at which nets are set may reduce seabird bycatch. Another approach is to change the height of nets (measured as the number of meshes in depth), if there is less netting it is theorised that there will be less available space for non-target species to get caught in.

16.1.1.2 There are a range of different ways that net heights and depths can be adjusted (Figure C 14) in order to change what bycatch species are considered. Mangel *et al.*, 2014 demonstrated how surface driftnets can be modified to float 1.3-2.5m below the surface by utilising extra weights on the leadline (Figure C 15) and The Fisheries Agency of Japan developing sub-surface nets with longer hanging lines between surface floats and midline (Hayase and Yatsu, 1993), originally hanging lines were placed 1m apart, however they tangled easily when setting, therefore this was reduced and net handling improved when they were hung 5m apart. These two techniques may predominately be used as bycatch reduction for surface-lunging species such as albatrosses, however other studies such as Carretta and Chivers (2004) have focused on adjusting netting to depths such as approximately 110m deep which may be used to reduce bycatch of diving species such as auks.

16.1.1.3 Adjusting net heights has been ongoing in fisheries around the world, showing improvement of target catch rate whilst minimising catch of non-target species (e.g., He, 2006; Wark *et al.*, 2013). However, although there have been suggestions that this method will improve seabird bycatch rates (Northridge *et al.*, 2016), there is currently little testing to back this up.

16.2 Success from trials to date: Set depths

16.2.1 Reduction in seabird bycatch in Japanese drift gillnet fisheries

16.2.1.1 Hayase and Yatsu (1993) compared nets submerged 2m below the surface to surface nets in Japanese high-seas drift gillnet fisheries in 1991. They found that seabird entanglements, mostly focused on sooty and short-tailed shearwaters, were significantly reduced by 27% in nets that were submerged at 2m. There was no significant difference in the bycatch rate of other species such as northern fur seal, small cetaceans and sea turtles, however, target catch of squid and Pacific pomfret had also reduced by 64% and 49%, respectively and fishing efficiency was reduced by up to 95%.

16.2.1.2 In Peru, similar tests have been completed by ProDelphinus on submerging surface gillnets in driftnet fisheries. Too few seabirds were caught to determine the effect, however sub-surface nets resulted in significantly less target catch, 73% reduction in sharks and 80% in rays (Mangel *et al.*, 2014).

