Study on Mitigation Measures to Minimise Seabird Bycatch in Gillnet fisheries

Service contract:
EASME/EMFF/2015/1.3.2.1/SI2.719535

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LIST OF ABBREVIATIONS:

AIS – Automatic Identification System (vessel traffic services)
BPUE – Bycatch per unit of effort
CPUE – Catch per unit of effort (target fish catch)
DFN - Drift and/or fixed net
DG ENV - European Commission Directorate- General for the Environment
DG MARE - European Commission Directorate-General for Maritime Affairs and Fisheries
DG RTD - European Commission Directorate-General for Research and Innovation
EASME – Executive Agency for Small and Medium-sized Enterprises
EMFF – European Maritime and Fisheries Fund
ERLOB – European Red List of Birds
EU – European Union
GNS - Set gillnets (anchored)
GLM - Generalised linear models
GMMM - Generalised linear mixed models
IBA - Important Bird and Biodiversity Area
ICES – International Council for the Exploration of the Sea
IUCN – International Union for the
LTD – Long-tailed Duck
MS – Member State
Natura- The EU Natura 2000 network of protected sites
NGO - Non-governmental organisation
NMD – Net metre days
NMFRI – Polish National Marine Fisheries Research Institute
OTOP - Polish Society for the Protection of Birds (BirdLife Partner in Poland)
PBR - Potential Biological Removal
PGP - Polyvalent passive gear vessels.
RSPB - Royal Society for the Protection of Birds (BirdLife Partner in UK)
SPA - Special Protection Area for Birds- a Natura 2000 site
SCI – Sites of Community Importance
SPEA - Sociedade Portuguesa para o Estudo das Aves (BirdLife Partner in Portugal)
STECF – Scientific, Technical and Economic Committee for Fisheries
VMS – Vessel Monitoring System

I. EXECUTIVE SUMMARY:

Background to seabird bycatch & mitigation in gillnets

The incidental capture of non-target marine animals in fishing gear, such as seabirds, cetaceans, elasmobranchs, and turtles, is commonly referred to as 'incidental bycatch'. Seabird bycatch in bottom set gillnet fisheries (GNS) is known to be a major conservation issue both globally and within Europe; an estimated 76,000 birds are caught annually in the Baltic Sea alone (Žydelis et al. 2013). Diving seabirds, such as seaducks, auks, divers, grebes and cormorants are particularly susceptible to capture in this gear.

Gillnets, made of thin nylon twine, are essentially invisible under water, and diving birds are presumably not able to perceive the net whilst foraging at depth, becoming entangled and drowning. This particular fishing gear is used extensively across Europe, with both small and large-scale fleets operating in EU member states' waters. A lack of systematic data collection across most of Europe on gillnet fishing effort (particularly small-scale vessels) and on bycatch has meant that little information is available to assess which countries, fleets and sites are particularly at risk of causing seabird bycatch. Despite the general lack of information, some studies on seabird bycatch in gillnets have been conducted over the past few decades and these indicate that specific regions of Europe are 'hotspots' for bycatch in this gear. The Baltic Sea, with its internationally important populations of wintering seaducks, such as long-tailed duck, velvet scoter, common and steller's eider is one such 'hotspot'.

In addition to the lack of fine scale information on gillnet fisheries, one of the most significant challenges for managing bycatch in this gear is the lack of technical solutions. For other fishing gears, such as longlines and trawls, technical solutions have already been developed and successfully implemented in a number of fisheries (largely outside of the European Union), resulting in substantial reductions (or even the elimination) of seabird bycatch.

Study objectives & tasks

The objective of this study is to identify technical solutions, both economically and biologically sustainable, to mitigate the incidental bycatch of seabirds in static net fisheries in EU waters (excluding the Mediterranean), with a particular emphasis on the Baltic Sea, eastern North Sea and western waters.

This study is divided into four main tasks:

1) Desktop study including the assessment of the present knowledge of incidental seabird bycatch in static net fisheries and of the current status of mitigation measures available for reducing seabird bycatch in static net fisheries and applicability to fisheries in Baltic, North Sea and western waters
2) Technical study to identify and then test at least two mitigation measures (devices or changes to fishing tactics) during key periods of high bycatch risk in two different sea basins (including the Baltic Sea)
3) Impact study to assess the short term economic impacts of the suggested technical solutions to the fishing industry; a long-term analysis on the likely impacts on threatened seabird populations on the basis of widespread usage of the technical solutions development.
4) Dissemination of results to stakeholders and the European Commission through a dedicated conference in European Commission DG-MARE premises on 28th September 2017.

Methods for technical and impact study

For the purpose of achieving the study objectives, a research team was formed from staff in the UK (BirdLife International, RSPB, MRAG Ltd), Poland (NMFRI, OTOP) and Portugal (SPEA). Teams in Portugal and Poland were responsible for organising and carrying out an observer programme to record data from at-sea trials of two different mitigation measures (high contrast panels in Portugal and net lighting in Poland) in collaboration with the local gillnet fishing industry. Experimental mitigation measures were chosen based on a sensory ecology approach, on the basis that these measures would provide visual cues to diving birds to alert them to the presence of the net. The trials were focused on existing Natura 2000 sites in both countries (Puck Bay Special Protection Area- SPA, Pomeranian Bay SPA in Poland; Berlengas Archipelago SPA in Portugal) where gillnet bycatch of seabirds was known to occur. Paired trials of control (standard nets) and experimental (nets carrying mitigation measures) sets were conducted in both countries. Economic data was collected by the on-board observers, and questionnaires for vessel skippers were distributed to allow an assessment of mitigation gear acceptability (the economic component of the impact study).

Furthermore, this study aimed to understand the potential impact of mitigation solutions on vulnerable focal seabird populations and on the economic viability of gillnet fishing fleets operating within the study area. A focal bird species was selected to explore likely impacts of bycatch in each region of the technical study, based on frequency of bycatch in the respective fishery and conservation status; long-tailed duck for Poland and razorbill for Portugal. Bycatch estimates were defined based on the available literature and data from this study and adjusted by results of the mitigation trials where appropriate, then compared with estimates of Potential Biological Removal (PBR) respectively. PBR is a method that can be used to identify the number of additional mortalities that can be sustained each year by a population.

Results of technical study

A total of 74 fishing trips were monitored by trained observers in Poland during the autumn/winter/spring of 2015/2016 and 2016/2017. Bycatch data in all 161 observed nets (experimental nets with lights and control nets) was recorded and used in a statistical analysis for direct comparison between control and experimental nets. A total of 106 bycaught birds were recorded during the paired trials, with long-tailed ducks being the most numerous species recorded (~74% of all bycaught birds).

A binomial generalised linear mixed model examining the probability of catching any seabirds indicated that the effect of net lights was slightly negative (e.g. bycatch was lower in experimental sets), but this was not statistically significantly.

A total of 22 trips were observed in Portugal, using the net panels. No seabird bycatch was recorded during the observed trips in Poland in either the control or experimental sets, making it impossible to assess the effectiveness of the high contrast panels using data collected by this study. Bycatch is episodic in nature, and the relatively few trips carried out (due to bad weather during the field season) meant that bycatch is likely to have occurred, just not on the observed vessels.

Results of impact study

- Impact on seabird populations

The impact analysis on seabird populations developed conservative estimates of PBR: 2,919 birds for long-tailed ducks (*Clangula hyemalis*) and 6,079 birds for razorbills (*Alca torda*). For this study, we have only been able to make relatively crude annual estimates of long-tailed ducks caught in one area of the Polish coast, Puck Bay: 2,486 and 2,350 long-tailed ducks in 2013/14 and 2014/15 respectively. However, these estimates represent between 81% and 85% of the more conservative estimate of PBR for the European population of long-tailed duck. Given the relatively substantial additional mortalities reported for this species from other human activities such as hunting, it is therefore easy to comprehend why this population is in decline.

Based on the bycatch data from previous research in Puck Bay, Poland, and the difference (not statistically significant) between experimental and control nets, we estimated that bycatch of long-tailed ducks could be reduced by 42% in Puck Bay if net lights proved to be an effective mitigation measure (and bycatch species composition remained the same).

- Economic impact of mitigation gear

Results of the economic impact study indicate that the costs to equip existing gillnets with each of the focal mitigation measures (outlay costs) were similar: The cost to equip a gillnet with lights in Poland cost ~0.42 Euro per metre of net; whereas the cost to equip a gillnet with high contrast panels was ~0.43 Euro per metre. Comparing the outlay costs to the original manufacturing costs of gillnets suggests that the costs to modify gillnets with lights represented a 45 – 50% increase to the original manufacturing cost of the net; whereas the cost to modify gillnets with high contrast panels represent a 26 - 40% increase.