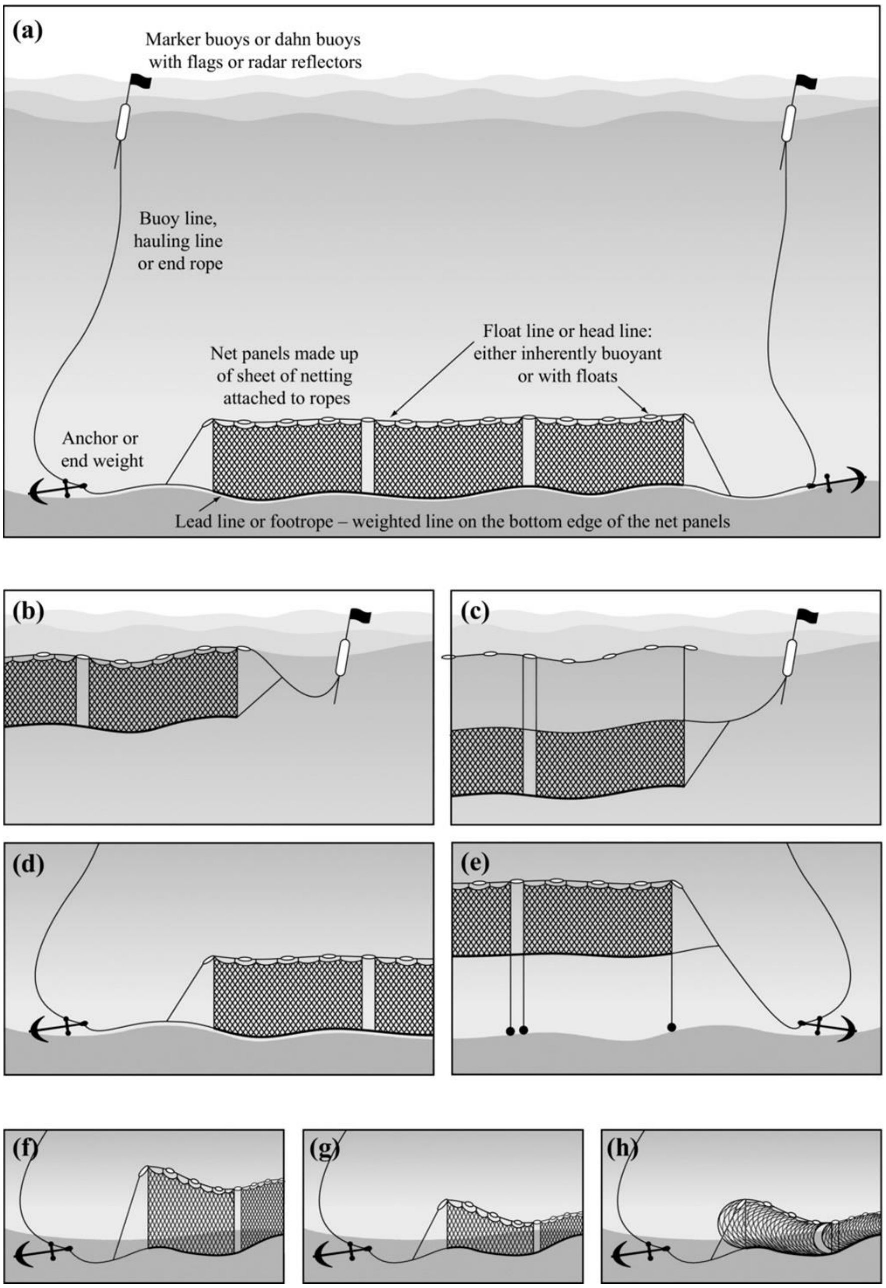

Figure C 14: Schematic representation of (a) a bottom-set gillnet; (b–e) ways in which the fishing depth of a gillnet can be modified: ([b], standard drift gillnet; [c], subsurface drift net; [d] standard bottom-set gillnet; [e], off-bottom set gillnet); and (f–h) adjustment of nets to reduce fishing height: ([f], standard gillnet; [g], half-height gillnet [h], gillnet with tie-down) (Northridge *et al.*, 2016).

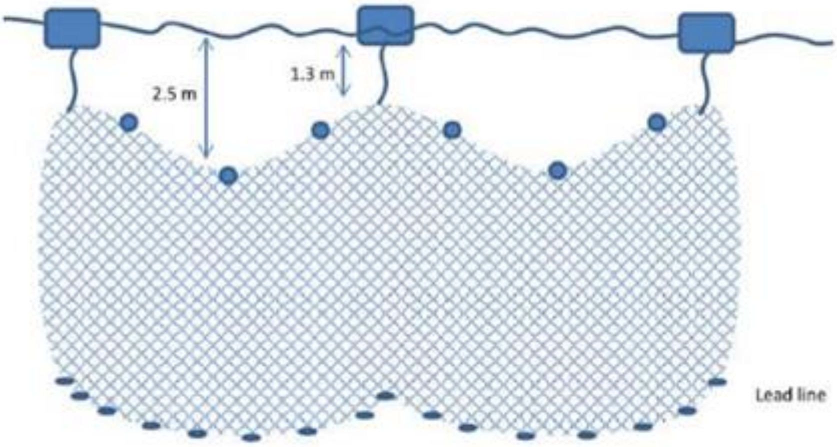

Figure C 15: Sub-surface net panel showing extra leadline weights used to pull the headline below the surface (taken from Mangel *et al.*, 2014).

16.2.2 Impacts of depth setting bans in California on guillemot

16.2.2.1 In California between Point Reyes and Point Arguello, a ban on gill and trammel nets inshore of 110m came into effect in September 2002. The ban was implemented due to concerns over levels of incidental mortality of guillemot and California sea otters by California Department of Fish and Game (CDFG).

16.2.2.2 Rules appeared to be adhered to by fishermen as no set gillnet fishing effort was reported in central California waters of Point Arguello over the first six months of 2003.

16.2.2.3 Banning of gillnetting in depths of less than 110m was found to almost eliminate the formerly high bycatch rates of guillemot in this area (Carretta and Chivers, 2004).

16.3 Success from trials to date: Net height

16.3.1 Netting height in German cod setnet fishery

16.3.1.1 In order to test the impacts of net height in fisheries, Mentjes and Gabriel (1999) ran trials comparing nets that were 12 and 30 meshes deep against control nets of 20 meshes in German cod setnet fishery.

16.3.1.2 These trials showed that there was no impact of mesh depth on the incidental capture of sea ducks, however the use of shortened nets (e.g., 12 meshes depth) resulted in significantly reduced cod captures, therefore impacting target capture rate.

16.4 Conclusion

16.4.1.1 These findings show that changing the depths at which fishermen place their nets can have an effect on seabird species, including reducing the bycatch of guillemot (Carretta and Chivers, 2004) and therefore, regulating depths at which gillnetting occurs could substantially reduce bird mortalities (Žydelis *et al.*, 2013). Longer term plans include investigating sunken headlines in UK bass driftnet fisheries, however these have not yet been conducted (Wiedenfeld *et al.*, 2015).

16.4.1.2 This approach however, has been shown to reduce target fish catch in Japan (Hayase and Yatsu, 1993) and the impacts this technique may have on shifting the problem of bycatch from one vulnerable species to another, as different species forage differently in the water column, is largely unknown. It is also important to consider that sub-surface and deeper bottom-set nets can still entangle birds during setting and hauling (Løkkeborg 2008), which is when large numbers of guillemot and razorbill are bycaught in nets. However, this approach needs to be tested on a fishery-by-fishery basis as the results will depend on the behaviour of the species in each region (Northridge *et al.*, 2016).

16.4.1.3 Currently, net height has been shown to reduce bycatch of species of turtle, porpoises and sturgeon (He, 2006; Gilman *et al.*, 2010; Wark *et al.*, 2013), however for seabirds, there is currently only evidence of this technique being unsuccessful on sea ducks, therefore it is unclear whether this would be true for other seabirds. It is difficult to compare results of sea ducks with the likely impact that this bycatch reduction method may have on auks as they have different diving behavioural mechanisms. Therefore, further studies would be required into seabird responses to net height.

16.4.1.4 Although there is a possibility that this method could improve bycatch rates of guillemot and razorbill, it has the potential to increase other bycatch and also would impact the fisheries which could ultimately impact target fish catch or the effort of fishing. Therefore, these bycatch reduction methods will not be taken forward through to the trialling stage.

17 Net type and setting: Hanging ratio

17.1.1 Bycatch reduction method and how it works

17.1.1.1 Hanging ratio describes the shape of the meshes once hung from the headrope of the net (Figure C 16). This determines the slackness of the netting, with higher hanging ratios, indicating slacker nets, being associated with greater entanglement rates of non-target catch. Although few studies have been conducted into the use of hanging ratios to reduce bycatch, with one study conducted on the impacts of hanging ratios on sea ducks, hanging ratio impacts the likelihood of entanglement across a diverse range of species, therefore it may be expected to impact seabird entanglement rates as well.

17.2 Success from trials to date

17.2.1.1 The effects of hanging ratios on turtle and marine mammal bycatch have been widely studied (e.g., Murray, 2012; Schnaittacher and Milliken, 2012). However, it has currently only been tested on birds once, an idea developed by the Institut für Fischereitechnik in Germany.

17.2.1.2 In a German cod set net fishery, hanging ratios of 0.33 and 0.4 were compared against a control of 0.5 (Mentjes and Gabriel, 1999). Results shows that there was no change in sea duck captures between the different hanging ratios, however target fish capture rate was greater in nets with a hanging ratio of 0.33 compared to control nets (Mentjes and Gabriel, 1999; Schnaittacher and Milliken, 2012).