The evaluation of fisheries catches indicates that there was no statistically significant difference between the volume of fish caught by normal gillnets and the volume of fish caught by gillnets equipped with the mitigation measures. This is a positive outcome for future mitigation work using visual cues, but it is recommended that more data are gathered to confirm this result. Interviews with fishermen participating in the field trials however, indicated that issues associated with handling gear equipped with mitigation measures were encountered in both Poland and Portugal. Specifically, nets equipped with lights caused entanglement when nets were hauled, and nets equipped with panels increased drag and weight of the nets. Further work is therefore required to improve the design of the focal bird bycatch mitigation measures to eliminate the reported handling issues.

Conclusions

- Overall assessment of mitigation measure effectiveness

The results of our net light trials in Puck Bay and the Pomeranian Bay did not demonstrate a statistically significant reduction in seabird bycatch in illuminated sets. However, a reduction in bycatch is evident (mean overall bycatch is reduced by 32% in illuminated sets), and is more pronounced for long-tailed ducks than for all species combined. Although the lack of statistical significance means this reduction should not be interpreted as an outright success, it does highlight that net illumination is a worthy avenue for future research.

More research is needed on what European seabirds find aversive (potentially with captive populations) and further trials with the same lights would help to highlight if this was the case.

In relation to net panels, there were no birds caught in the control or the experimental sets during the observed trips in Portugal. Whilst this lack of bycatch prevented us from examining the efficacy of net panels in reducing the number of seabirds caught, complementary research in Lithuania has found that panels did not reduce bycatch. The work in Lithuania demonstrates that panels, whilst most likely visible to seabirds (Martin and Crawford, 2015), are not sufficiently aversive to result in birds avoiding nets.

- Issues/assumptions

The most fundamental issue this study encountered was a lack of data- not only on bycatch mitigation in gillnet fisheries, but numbers of birds caught in gillnets and basic gillnet effort data. These knowledge gaps create substantial barriers for assessing bycatch impacts on populations and measuring change - a number of future recommendations are targeted to address these issues.

The wide scope of this study also presented a challenge - it is difficult to design a study that simultaneously develops mitigation measures (which requires directing data collection towards areas of known high bycatch to obtain large enough sample sizes) and assesses bycatch in gillnet fisheries at a broader (i.e. country) scale (which requires stratified, non-biased sampling across space and time). This restricted our ability to assess the potential population-level effects that mitigation measures might have.

The changes to seabird populations, at-sea distributions and the effects of a host of threats (climate change, oil pollution, hunting, invasive species) make it difficult to disentangle the importance of individual threats. This is a further complicating factor in assessing the influence of bycatch on seabird populations.

- Recommendations for future research

This study has identified a number of key recommendations for research in order to make further progress in identifying effective solutions for this fishery:

  - Further research work is needed to determine the suitability of LED lights as a mitigation measure for gillnet bycatch.
  - Further work is needed to investigate aversive stimuli for the most susceptible species of seabird (velvet scoter, long-tailed duck, razorbill, common guillemot, common eider,

    great cormorant) (i.e. work with captive birds to discern what ‘scares’ them effectively).
    - Based on the output of this work, design audio and visual (including light) alerts and test behavioural responses and impacts on bycatch rates in active fisheries.
    - Collaboration between fishing industry, government bodies, expert bodies such as ICES, NGOs and academia should be sought and strengthened in order to focus on answering key scientific questions, and examining opportunities for financing experimental work & scientific research.
    - Collaboration with oceanographers to understand the environmental characteristics of key sea basins at the time of highest bycatch (i.e. Baltic/Atlantic in the winter).
    - Further research into seabird distribution and habitat use at sea - combined with research into fish behaviour, catch rates and efficiency - would assist in better design of temporal and spatial fisheries management to minimise economic impacts and bycatch at the same time.

- Policy recommendations based on outcomes of this study

This study has identified a number of key recommendations for policy in order to strengthen the management of fisheries in EU member states.

    - Systematic and standardised data collection on fishing effort and bycatch in small scale gillnet fishing fleets (including vessel monitoring AIS/VMS), particularly where fishing occurs in Natura 2000 sites
    - Improved availability of fine scale fishing effort and bycatch data for fisheries research purposes to allow for identification of high bycatch risk areas and extrapolation of bycatch to fleet level, including with expert groups such as ICES who hold different data sets.
    - Dedicated research programmes needed in EU member states to test gillnet bycatch mitigation solutions over longer periods of time and in high bycatch areas
    - Additional funding and investment needed in developing mitigation solutions that are specifically designed for gillnet operations
    - In the absence of effective mitigation, and in the context of Natura 2000 sites with high concentrations of seabirds, all the available management options require examination by EU member states (e.g. temporal/spatial closures, gear switching to traps/pots etc.), although this may not be appropriate in all fisheries/sites/contexts.

Additional recommendations for policy in order to strengthen the management of fisheries in EU member states.

- EMFF- EU Member States should promote the use of this funding stream to investigate gillnet bycatch and mitigation measures- particularly in countries with high bycatch risk- and NGOs should be eligible to lead innovation and research activities

Dissemination of results

The results of the technical and impact study, and the recommendations for research and policy were presented by the study team during a lunchtime conference in DG MARE premises on 28th September 2017 with the participants from the European Commission services (DG MARE mainly, EASME, DG ENV and DG RTD).

II. GENERAL SUMMARY:

Bycatch of seabirds in gillnets is a globally important conservation issue. The Baltic Sea, with its internationally important populations of wintering seaducks, such as long-tailed duck, velvet scoter, common and steller's eider is considered a global 'hotspot' for seabird bycatch in this fishing gear.

Gillnets, made of thin nylon twine, are essentially invisible under water, and diving birds, such as seaducks are presumably not able to perceive the net whilst foraging at depth, becoming entangled and drowning. This particular fishing gear is used extensively across Europe, with both small and large-scale fleets operating in EU member states' waters. A lack of systematic data collection across most of Europe on gillnet fishing effort (particularly small-scale vessels) and on bycatch has meant that little information is available to assess which countries, fleets and sites are particularly at risk of causing seabird bycatch.

In addition to the lack of fine scale information on gillnet fisheries, one of the most significant challenges for managing bycatch in this gear is the lack of technical solutions. For other fishing gears, such as longlines and trawls, technical solutions have already been developed and successfully implemented in a number of fisheries (largely outside of the European Union), resulting in substantial reductions (or even the elimination) of seabird bycatch. Given that gillnets are so widespread, and that threatened populations of seabirds are at risk of capture, and that there are currently no technical gear solutions, there is therefore an urgent need to determine if technical gear modifications could reduce seabird bycatch in this fishing gear.

This study: *Mitigation Measures to Minimise Seabird Bycatch in Gillnet fisheries* has focused on this specific issue, including on identifying, testing and assessing the effectiveness and impact of two experimental, technical gear modifications for bycatch reduction on gillnet fishing gear.

The **overall objective** of this study was to identify technical solutions, both economically and biologically sustainable, to mitigate the incidental bycatch of seabirds in static net fisheries in EU waters (excluding the Mediterranean), with a particular emphasis on the Baltic Sea, eastern North Sea and western waters. The study did this through four specific tasks:

1. Desktop study including the assessment of the present knowledge of incidental seabird bycatch in static net fisheries and of the current status of mitigation measures available for reducing seabird bycatch in static net fisheries and applicability to fisheries in Baltic, North Sea and western waters
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4. Dissemination of results to stakeholders and the European Commission through a dedicated conference held in the European Commission DG-MARE premises on September 28th 2017.

The technical study identified the most suitable experimental mitigation measures- high contrast net panels and net lights- to test on fishing vessels in different countries and sea basins. The Baltic Sea (Poland, for net lights) was chosen and the south-western waters (Portugal, for net panels). As part of the impact study, economic data was also collected in order to assess the potential impact of wide-scale adoption of mitigation measures.

Net lights were shown to potentially reduce bycatch, although the results were not found to be statistically significant, and a larger sample size is needed in order to more conclusively demonstrate their effectiveness. It was not possible to determine if net panels were effective in reducing bycatch from the data available in the study, although results from external studies carried out concurrently suggest that they are not effective as a mitigation measure (at least in the Baltic Sea). Results of the economic impact study indicate that the costs to equip existing gillnets with each of the focal mitigation measures (outlay costs) were similar. The evaluation of fisheries catches indicates that there was no statistically significant difference between the volume of fish caught by normal gillnets and the volume of fish caught by gillnets equipped with the mitigation measures.

An assessment of the impact of bycatch on threatened seabird populations focused on the long-tailed duck *Clangula hyemalis* and razorbill *Alca torda*, as the most regularly caught species in each of the countries. An analysis to identify the number of additional mortalities which could be sustained each year for the European populations of both species produced conservative estimates of 2,919 long-tailed duck and 6,079 birds for razorbills. Our findings suggest that bycatch in Puck Bay, Poland, alone could represent between 81% and 85% of the more conservative estimates for the European population of long-tailed duck. Furthermore, we estimated that bycatch of long-tailed ducks could be reduced by 42% in Puck Bay if net lights proved to be an effective mitigation measure (and bycatch species composition remained the same).

Further research, including additional testing of net lights, and investigating aversive stimuli for seabirds is needed, and national research programmes should be developed to tackle gillnet bycatch mitigation. Fine scale information on seabird distribution is needed to inform potential temporal/spatial closures. Data collection of bycatch and fishing effort for all fishing gears, and particularly small-scale fleets using gillnets needs to be strengthened, and data made available for similar research efforts.

1. INTRODUCTION

1.1. BACKGROUND INFORMATION ON SEABIRD BYCATCH IN GILLNETS

Seabird bycatch in gillnet fisheries (set nets and driftnets) is a conservation issue of global concern, with an estimated 400,000 seabirds caught annually across the world (Žydelis *et al.,* 2013). Some of the most problematic fisheries are known to occur in Europe (see 3.1.1, 3.1.2, 3.1.3, 3.1.4).

Bycatch in gillnets occurs simply because the nets are not detected by seabirds - nets are essentially invisible underwater (Žydelis *et al.,* 2013; Martin & Crawford, 2015). This is due to the nature of the underwater visual environment (low light, few visible wavelengths), the need for birds to adapt their vision to two very different media (air and water) resulting in visual trade-offs in each environment for seabirds, and the fine nylon from which almost all modern gillnets are constructed making them invisible underwater (Martin & Crawford, 2015).

A review of seabird bycatch in gillnet fishing gear identified 148 species across the world which are thought to be particularly susceptible to being caught in both driftnets and set nets based on their feeding ecology (Žydelis *et al.,* 2013). Seabirds that forage by diving for fish or benthic fauna are most at risk (Žydelis *et al.,* 2013).

In total, there are 40 European seabird species which have been assessed as at risk from bottom set gillnet fishing gear (Žydelis *et al.,* 2013; Annex 1). The European seabird species considered to be most susceptible to gillnet bycatch include common guillemot *Uria aalge*, thick-billed murre *Uria lomvia*, red-throated loon *Gavia stellata*, greater scaup *Aythya marila* and long-tailed duck *Clangula hyemalis* (Žydelis *et al.,* 2013). Recent studies have also indicated that bycatch occurs in significant numbers for the velvet scoter *Melanitta fusca* - a species listed as Vulnerable on the IUCN Red List - during the autumn and winter months in the Baltic Sea (e.g. in Lithuania, Tarzia *et al*., 2017). Within Europe, bycatch has also been recorded of the critically endangered balearic shearwater *Puffinus mauretanicus*, and the vulnerable razorbill *Alca torda*, along the Portuguese Atlantic coast (Oliveira *et al.,* 2015). Black Guillemots *Cepphus grylle*, are known to be caught in this fishing gear (BirdLife International, unpublished), although the available data is from Iceland and not from within the EU. A further 10 species have been recorded as bycatch, although their foraging ecology makes it less likely that they will be regularly caught. Other seabirds such as gulls and terns may become entangled during setting or hauling, rather than when the net is in place at depth (Žydelis *et al.,* 2013).

1.1.1. GILLNET BYCATCH IN EUROPE: THE OVERALL PICTURE

Gillnets are an important fishing gear within EU countries. Excluding vessels registered in EU Mediterranean countries, there are 24,577 vessels that are registered as using set gillnets as primary or secondary gear, and 22,575 of these vessels are small scale (<12m) (EU Fishing Fleet Register, 2016; see Annex 3). The small-scale nature of these vessels means that vessel monitoring (VMS, AIS) is largely unavailable, making it difficult to assess, at the broad scale, the extent to which these vessels are overlapping with areas used by susceptible seabirds. At a finer scale, there has been a lack of systematically collected seabird bycatch data on vessels across fishing gears which is further detailed below (JWGBIRD, 2017), though the recently adopted Data Collection Regulation ((EU) 2017/1004 and Commission Implementing Decision (EU) 2016/1251) brings in requirements for Member States to report on seabird and other non-target bycatch in fisheries and Commission Implementing Decision (EU) 2016/1701 provides rules for the reporting format of data collection in the fisheries and aquaculture sectors.

Across Europe a number of studies have been carried out- although limited to specific countries and sites- over the last three decades to directly examine the seabird bycatch in this fishing gear type (Žydelis *et al.,* 2009; Bellebaum *et al.,* 2013; Oliveira *et al.,* 2015) and some studies have compiled and examined this information at larger regional scales (ICES 2013a, 2013b, 2015, 2016b; Žydelis *et al.,* 2013). Large gaps exist in our understanding of this issue within the European region. Most studies are focused at the level of a single site within a country and bycatch estimates are rarely scaled up to the national fleet level due to a lack of information on fishing effort. Furthermore, there has been a lack of consistency in how bycatch rates have been presented, with measurements including bycatch per boat and per trip, or by the extent of nets set by day (1000 net metre/day). This has made meaningful scrutiny of an already patchy data set more complex. It is therefore difficult to produce estimates of numbers of birds caught annually at national or regional level; or understand the susceptibility of a species in a specific location without direct observation; or understand the spatial and temporal distribution of gillnet fishing fleets and fine scale overlap with the susceptible seabird species.

Understanding the impact of bycatch on seabird populations is further complicated by climatic changes, which are shifting seabird migrations in time and space and altering benthic and pelagic food supplies. These factors make the predictions of overlap between seabirds and gillnet fisheries even more complex. For example, climatic changes in the Arctic breeding grounds and other pressures such as predation have reduced the numbers of wintering seaducks arriving in the Baltic Sea (Skov *et al.,* 2011). Changes in winter sea ice extent has also altered the distribution of seaduck species, allowing birds to disperse much further across the Baltic Sea (Skov *et al.,* 2011).

The information summarised below for each EU sea basin represents the state of existing knowledge on seabird gillnet bycatch, much of which has already been collated in published reviews (Žydelis et al., 2009, 2013). A more detailed country breakdown is provided in Annexes 3 and 4.

1.1.2.BYCATCH IN THE BALTIC SEA

The Baltic Sea is globally important for over-wintering seaduck species (Skov *et al.,* 2011), which as benthic feeders are particularly vulnerable to being caught in gillnets. There are also breeding populations of seaducks, including in the Gulf of Bothnia. Auks (Annex 1, the Alcidae family, including species such as common guillemot and razorbill) are also present in the Baltic with breeding sites in both Denmark and southern Sweden. The gillnet fisheries operating across the Baltic Sea region are estimated to catch 76,000 seabirds annually, one of the highest estimates globally (Žydelis *et al.,* 2009 & 2013; ICES 2013a). To investigate the number of seabirds caught in gillnets, research (via both on-board observation and questionnaires) has been carried out in some countries over a number of years, including Lithuania, Poland and Germany. In other Baltic countries, such as Estonia, Finland, Latvia, Sweden and Denmark, there has been much less dedicated research, with few published reports quantifying bycatch numbers. Progress is being made however, with recent work by Dagys *et al.* (2009) in the south-eastern Baltic countries, and current ongoing work in Denmark (I. Krag Petersen, pers. comm; Kindt-Larsen, pers. comm.).

As discussed above, climatic changes are altering the number and distribution of wintering seaducks within the Baltic Sea. Furthermore, a recent series of warmer winters has also changed the availability of target fish species, altering the timing and duration of fishing activity in some Baltic countries. For example, in gillnet fisheries in Puck Bay, Poland, a drastic decrease in cod catches has been recorded, i.e. from 253.2 tons in 2012 to 20.9 tons in 2016 (source: Polish Fisheries Monitoring Centre) A similar trend was also observed in flounder catches with approximately 30% decrease during the same period. Although there is no evidence to link such changes directly to changing climate, the decrease in cod and flounder during the warmer winters, most likely led fishers to move further out of Puck Bay to deeper waters and therefore away from the areas with highest bird densities (T.Linkowski. pers. comm).

1.1.3.BYCATCH IN THE NORTH SEA

The North Sea is important for breeding and non-breeding seabirds. An estimated 2.5 million pairs of seabirds breed along the North Sea coastline, including auks, cormorants, gannets and gulls (ICES, 2008) that use the North Sea to feed. Migrating seaducks such as common eider, greater scaup, common merganser, common goldeneye and loons and grebes spend time during the winter along the coasts of Germany, the Netherlands, Belgium and the UK (BirdLife International, 2016). The North Sea is an important and productive fishing ground but again there is very little information on gillnet bycatch across the region, making it very difficult to assess the threat, despite the year-round presence of large numbers of susceptible species (particularly auks, cormorants etc.). Žydelis *et al.* (2009 & 2013) estimated gillnet bycatch in the North Sea and Baltic Sea combined at 90,000-100,000 birds annually, suggesting that up to 24,000 birds could be caught in the North Sea alone. The lack of knowledge is an important gap which requires attention, and on-board observation, fisher surveys and evaluation of the temporal and spatial distribution of effort should be carried out.