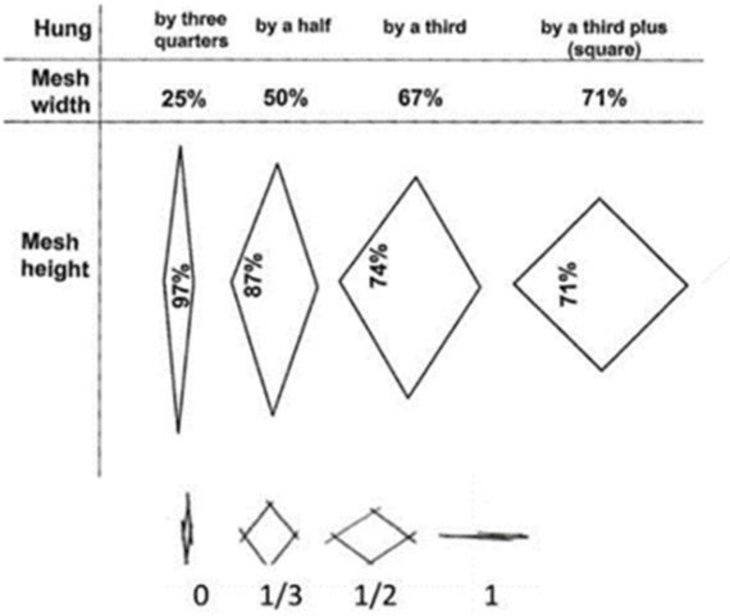

Figure C 16: Hanging ratio is the ratio of headrope length to net length, affecting mesh width and height (taken from He, 2006; Schnaittacher and Milliken, 2012).

17.2.1.3 Overall, this study showed that sea ducks bycatch rates were not impacted by hanging ratios, although this may not be directly comparable to how it may impact other seabird species such as pursuit diving auks. It is also shown that hanging ratio has been shown to impact fish species entanglement rates and target specificity (He, 2006). Therefore, as there is no evidence that this bycatch reduction technique works with seabirds and that fish target catch rate changes with hanging ratio, this method will not be taken through to trialling stages.

18 Net type and setting: Weights

18.1 Bycatch reduction method and how it works

18.1.1.1 Weights used in longline fisheries have been tested extensively, with many successful examples of how weighting can reduce seabird bycatch (e.g., Melvin *et al.*, 2001b; Robertson *et al.*, 2006) without reducing the catch of the target fish species. Limited studies have been completed on how weighting of gillnets may impact bycatch rates of seabirds.

18.1.1.2 The amount of weighting on a leadline influences the tension of the net and for nets that are set close to the surface of the water, weighting can limit the ability for air breathing animals to surface once entangled. Therefore, investigations such as Erdmann *et al.* (2005) have been conducted on the ability for entangled seabirds to reach the surface in gillnets depending on the weighting of the nets.

18.2 Success from trials to date

18.2.1.1 Erdmann *et al.* (2005) conducted studies on weights used in surface gillnets in salmon and sea trout fisheries. They found that when surface gillnets removed the lead weights, entangled birds could reach the surface of the water in order to breathe compared to nets with traditional weights. However, this method is likely to negatively impact fishing effort (Erdmann *et al.*, 2005).

18.3 Conclusion

18.3.1.1 This technique found that although weighting nets could lead to reduce deaths from entangled birds, it was also likely to negatively impact fishing effort (Erdmann *et al.*, 2005). As this does not fulfil the criteria posed by O'Keefe *et al.* (2012) for a successful bycatch reduction measure, therefore, this method will not be taken through to the trialling stage.

19 Other net types and settings

19.1 Bycatch reduction method and how it works

19.1.1.1 Other suggestions have been made of potential net type and setting bycatch reduction strategies that could reduce seabird bycatch namely; tie-downs to reduce net profiles and altered float lines. These methods have been tested on a number of species such as turtles and harbour porpoises, however to date, have not been tested on seabirds.

19.1.1.2 Tie-downs work in that they reduce the net height and therefore increase the bagging of the net. In the US, gillnets are sometimes tied down with a series of lines connecting the float line and the leadline, this lowers the net profile or the maximum height of the float line. Using tie-downs result in the netting being in a 'C' configuration so that it acts like a bag rather than a sheet on netting. This method has been used to investigate bycatch of turtles and cetaceans such as harbour porpoise.

19.1.1.3 Float line types have been shown to have some influence of the bycatch rates of vulnerable species, however the extent of this is not fully understood (Palka, 2000). The reason for this effect on bycatch is unknown, however it may be due to different floatline types affecting the way net meshes behave underwater, such that they lead to different net configurations, or that different float lines lead to different detectability among species. Different float line configurations have been trialled across a number of species, however not seabirds, with mixed results.

19.2 Success from trials to date

19.2.1.1 Currently there are no seabird studies related to tie-down lengths and float line types. Tie-down lengths have had mixed results for other bycatch species, studies in northeast US suggest that tie-downs are associated with lower bycatch rates of harbour porpoises (NMFS, 1998) and He and Jones (2013) found that shorter tie-downs reduced sturgeon bycatch. However other studies found that longer tie-downs reduced turtle entanglement (Price and Van Salisbury, 2007) and studies in Baja California Sur found no effect of reducing tie-downs from 1.8m to 0.9m on turtle bycatch (Peckham *et al.*, 2009).

19.2.1.2 Therefore, the use of tie-downs has been correlated with changes in marine mammal and turtle bycatch rates (NMFS, 1998; Peckham *et al.*, 2009), however this has been unstudied in seabird species. The use of tie-downs may only be useful in certain fishery types such as for flounders (Northridge *et al.*, 2016), therefore more research needs to be done in target fisheries in order to assess the potential ability to use this method to reduce seabird bycatch.

19.2.1.3 Changes in float lines such as the elimination or reduction in buoys and changes from polypropylene lines to floating lines have had varying results to bycatch. One experiment showed that turtle bycatch rate reduced by 68%, whilst maintaining target catch rates and composition, with nets without buoys (Peckham *et al.*, 2015) whereas another experiment found that there was not a significant reduction of turtles caught when reducing number of buoys on the floatline (Peckham *et al.*, 2009).

19.2.1.4 Palka (2000) found that bycatch rates of porpoise were lower in nets using float lines than polypropylene lines in US Mid-Atlantic coastal sink gillnet fishery. Whereas SMRU *et al.* (2001) found an opposite result where porpoise bycatch increased in nets using floating rope compared to polypropylene in the Celtic Sea.

19.2.1.5 Despite these contradictory results for float line types, it appears that changing the ways that nets are rigged will influence the bycatch results of vulnerable species.

19.3 Conclusion

19.3.1.1 Due to the lack of testing on seabirds it is difficult to conclude whether these methods may be feasible for guillemot and razorbill. In order to assess the potential of the methods, trials would need to be carried out. Due to the great uncertainty of these techniques, they will not be short-listed.

20 Net operations: Time of setting and hauling

20.1 Bycatch reduction method and how it works

20.1.1.1 For diving seabirds, there is a clear trend of elevated bycatch rates in specific areas as well as at particular fishing depths, distances from the shore and time periods. This shows an initial indication that measures such as space and time closures for fisheries may be an effective bycatch reduction strategy in order to reduce incidental mortality of seabirds in gillnets (Bærum *et al.*, 2019).

20.1.1.2 It is possible to either close fisheries during certain times of the year or seasons or restrict fishing to certain times of the day. Restricting the times of setting and hauling may be implemented such that nets are restricted to setting at certain times of the day when bycatch species are least abundant in order to minimise the risk of encounters with fishing gear. This method was developed following observations that seabirds are more abundant at certain times of the day than at others.

20.1.1.3 Melvin *et al.* (1999) found that guillemots are most at risk of being caught in nets at dawn and dusk, whereas auklets were most endangered only at dawn. Restrictions on times of net settings may therefore decrease auk bycatch rates elsewhere.

20.2 Success from trials to date

20.2.1.1 Melvin *et al.* (1999) first developed the idea of restricting netting times in order to test its impacts on seabird bycatch. Their study found that compared to during the day, guillemot entanglements were higher at both dawn and dusk, while target catch (sockeye salmon) and auklet entanglements were highest at dawn (Melvin *et al.*, 1999). Therefore, they trialled experiments of avoiding fishing at sunrise, results showed that there was a significant reduction of 30% in bycatch of guillemot and 60% in auklet when fishing was conducted during the day compared to fishing at sunrise, however, there was also a reduction of target species catch rate by 5%. As a result of this study, restrictions were enforced in Puget Sound, which meant that fishermen could not fish during dawn or dusk, despite the anticipated reduction this would cause to the target catch rate (Moore in Wiedenfeld *et al.*, 2015).

20.2.1.2 Comparing this to trailing restrictions in cod setnet fishery in Germany, Mentjes and Gabriel (1999) found that restricting to just one of the dawn or dusk periods had no effect on duck capture rates, however it significantly reduced target fish captures.