1.1.4.BYCATCH IN THE WESTERN WATERS

The Western waters of the North East Atlantic, including the UK (English Channel, Celtic Seas), Ireland, France, Portugal and Spain are important for both breeding and non-breeding seabirds and are also important fishing grounds. Žydelis *et al.,* (2013) suggested that gillnet bycatch might be lower in this region compared to the Baltic and North Sea, however very little research has been carried out across this region. Recent research in Portugal (Oliveira *et al.,* 2015) and in France (Bugot & Boue, 2012) indicate that the critically endangered balearic shearwater could be caught in low numbers in this fishing gear. Since this species migrates across the Western Waters region (extending up to the English Channel), and has a high extinction risk (Genovart *et al.* 2016) it is important to understand the extent to which bycatch of this species occurs in this region and fishing gear. The region is also used extensively by other susceptible species, such as northern gannet *Morus bassanus*, razorbill, common guillemot and atlantic puffin *Fratercula arctica*.

1.2. CURRENT STATUS OF TECHNICAL MITIGATION MEASURES

In addition to the lack of fine scale information on gillnet fisheries, one of the most significant challenges for managing bycatch in this gear is the lack of technical solutions. For other fishing gears, such as longlines and trawls, technical solutions have already been developed and successfully implemented in a number of fisheries (largely outside of the European Union), resulting in substantial reductions (or even the elimination) of seabird bycatch.

Technical mitigation measures are adjustments made to standard fishing gear in order to reduce bycatch. Overall, very little research has explored technical means of reducing avian bycatch in gillnets (Žydelis *et al.,* 2013).

To date, this has resulted in a greater focus on changes to fishing tactics by fisheries managers and other stakeholders attempting to reduce gillnet bycatch, particularly operational measures (e.g. spatial/temporal closures) (Carretta and Chivers, 2004; Washington Department for Fish and Wildlife, 2015). Here we review both approaches to bycatch reduction: focussing firstly on existing research and recent developments in technical mitigation, and then potential changes to fishing tactics to reduce seabird bycatch.

This study has focused on developing mitigation for bycatch occurring in set nets (GNS), rather than driftnets (DFN), given its prevalence as a fishing gear across the EU. Little is known about mitigating bird bycatch in either gear configuration. Although the focus is on static net fisheries, we have included a summary of experimentation in driftnet fisheries that may have relevance to set nets. This section is divided into visual and acoustic bycatch mitigation measures.

1.2.1.VISUAL BYCATCH MITIGATION

- Visual bycatch mitigation- high visibility sections of netting

Melvin *et al.* (1999) examined the effects of high-visibility sections of netting on seabird bycatch in the coastal salmon driftnet fishery in the Puget Sound, Washington State, USA (see Figure 1). This involved comparing bycatch levels in normal monofilament nets against two different experimental nets, incorporating sections of high-visibility (white) multifilament meshes, 20 and 50 meshes ‘deep’ at the top of the net (representing ~10% and ~25% of the net ‘height’ respectively).

Figure 1. Vessel deploying salmon driftnet with upper 20 meshes of white netting in Puget Sound fishery, USA ©Rory Crawford, BirdLife International

This design was based on the observation that most bycatch occurred in the upper sections of the nets, particularly when large numbers of 'rafting' auks drifted towards nets on currents and were startled by the float line, after which they attempted to dive underwater to escape it (Melvin *et al.,* 1999; S. Moore, Puget Sound Fisherman, pers. comm.). By introducing more visible upper meshes, it was hoped that birds would fly or jump over the float line as an escape response rather than diving. The 20 and 50 mesh sections resulted in 45% and 40% reductions, respectively, in common guillemot bycatch. Rhinoceros auklet *Corrina monocerata,* bycatch was only reduced in the 50-mesh section net (by 42%), indicating species-specific effects. Although effective in reducing the bycatch of both species, the 50-mesh panel net also resulted in a substantial reduction in target fish catch. These experiments resulted in the 20 mesh panel nets - which maintained target catch rates - being legally mandated in the Puget Sound salmon driftnet fishery (Washington Department for Fish and Wildlife, 2015).

Similar nets were trialled on a pilot basis in the bottom-set Baltic cod (*Gadus morhua)* gillnet fishery in Lithuania, in 2014. While only a small number of trials were possible, there appeared to be no discernible difference in bycatch levels (largely of velvet scoter) (Crawford, R. and Morkūnas, J., pers obs.). In consultation with sensory ecologists, it became clear that such modifications would not make nets any more visible to birds at depth in the Baltic Sea (Martin and Crawford, 2015). However, adjustments to mesh thickness and colour may continue to have utility in clear waters, particularly for driftnet or surface-set fisheries, as experiments with captive penguins by Shet *et al.* (2016) indicate this is worthy of further exploration.

Under a byelaw introduced in 2010, salmon and trout netsmen in Filey Bay, UK, are obliged to use modified surface-set nets to prevent seabird (particularly razorbill and common guillemot) bycatch. These nets are J-shaped when viewed from above, with a leader section that funnels the fish into a curved area at the end, trapping them. These modified nets incorporate a thicker, high-visibility black multifilament leader section. This does not reduce target fish catch (indeed, some fishermen have commented that it enhances fishing (Harrison, R., pers comm.)), and is thought to help reduce bycatch (fishers note that fewer birds are caught in the leader section compared to the curved section). However, no direct comparison has been made between these nets and the old, all-monofilament nets.

- Visual bycatch mitigation- Metal oxide nets

In 2003, Trippel *et al.* published work examining the cetacean bycatch reduction efficacy of nets that incorporated metal oxides (in this case, barium sulphate $BaSO_4$) into the net material. The premise of this study was that the increased acoustic reflectivity of the gillnet would allow cetaceans to better detect them with echolocation. This study found that harbour porpoise *Phocoena phocoena* bycatch was reduced in the metal oxide net compared with a normal monofilament net, and inadvertently found there to be a substantial (4x) reduction in great shearwater *Puffinus gravis* bycatch, thought to be a result of the greater visibility of the metal oxide net. No reduction in target fish catch was recorded. Conversely, Northridge *et al.* (2003) recorded higher bycatch rates of harbour porpoises and seals in barium sulphate nets compared with monofilament nets (bird bycatch was not examined in this study). More recent studies have added to these mixed findings, with some demonstrating bycatch reductions for cetaceans in metal oxide nets (Larsen *et al.,* 2007) and others finding no difference (Bordino *et al.,* 2013). It seems that the incorporation of metal oxides changes the behaviour of nets in a way that is not fully understood: Larsen *et al.* (2007) proposed that the changes in bycatch were the result of changes in the physical properties of the net, rather than acoustic reflectivity.

- Visual bycatch mitigation- Net panels

Martin and Crawford (2015) published a review examining gillnet bycatch from a sensory ecology perspective, primarily to inform the design of mitigation measures based on how birds (and other taxa) perceive the underwater world. The challenges of underwater vision (i.e. reduced light availability and limited wavelengths penetrating at depth, trade-offs for animals like seabirds that require eyes to operate in both air and water) led these authors to conclude that the best way to alert birds to nets is to incorporate stimuli with high internal contrast. Based on this, black and white panels, attached at regular intervals (every 4m) along gillnets, are proposed as a mitigation measure in this study. These underwent preliminary testing in 2015/16 in Lithuania, where they showed initial promise as a bycatch mitigation measure (numbers of birds caught overall lower in nets with panels attached, though with no significant difference) (see Figures 2 and 3 below). Further paired trials of net panels were conducted in Lithuania concurrently with this project to try and derive more conclusive results (Tarzia *et al*., 2017).

Figure 2. Net panel attached to cod gillnet, Lithuania © Julius Morkūnas, Seabird Task Force, BirdLife International

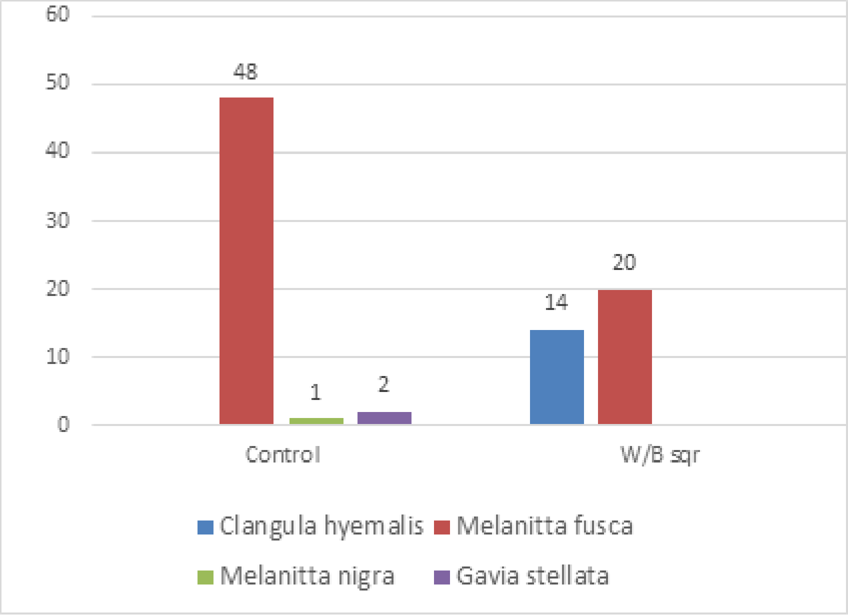

Figure 3. Preliminary results from 78 trips on cod gillnet vessels in Lithuania comparing control sets (left hand side) and experimental sets with panels attached (right hand side)

- Visual bycatch mitigation- Net lights

Net lighting (using longline fishing Light Emitting Diode (LED) lights clipped along the headline at regular intervals) shows promise as a multi-taxa gillnet mitigation measure (see Figure 3 below). Originally developed by using a sensory ecology approach for sea turtles (Wang *et al.,* 2013; Ortiz *et al.,* 2016), testing in Peruvian demersal-set nets (lights attached every 10m along the floatline) suggests that green-coloured LED lights are effective for sea turtles and may also reduce the bycatch of seabirds, with statistically significant reductions of ~84% recorded for guanay cormorant *Phalacrocorax bougainvillii* in illuminated nets versus standard set nets (Mangel *et al.,* 2014; Mangel *et al.,* unpubl. data).

- Visual bycatch mitigation- Lowering net profile and sub-surface setting

Lowering the profile of gillnets in the water column has been utilised as a mitigation measure to reduce turtle bycatch, with reductions found in some fisheries (Price and Van Salisbury, 2007) but not others (Maldonado *et al.,* 2006). This measure has not been tested for seabirds, though some authors suggest that it will have minimal effect given the benthic or near-benthic foraging ecology of a number of vulnerable species (seaducks, cormorants) (Koschinski and Strempel, 2012). However, the measure may have utility for some species, depending on their foraging ecology. By way of example, dropping the headline of driftnets below the surface was shown to reduce shearwater and albatross bycatch on Japanese squid vessels, though target catch rates were also reduced significantly (Hayase and Yatsu, 1993).

Figure 4. Hauled gillnets in Peru with net lights attached to headline. © Jeff Mangel, ProDelphinus

1.2.2. ACOUSTIC DETERRENTS

Melvin *et al.* (1999) tested pingers (acoustic deterrents are more widely used to reduce cetacean bycatch (Dawson *et al.,* 2012)) in the same experiment that examined high-visibility sections of netting (see Figure 1 above). These were tuned to the generic audiogram of birds (~1.5kHz) and trials recorded a 50% reduction in common guillemot bycatch – though rhinoceros auklet bycatch was not reduced, indicating species-specific effects. Target catch was unaffected in the Melvin *et al.* (1999) study, though there is some evidence that suggests pingers may increase seal depredation of gillnets (via a 'dinner bell' effect) (Kraus, S., 1999); however, research in other fisheries refutes this (Carretta and Barlow, 2011). Curiously, pingers tuned to deter marine mammals in Kodiak Island salmon fisheries were found to *increase* seabird bycatch (Manly, 2009).

Acoustic deterrents do show promise, but with such mixed results, further research into seabird hearing, potentially with captive birds, will allow the use of acoustic mitigation measures to be better understood and further refined (Wiedenfeld *et al.,* 2015).

1.2.3. CHANGES TO FISHING TACTICS

- Changes to fishing tactics- Spatial/temporal closures

In the absence of effective best practice technical mitigation measures, there is often a reliance on separating gillnet fishing from bycatch-susceptible seabirds in either space or time through the use of area or temporal closures. To be truly effective, however, this approach requires sound knowledge of critical habitat and life history of bycatch species, as well as enforcement capacity (O'Keefe *et al*., 2013).

Only a small number of studies have examined the efficacy of spatial or temporal fisheries closures for birds. Melvin et al. (1999) did not test this specifically, but the effects of fine-scale closures on salmon fishing at times of day with peak bird abundance and bycatch (dawn and dusk) were considered. Avoiding sunrise and dusk fishing would have reduced bycatch by 25% in the year that the authors considered, and more substantial reductions in bycatch (43%) could have been achieved by restricting fishery openings across the season to times of peak target species abundance. This shows the potential for fine-scale adjustments to reduce bycatch, but only where there are good data on target and bycatch species life histories, an issue elaborated on in O'Keefe *et al*., (2013).

Nearshore spatial closures of the set net fishery for California halibut *Paralichthys californicus*, implemented through the 1980s, became progressively more restrictive, and reduced seabird (largely common guillemot) bycatch significantly (Wild, 1990). In 1994, these closures were extended to three nautical miles from land in southern California, and then other parts of the state's waters were closed, further reducing bird bycatch (Carretta and Chivers, 2004).

Two studies from the Baltic Sea indicate that bycatch is higher in shallower waters (Stempniewicz, 1994; Bellebaum *et al*., 2013), which may indicate the potential for depth-based spatial closures - although this will depend on the species present, so this must be looked at on a case-by-case basis (e.g. velvet scoters forage in deeper water than long-tailed ducks, so species ecology, abundance and vulnerability should be central to any management proposals (J. Morkūnas, pers comm.)).
Temporary spatial closures in the UK have been triggered by certain levels of bird bycatch, as in St. Ives Bay, where bass driftnets are prohibited for 21 days if there are reports of 100 or more bird mortalities. However, no analysis is available on levels of bird bycatch outside of the bay after the temporary closure has been triggered.

Overall, temporal and spatial closures do show some potential for reducing seabird bycatch where there is enough information for effective design at the appropriate scale (Melvin *et al.,* 1999). The economic impact of closures can be substantial, depending on the ability of vessels to find other suitable fishing grounds.

- Changes to fishing tactics- Gear switching

Switching gillnets for other fishing gear has been tested as a means of reducing bycatch. This has included switching to longlines and jigging reels for cod in Germany (Mentjes and Gabriel, 1999; Detloff, K., unpublished data), as well as tests of fish traps for herring in Lithuania (Vetemaa and Lozys, 2009) and baited pots for cod in several countries (Strempel and Koschinski, 2012).
Longlines in Germany have recorded substantially less bird bycatch than cod gillnets. Mentjes and Gabriel (1999) found 13.8 birds caught per tonne of longlined cod compared to 43.9 birds/t cod in gillnets. Vetemaa and Lozys (2009) recorded no bird bycatch in cod longlines in Lithuania, and target species catch did not appear to decrease significantly. However, the catch efficiency for the target species can be vastly reduced, as recorded in recent trials in Germany, where some gull bycatch also occurred (Detloff, K., pers comm.). Jigging reels targeting cod have undergone only preliminary testing and data are not currently available to compare their economic viability or bycatch reduction potential to gillnets (Detloff, K., pers comm.).

Lithuanian trials of herring trap nets were shown to have improved catch efficiency versus gillnets, with no bird bycatch (Vetemaa and Lozys, 2009). The higher capital costs and the need to learn a new method of fishing may be reasons that this method has not been more widely adopted, but otherwise this gear merits further research. However, it should be noted that in Lithuania the cod gillnet fishery records far higher bycatch rates than in those fisheries for smaller species, perhaps a function of the larger mesh size used (Dagys and Žydelis, 2002; Morkūnas, J., pers comm.).
Baited pots have been tested in fisheries that might otherwise use gillnets, for example to target cod in Norway (Furevik and Lokkeborg, 1994), Germany (Lorenz and Schulz, 2009), Denmark (Hedgärde *et al*., 2016) and Sweden (Ljungberg, 2007). In trials, bird bycatch is substantially reduced compared to gillnets, though fishing efficiency may also be reduced (Koschinski and Strempel, 2012). However, with further development and testing, this method may become more efficient, and recent trials suggest pot design could be further refined to improve catch (Hedgärde *et al*., 2016; L. Kindt-Larsen, pers comm.).