20.2.1.3 Despite the few studies that have been conducted into reducing setting times, Melvin *et al.* (1999) shows promising signs that this technique may be successful in reducing auk bycatch. However, this method may also result in decreases of target fish catch.

20.3 Conclusion

20.3.1.1 Although Melvin *et al.* (1999) found that seabird bycatch rates, including guillemot, were reduced when changing setting and haul times, this method has also been shown to impact the target fish capture rate, which would influence the effort needed by fishermen (Melvin *et al.*, 1999; Mentjes and Gabriel, 1999). This therefore, does not fulfil the bycatch reduction criteria set out by O'Keefe *et al.* (2012), and so this method will not be taken forward to the trialling stage.

21 Net operations: Soak times

21.1 Bycatch reduction method and how it works

21.1.1.1 Among other operational factors, soak duration i.e., how long a net is in the water for, may affect bycatch rates of at least two taxa, namely mammals and turtles (Northridge *et al.*, 2016) as the probability of bycatch occurring per haul will likely increase with longer soak times. Currently there are no studies on the soak times for seabirds, therefore it is unknown whether this impacts their bycatch rate.

21.1.1.2 Lopez-Barrera *et al.* (2012) found that one of the most important factors resulting in green turtle being bycaught in Brazil is soak-time. Other studies show that turtle mortality increases with soak-time (e.g., Sasso and Epperly, 2006), however this may not be as a result of increased capture rates but due to turtles being unable to survive in the nets when soak-time increases. This is demonstrated by Murray (2009) that the proportion of dead turtles recovered from gillnets approaches 100% after a soak time of 80-100 hours, compared to 50% after 40-60 hours.

21.1.1.3 Shorter soak times may provide a bycatch reduction technique which could reduce bycatch of species or reduce their mortality rates by successful removal of live animals from nets, however it will also likely reduce fish catches. Therefore, alone, this technique will only be successful if there is a less-than-linear relationship between soak time and target fish catch or a great-than-linear relationship between soak time and bycatch (Northridge *et al.*, 2016).

21.2 Success from trials to date

21.2.1.1 There are a number of studies that have demonstrated how increased soak-time increase bycatch of species such as Mackay (2011) finding a linear relationship between soak-time and bycatch of porpoises in the North Sea. Palka (2000) found similar results, however model results showed that after very long soak times, bycatch rates were observed to decrease. This is likely due to entangled animals dropping off from the nets after the first or second tides (Northridge *et al.*, 2016).

21.2.1.2 Ability to use soak-time as a bycatch reduction technique may vary depending on the fishery. In the US East Coast bottom set monkfish fishery, the fishery has four-day long soak times, therefore, changing time of day or soak time is not a feasible option here whilst also maintaining target fish catch levels (Wiedenfeld *et al.*, 2015).

21.3 Conclusion

21.3.1.1 Although soak time may be useful for reducing marine species bycatch, it may not be possible in some fisheries due to necessity of long soak-times and may also impact the target catch rate. Therefore, as these criteria do not meet that outlined by O'Keefe *et al.* (2012) this technique will not be taken through to the trialling stage.

22 Other net operations

22.1.1.1 Other net operation bycatch reduction techniques that have been suggested could reduce bycatch of seabirds are:

- nocturnal setting,
- net sensors (alarm or light), and
- net-checking frequency (Wiedenfeld *et al.*, 2015).

22.1.1.2 Variability in the time of day that species forage has been observed across a number of species including pelagic fish and sea turtles (e.g., Bigelow *et al.*, 2002; Ward *et al.*, 2004; Musyl *et al.*, 2003, 2011), and also occurs in pelagic seabirds (Gilman *et al.*, 2019). In some regions where fisheries are restricted to night settings in order to protect species of diurnal foraging seabirds such as albatrosses, this has also led to higher bycatch of nocturnal foragers such as northern fulmars (Melvin *et al.*, 2001b). Therefore, the success of this bycatch reduction technique will depend on the species distributions in the target fishing areas.

22.1.1.3 Net sensors and net-checking frequency are suggestions made that may reduce bycatch, however they have so far not been tested and have no known implementation at fisheries. The use of these techniques would, however, likely lead to the increase in effort required by fishermen and if nets were being taken out of the water more often to check and remove seabird bycatch, then it would likely impact target catch rates. Therefore, it is unlikely this method would meet the criteria posed by O'Keefe *et al.* (2012), and so these methods will not be taken through to trialling.