- Changes to fishing tactics- Net attendance

Depending on the characteristics of the fishery, it may be feasible for fishers to attend to their nets as they are fishing, and safely remove and release bycaught birds alive. Net attendance is undertaken by Filey Bay salmon netsmen in the UK for the month of June, when the risk of bycatch is thought to be highest (Harrison, R., pers comm.). However, there are many practical barriers to implementing these measures in set net fisheries, including: the overall lengths of nets set and their geographical location (i.e. impractical to observe all sets at once), the duration of the fishing period and the level of visibility/ability to detect bycatch (particularly in bottom-set gillnets).

1.3. APPLICABILITY OF MEASURES TO EU STATIC NET FISHERIES (EXCLUDING THE MEDITERRANEAN SEA)

Evidently, it is difficult to assess the success of seabird bycatch mitigation trials in gillnets, particularly with an EU focus, with the limited body of published literature. However, there are a number of important research avenues to pursue with regard to seabird bycatch mitigation in static net fisheries. In the context of this project, our focus for the technical study has been determined by the need to test measures in two sea basins, the limited budget and timescale. Clearly, it was not feasible to trial all the experimental mitigation methods reviewed above. The following assessment provides the logic for choosing the two focal mitigation measures, and will allow others to follow the most likely successful routes for bycatch mitigation.

- Assessment of potential mitigation measures to trial

High visibility nets utilising thicker, more visible twine in the upper net meshes (akin to Melvin *et al*., 1999) or along much of the net (as in Filey Bay, UK) do show potential in reducing bycatch. However, examining bycatch from a sensory ecology perspective (and preliminary results from testing in a bottom-set fishery) (Martin and Crawford, 2015) suggests that this approach, while relevant to some driftnet fisheries, is perhaps not more widely applicable, particularly in the bottom-set net fisheries that dominate in the gillnet bycatch 'hotspot' of the Baltic (Žydelis *et al*., 2013).

Metal oxide nets have had mixed success and do not show much promise, although an improved understanding of the physical properties of these nets, and how they behave in water, may help to determine what specific aspects have previously resulted in lower bycatch rates. Given these issues, we opted not to explore these two routes further in this study.

Lower profile nets may have utility in some fisheries. Intuitively, a net of lower height has a smaller surface area and thus presents a smaller area for entanglement, though this carries the risk of lower target catch rates as well as reduced seabird bycatch. Further on, with bycatch in the EU comprising a large number of benthivorous ducks and seabirds foraging near the seabed (Žydelis *et al*., 2013), this method is unlikely to be particularly effective, as so the team decided not to pursue this further in this study (Koschinski and Strempel, 2012). The research of Melvin *et al*. (1999) shows that acoustic deterrents have a potential role (although birds are primarily visually-guided foragers (Martin and Crawford, 2015)), but better understanding of seabird hearing underwater is fundamental to designing seabird pingers that are effective (Wiedenfeld *et al*., 2015). Trials with captive birds would appear to be the most viable route for furthering knowledge in this area, but are clearly not in scope for this study.

With the right information, enforcement and when properly designed, spatial and temporal closures can successfully reduce bycatch (Melvin *et al*., 1999; Carretta and Chivers, 2004; O'Keefe *et al*., 2013). With sufficient information, these can be designed on a scale that is fine enough to result in minimal economic impact (Melvin *et al*., 1999), but in other cases may impact more heavily, depending on the scale of closures and the ability of vessels to adapt. Closures in the US have resulted in legal challenges (Carretta and Chivers, 2004). The team decided to focus instead on trialling technical gear modifications.

Gear switching to methods with lower bycatch rates presents an opportunity where catch efficiency can be maintained from gillnets to new gear types. Baited pots and longlines show some potential (Mentjes and Gabriel, 1999; Koschinski and Strempel, 2012, Hedgärde *et al*., 2016), though such approaches may meet resistance from fishers that have built up expertise in fishing with gillnets, and further because switching may carry substantial vessel re-fit costs. It will, of course, be important to examine any evidence of moving bycatch impacts from one group of species to another with any gear switching trial. Net attendance may be an option in some small-scale driftnet fisheries, but is probably not practical for the vast majority of static net fisheries in the EU, and so was not considered further for this study.

In examining gillnet bycatch from a fundamental sensory ecology perspective, Martin and Crawford (2015) devised the high contrast net panel proposal. The sensory ecology approach to bycatch mitigation has hitherto been under-researched for birds, so this mitigation proposal represents an opportunity to test the efficacy of low-tech visual stimuli. Early (pre-analysis) results from BirdLife's work in Lithuania indicated that there were no operational issues with deployment, and that target catch appeared to be unaffected, and that there may be some reduction in seabird bycatch (Morkūnas, J., pers comm.). Wang *et al*., (2013) also grounded their work on turtle bycatch mitigation in understanding of the sensory systems of their focal bycatch species. This drove the development of net light testing, and though not originally designed for seabirds, it shows promise as a cross-taxa mitigation measure (Mangel *et al*., 2014). As a comparatively 'high-tech' measure, lights are relatively expensive at present, but costs could come down if trials prove effective and larger-scale production of gillnet-specific lights becomes feasible. The advantage of these two measures is that there is a fundamental physiological basis for their design, which cannot be said for many gillnet mitigation measures.

Focussing on EU static net fisheries, the team used information from the most up-to date research in sensory ecology (Martin & Crawford, 2015; Wiedenfeld *et al*. 2015), preliminary results from ongoing studies and expert opinion to identify the most suitable experimental measures for testing in gillnet fisheries- net panels and lights. These measures stem from a more fundamental need to understand and respond to the sensory systems and behaviour of birds. Gear switching also shows some promise in bycatch mitigation, though the changes fishers would have to undergo are more fundamental than net modifications. Other research priorities include improving our understanding of underwater bird hearing (and the design and testing of acoustic deterrents attuned to this) and examining the potential for finer-scale spatial and temporal measures that minimise economic impacts by improving understanding of bird aggregations and movements, peak times of bycatch, understanding target species abundance and key fish capture times.

2. METHODS/SCIENTIFIC APPROACH

The technical study was focused on identifying and then testing the chosen experimental technical mitigation measures on gillnet fishing gear, in specific sites in the Baltic Sea and in the Atlantic Ocean (south western waters). The study carried out field work in Poland and Portugal, two countries chosen for their suitability in relation to gillnet fisheries, seabird bycatch, and feasibility of carrying out on-board wok. The impact the study examined the economic impact of implementing mitigation measures and the potential impact of bycatch and mitigation on threatened seabird populations.

2.1. TECHNICAL STUDY

2.1.1. POLAND- SITE DESCRIPTION, FLEET DESCRIPTION

Poland was chosen by the study team as bycatch of seabirds in gillnets is a known issue, and prior work had been conducted on board gillnet fishing vessels by trained observers (Žydelis *et al.,* 2013; Psuty *et al.* in prep, 2017). This therefore meant that undertaking experimental trials was likely to be feasible, both from a bycatch sample size perspective, and from the accessibility of getting on board vessels. Within Poland, the study focussed on two of the country's largest marine Natura 2000 areas, the Pomeranian Bay[1] and Puck Bay[2], both of which host intensive coastal fisheries, predominantly small-scale fishing vessels (<12m) which are operating gillnets (GNS).

It is important to note that these locations were selected based on the results of an earlier project (Psuty *et al.* in prep), indicating that there were higher levels of bycatch compared to other areas. High bycatch levels were needed to complete the main project task, i.e. to ensure we had a sample size sufficient to assess the effectiveness of the proposed technical measures to reduce bycatch. While this approach provides us with the best opportunity of testing mitigation measures, it does not provide a representative sample of bycatch across the fleet, which would be achieved by sampling more statistical squares across a wider time period. Particularly in the Puck Bay region, considerable variation in the bycatch of birds has been recorded both temporally and spatially (Psuty *et al.* in prep). For this reason, the bycatch rates obtained from these trials are appropriate for comparing the efficacy of mitigation, but not for extrapolation across the whole fleet.

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[1] Standard Data Form for Pomeranian Bay Natura 2000 PLB 990003

[2] Standard Data Form for Puck Bay Natura 2000 PLB220005

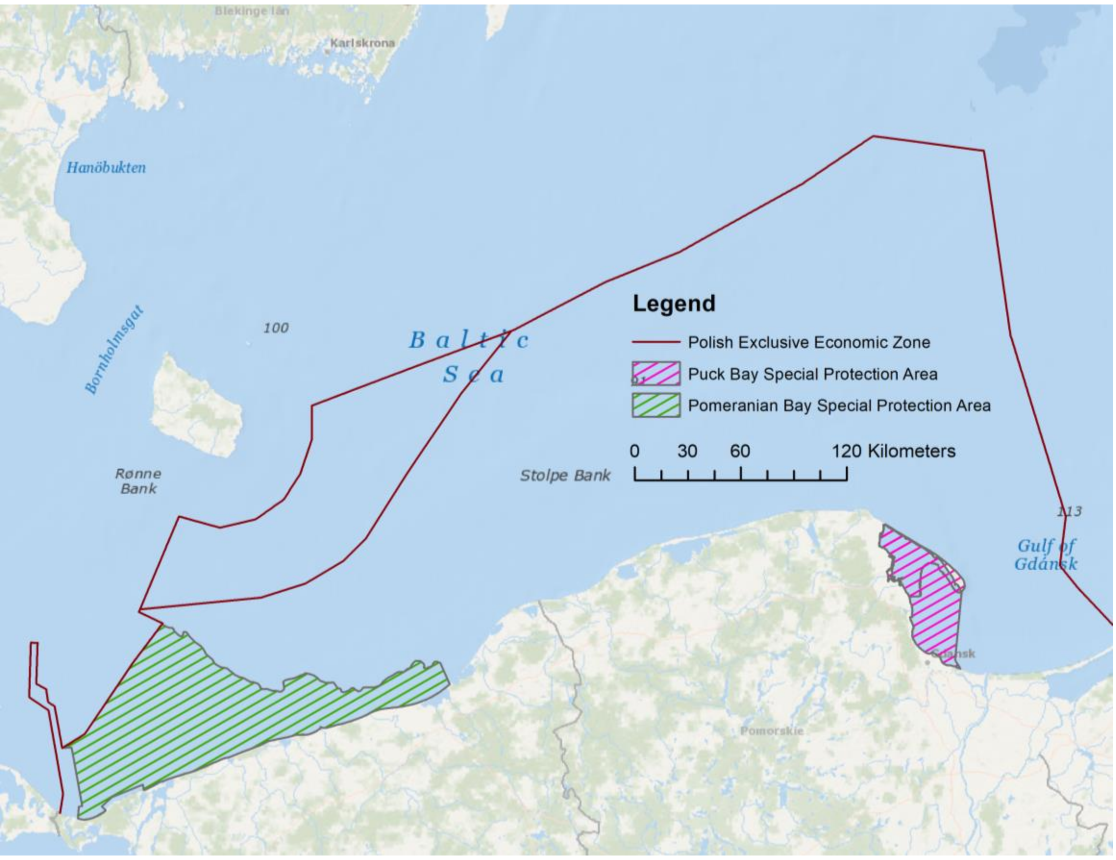

Figure 5. Map of Special Protection Areas (Natura 2000) in Poland; Pomeranian Bay PLB 990003 and Puck Bay: PLB 220005 and PLH 220032- focus of technical study work

Puck Bay is almost exclusively marine (see Figure 5). The bay was identified and designated as an SPA primarily because of its importance for waterbirds and seabirds (Natura 2000 Standard Data Form, 2015a). The most abundant groups of birds are seaducks such as the long-tailed duck (up to 30,000 individuals in winter) and velvet scoter (up to 9,000 in spring). Both of these species are listed as 'vulnerable' on the IUCN Red List (BirdLife International, 2016, 2017b). The remaining Anseriformes are abundant from autumn to spring with peak abundance in winter: Mallard *Anas platyrhynchos* (up to 7,000), tufted duck *Aythya fuligula* (up to 13,000), common goldeneye *Bucephala clangula* (up to 5,700), mute swan *Cygnus olor* (up to 3,000) and goosander *Mergus merganser* (up to 2,100) can be found here. Other species groups reach peak numbers in autumn and are sometimes more abundant in winter, such as the great cormorant *Phalacrocorax carbo* (up to 16,000), great-crested grebe *Podiceps cristatus* (up to 1,900), and coot *Fulica atra* (up to 2,100). There can also be significant numbers of razorbill (up to 1,700 in winter). Of these species, long-tailed duck, velvet scoter, and tufted duck are the most susceptible to bycatch.

The area also hosts key fishing grounds, with ¼ of the total gillnet fishing effort of the Polish marine area concentrated in Puck Bay. Perhaps inevitably, the overlap of diving seabirds and gillnet gear has resulted in bycatch, and a range of estimates have been made through the years: 3,740 for a single port (Kieś and Tomek, 1990), 13,800/year for Puck Bay (Stempniewicz, 1994) and most recently, 3,176 birds/year (Psuty *et al.* in prep 2017) through an NMFRI (National Marine Fisheries Research Institute) pilot project utilising video monitoring.

These factors, alongside the limited ability of small-scale vessels to change fishing grounds or fishing techniques, make this an excellent site to study technical mitigation to reduce bycatch.

The **Pomeranian Bay** is a transitional area between the open Baltic Sea and the estuary of the River Oder (Figure 5). The bay is one of the most important wintering areas for birds in the Baltic

Sea, and are key features in the Special Protection Area (Durinck *et al.,* 1994; Meissner 2010; Chodkiewicz *et al.*, 2012; Natura 2000 Standard Data Form, 2015a), many of which are susceptible to gillnet bycatch, including long-tailed duck*,* velvet scoter, common scoter, red-throated diver *Gavia stellata*, black-throated diver *G. arctica*, greater scaup and black guillemot *Ceppus grylle*.

Small gillnet fisheries targeting herring, cod, flounder, pikeperch and perch operate in the Pomeranian Bay over winter, coinciding with peak bird abundance and resulting in bycatch, particularly in autumn and spring. While there is a single study of bycatch in the area (Kowalski i Manikowski 1982), it is now outdated.

2.1.2. PORTUGAL- SITE DESCRIPTION, FLEET DESCRIPTION

Portugal was chosen as a focal country within this study, as existing bycatch studies had been undertaken with the gillnet fleet (Oliveira *et al.,* 2015), and seabird bycatch was a known issue and its location in the Atlantic Ocean provided contrasting environmental conditions to the Baltic Sea and Polish case study. BirdLife's partner in Portugal, SPEA, began working on seabird bycatch in 2009, collaborating closely with the fishing industry, and have thus developed close ties with local fishers and producer organisations. Within Portugal, the Natura 2000 site- **Berlengas Archipelago** (Berlengas is a Special Protection Area [SPA] classified under the Birds Directive) was chosen as the location for field work. The Berlengas are found off the coast of Portugal in the Atlantic Ocean (Figure 6). The archipelago is composed of Berlenga Island and associated reefs, in addition to the Islets Farilhões-Forcadas and Estelas. The islands are important seabird breeding grounds (cory´s shearwater *Calonectris borealis*, european shag *Phalacrocorax aristotelis*, yellow-legged gull *Larus michahellis*, lesser black-backed gull *Larus fuscus* and band-rumped storm-petrel *Hydrobates castro*), and host numerous migratory and/or wintering populations of other seabird species including the balearic shearwater and the razorbill.

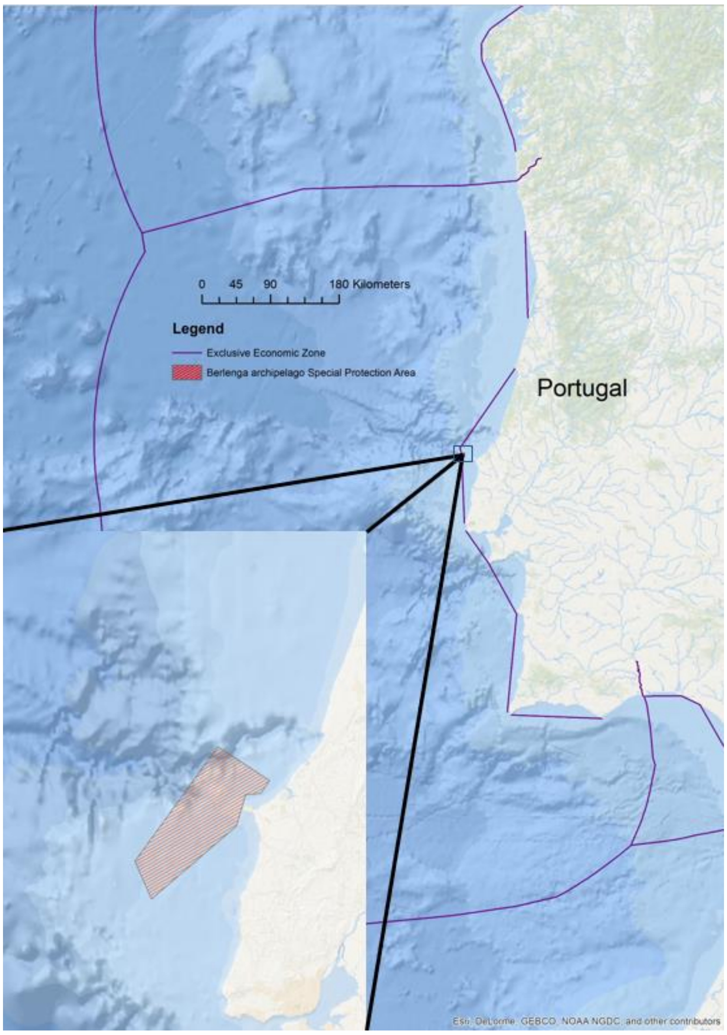

Figure 6. Special Protection Area (SPA- Natura 2000) Berlengas Archipelago- PTCON0006 in Portugal

Formerly, the island hosted a breeding population of common guillemot*,* and gillnets have been suggested as one of the main reasons for the local extinction of this species (Munilla *et al.,* 2007). Further, Portuguese NGO SPEA (BirdLife in Portugal) together with partners of a LIFE project (LIFE MarPro) have recorded high levels of razorbill bycatch in gillnets from 2011-2015 (Vingada *et al.,* 2012; see also Oliveira *et al.,* 2015).