23 Operational fishing measures: Fisheries closures

23.1 Bycatch reduction method and how it works

23.1.1.1 Seabird bycatch rates have been shown to fluctuate throughout the year and depend largely on the distribution of vulnerable bycatch species versus fishing efforts. In the North Sea, 60% of seabird bycatch is shown to occur between December and March (Erdmann, 2005), whilst bycatch rates of seabirds in the German Baltic bottom set gillnet fishery were recorded at five times higher from November to April than during the summer months (Bellebaum *et al.*, 2009).

23.1.1.2 These seasonal changes in bycatch rates are due to migration and are likely to be a significant factor for many species including auks, whose numbers in the North and Baltic Seas increase in the winter due to the migration of birds from the wider Northeastern Atlantic and Barents Sea (Žydelis *et al.*, 2009).

23.1.1.3 Therefore, it has been suggested by Žydelis *et al.* (2013) that the current best practice for minimising seabird bycatch rates is through the exclusion of fishing using gillnets at particular times of the year when areas are known to have high concentrations of vulnerable species. This bycatch reduction technique works through understanding precise knowledge of the distribution patterns of species throughout the year, which depends on the depth of the water, the state of the seafloor and the density of food organisms (International Council for the Exploration of the Sea, 2008) and how bycatch rates change temporally. By accumulating this knowledge, restrictions may be enforced that limit the deployment of nets at certain times of year or in certain locations, such as certain depths or distances from coastal areas, of major bird concentrations (Koschinski and Strempel, 2012).

23.1.1.4 Nevertheless, this bycatch reduction technique incurs social and economic costs to fisheries therefore will not be considered by the Applicant.

23.2 Success from trials to date

23.2.1 Canadian fisheries closures impact on seabird populations

23.2.1.1 In 1992, eastern Canadian gillnet fisheries for northern cod and Atlantic salmon were largely closed resulting in the removal of thousands of gillnets, particularly from inshore regions. Regular *et al.* (2013) used the Canadian Wildlife Service colony-based census data collected from 1968 to 2012 in order to compare population trends of diving seabirds (namely; guillemot, razorbill, Atlantic puffin and northern gannet) with trends in populations of surface-feeding seabirds (namely; herring gull, great black-backed gull and black-legged kittiwake) at five major seabird ecological reserves in Newfoundland and Labrador.

23.2.1.2 They found that inshore gillnet fisheries closures resulted in population increases of guillemot, but resulted in the decrease of surface-feeding seabirds, such as herring gull, throughout eastern Canada. This is likely due to reduced bycatch mortality of divers, however surface-feeding species likely decreased due to the elimination of discards and offal around breeding colonies due to closures.

23.3 Conclusion

23.3.1.1 Fisheries closures have been shown to increase populations of guillemot numbers (Regular *et al.*, 2013), however they were shown to decrease populations of gulls. The use of this method is also likely to change the effort and target catch rate of fishermen, therefore not fulfilling the criteria of O'Keefe *et al.* (2012) for bycatch reduction methods. Any technique that would result in a negative impact to fisheries will not be considered by the Applicant, therefore, this method will not be short-listed and taken into the next stage of trialling.

24 Operational fishing measures: Gear switching/ restrictions

24.1 Bycatch reduction method and how it works

24.1.1.1 A final approach is to switch from using gillnets to other fishing gears. Often in fisheries there are alternative means in which to capture target fish species, some of which may be viable practically and economically. In the UK, guillemot and razorbill populations were impacted mostly from gillnet and midwater trawlers (Northridge *et al.*, 2020), however longlines did not appear to result in increased bycatch of these species.

24.1.1.2 Replacing gillnets with longlines (Vetemaa and Ložys, 2009; Mentjes and Gabriel, 1999), baited pots (Koschinsku and Strempel, 2012) and fish traps (Vetemaa and Ložys, 2009) have been tested with variable results.

24.1.1.3 However, by changing gear types, it must be considered that other bycatch may increase. Between 1458 and 2174 guillemots were estimated to be bycaught in UK static net fisheries in 2017, compared to zero in longline fisheries. However, fulmar bycatch estimates were 2613 to 8949 individuals in 2017, therefore if longlining were to increase, fulmar (and other longline vulnerable species) bycatch would also be expected to increase.

24.1.1.4 As well as considering bycatch and fish capture rates, attitudes towards changes also need to be considered, as imposing restrictions or making fishing effort harder for current fishermen may not be widely accepted. This is important to consider for all of the bycatch reduction techniques considered in this study.

24.2 Success from trials to date

24.2.1 Gear switching in the Baltic Sea

24.2.1.1 In the German Baltic Sea, it was proposed that replacing gillnets with longlines would reduce sea duck bycatch as per tonne of landed cod, bird bycatch was estimated at approximately three times lower for longlines than for gillnets (Mentjes and Gabriel, 1999; Bellebaum *et al.*, 2013). A similar suggestion was proposed in eastern Baltic as it was found that switching to longlines would nearly eliminate the bycatch of birds whilst offering a viable alternative for fishing and potentially salmon (Vetemaa and Ložys, 2009). However, in UK fisheries, although changing gillnetting practices to longlining may decrease the numbers of guillemot and razorbill caught, it may also significantly increase the impacts on other non-target bycatch such as fulmar where bycatch estimates were between 2613 to 8949 individuals in 2017 (Northridge *et al.*, 2020), therefore if longlining were to increase, this estimate of bycatch would also be expected to increase.

24.2.1.2 Whilst in Lithuanian trials herring trap nets showed that bycatch reduced to zero for birds whilst also increasing catch efficiency (Vetemaa and Ložys, 2009). This was similar to German Baltic Sea, where an experiment was conducted switching to baited pots for cod and found that there was almost zero bycatch recorded compared to standard gillnets nearby where numbers of bycatch remained high (Bellebaum *et al.*, 2013).

24.2.1.3 However, in other studies, baited pot trials have indicated a decrease in seabird bycatch but also caused a negative impact to target fish catch (Koschinski and Strempel, 2012). More recent work has shown that with further refinement, this catch efficiency problem may be able to be improved in baited pots (Hedgärde *et al.*, 2016).

24.3 Conclusion

24.3.1.1 These examples show how it is possible to reduce bycatch of species whilst maintaining target fish capture rate, however in some circumstances switching to alternative gear may increase mortality rates of other vulnerable bycatch species, may decrease target fish capture rates or have other undesirable effects on marine ecosystems (Žydelis *et al.*, 2013). As a result of the unknown consequences changing gear could have on fishermen effort, target catch rates and ecosystems, this technique may therefore not appeal to many fishermen, we therefore, do not recommend taking this method through to a bycatch reduction trial stage.

25 Summary

25.1.1.1 From this analysis of the long-listed bycatch reduction techniques, the most suitable methods (potential for bycatch reduction without causing negative impacts on the fisheries) for guillemot and razorbill bycatch reduction are:

- Net illumination
- Visual net modifications (reflective nets and high visibility nets)
- Acoustic deterrents
- Above water deterrents

25.1.1.2 Visual net modifications (high visibility netting and reflective nets) were short-listed due to meeting the evaluation criteria (O'Keefe *et al.,* 2012). Note not all evaluation criteria could be assessed. Although there was an effect on non-target species with net illumination (Mangel *et al.,*2018), the increase of bycatch in non-target species was too small to be statistically significant (four individuals) and has therefore been short-listed and the impact will be assessed at the trial stage. In addition, acoustic pingers have been suggested to increase marine mammal bycatch (Melvin *et al.* 1999), however this is dependent of acoustic frequency (this will also be assessed at the trial stage). Acoustic pingers have therefore been short-listed to test the success of specific frequencies, ensuring there is no increase in marine mammal bycatch.

25.1.1.3 No operational fishing measures were short-listed due to the potential for these methods to negatively impact target catch. No bycatch reduction technique will be short-listed that has negative impacts on fisheries.

25.1.1.4 The short-listed methods will be trailed in a pilot study to test their suitability as a compensation measure for guillemot and razorbill within the English Channel. (see the Bycatch Reduction Roadmap for an outline of this process (**B2.8.2 Compensation measures for FFC SPA: Bycatch Reduction: Roadmap**)).

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