Fisheries are one of the main economic activities within the SPA, with Peniche (on mainland Portugal) the nearest fishing port. Peniche is an important port with a diverse fishing fleet. It is estimated that small scale fisheries represent between 20% and 40% of total landings and gillnets are one of the most commonly used fishing gears (Abreu *et al.,* 2010, Almeida *et al.,* 2016).
The fishing capacity of the local fleet (made of Peniche-based vessels and those bordering this area) include 215 fishing licenses for set nets. This number is further supplemented by the Portuguese coastal fleet which includes 353 and 348 licenses for gillnets and trammel nets respectively, which can operate all over the country.

The extent of overall effort in the SPA is unknown (Almeida *et al.,* 2016), and it should also be noted that there are discrepancies between the number of licences and actually active boats, meaning that there are licenses for gears granted for boats that are not fishing or using that particular gear. This happens frequently in polyvalent fleets as fishers get licenses for different gears, but then can use only one as the main gear, depending on the sea conditions, market prices, etc. Some differences are explained by the fact that the majority of boats have several fishing licenses, allowing them to use more than one type of gear. Even if a gear type is not used during a fishing season, fishers will continue to request a full range of fishing licences in future seasons.

The main fish species landed in Peniche are horse mackerel *Trachurus trachurus*, chub mackerel *Scomber japonicus* and sardines *Sardina pilchardus*. Other important species include blue jack mackerel, octopus, hake, conger and ray.
The existing links with fishermen, alongside the importance of these islands for seabirds and the historical and recent evidence of bycatch, make the Berlengas Archipelago SPA an excellent location to study potential solutions to the problem.

2.1.3. IDENTIFICATION AND DESCRIPTION OF GILLNET MITIGATION MEASURES

As described above this study required the trialling of two different mitigation measures in each of the two sea basins. Net illumination was chosen for trialling in the Polish Baltic Sea, and net panels were chosen to be tested in the south-western waters (Atlantic) off Portugal. The rationale for selecting these sites is provided above, and the reasons for the selection of net illumination and net panels is provided above [see section 1.3]. In summary, based on a sensory ecology approach and previous preliminary work, these two measures show promise as a potential mitigation measure.

- Experimental gillnet mitigation- net lights

Net illumination is broadly described as a mitigation measure under section 3.2.1 [Visual bycatch mitigation- Net lights]. For this experiment, we purchased 350 longline lights (model YML-1000) from the Korean company YM fishing. Our original intention was to purchase a brand of lights- Centro lights- as used in the Ortiz *et al.* (2016) study, but this company was unable to supply the lights on time. However, the different branded YM Fishing lights which were purchased for this study are of a very similar specification and design to the Centro lights. Green lights were used, as per the Ortiz *et al.* (2016) study that recorded a reduction in bycatch of the guanay cormorant in Peru (Mangel *et al.*, 2014).

Figure 7. YM Longline lights being mounted on fishing net © Tomasz Linkowski

- Experimental gillnet mitigation- net panels

Net panels are also broadly described in section 3.2.1 [Visual bycatch mitigation-Net panels]. The panels used in this experiment were constructed manually in Portugal using polyester strips, a lightweight but robust material (so as not to impact net behaviour in the water and endure repeat soaking and sea conditions). Consecutive black and white strips (6cm strip width x 60cm strip length) of this material were attached to polyester straps (that had metal eyelets for net attachment) at the top and bottom to create panels 60cm x 60cm in size, as per Martin and Crawford (2015).

Figure 8. Net panels used in Portugal © Ana Almeida, SPEA

2.1.4. MITIGATION MEASURE TESTING- PAIRED TRIALS

In both Poland and Portugal, 'paired trials' of gillnets were conducted to allow simultaneous data collection of gillnets deployed with normal fishing gear (the control set) and those with mitigation gear (the experimental set). This was to enable the research team to control for other variables (weather, water depth, bird abundance etc.) and allow for a direct comparison of fish catch and bycatch in control and experimental treatments. Aside from the experimental sets having panels or lights attached, the experimental and control nets were identical in every other way, with the same net length, height and mesh size, as well as being deployed relatively close to each other, to ensure that any differences observed were the result of the treatment.

2.1.5. BYCATCH DATA COLLECTION- POLAND

The duration of the technical study was extended in order to allow for a full winter field season of the observer programme by the study team (e.g. partial season in 2015/2016 and full season 2016/2017)

Four fishing vessel owners, two from the Pomeranian Bay and two from Puck Bay, agreed to work with the team to trial mitigation measures. These vessels were good representatives of their fleet segment, as they work within the fishing grounds which potentially pose the greatest threat to wintering diving birds. Trained observers were present on-board vessels to collect data on bycatch and fish catch from both experimental and control sets.

Confirmed via signed contracts, fishers agreed to set the appropriate number of control (normal nets) and experimental nets (with lights attached) for the paired trials. The fishers were also responsible for the installation, dismantling and –if necessary- translocation of the lights to other nets in the event of changing fishing gear for a different target species. Lights were attached every 10m along the float line using thin nylon cord, following Ortiz et al. (2016) (Figure 7).

Trips were conducted in traditionally exploited fishing grounds, and the fish caught in experimental and control nets remained the property of the vessel owner. During each trip, every vessel deployed two sets of experimental nets (with lights) and two sets of control nets. The order and manner of deploying particular sets was dependent on the operating situation, i.e. the sets were deployed in a line or within short distances from each other, in parallel or obliquely. Fishers were asked to fish normally, and therefore skippers used their standard on-board gears. The length of sets varied (from 200m - 910m) depending on the boat, fishing location and target species, but control and experimental pairs were always kept at the same length on each vessel to ensure the trial was truly paired.

Based on data from elsewhere (BirdLife International, unpublished data; Žydelis *et al*, 2013), our trials initially focussed on fisheries targeting cod, sea trout, whitefish and pikeperch, which utilise a larger mesh size (55-70 mm from knot to knot). However, due to the very low Catch Per Unit of Effort (CPUE) of these species, the fishers decided to re-focus their catches on herring earlier than expected. Accordingly, the lights were transferred to the gear used for catching herring (52-54mm from knot to knot) and the study continued using these nets. Since there was no technical possibility of measuring fish on the boats due to space limitations, and the whole catch of every species from every net was weighed onshore (and information shared with this study), there was no need to take fish length-measurements. Initially it was assumed that length measurements would help in the recalculation of fish weight when weighing on board was impossible or heavily biased.

2.1.6.BYCATCH DATA COLLECTION- PORTUGAL

To determine and resolve any operational or technical issues arising from the attachment of net panels to the gear, before the commencement of full trials, the team conducted preliminary trips in May-June 2016. These first trips are not included in the data analysis since some of the technical details were not decided upon (i.e. location of the panel on the net).

Full trials were carried out in autumn/winter 2016-2017, the most critical time for auk bycatch. The trials were conducted on-board three different boats, all operating in the Berlengas SPA area or nearby, and within traditionally exploited fishing grounds. All the vessels were small-scale (less than 12 meters in length), registered as multi-gear vessels. A number of different mesh sizes are used: 100mm, 120mm and 150mm (stretched mesh size). The main target fish species include meagre, European seabass, seabream and common sole. Vessels were selected based on operational characteristics (primarily the use of single panel gillnets rather than trammels) but also took into account the receptivity of captains.

The attachment of the panels to the nets was done manually by SPEA staff and the fishing crew using multifilament fishing line. Panels were attached centrally on the net every 4 meters. All trips were monitored by a fisheries observer on board, who collected the data on bird bycatch and target fish catch using standardized forms and methods.

During each trip, the vessels deployed one set of experimental nets (with panels) and one set of control nets (without panels) in addition to their normal sets. The order of deploying particular sets was dependent on the vessel and the exact gear specifications. The total length of sets varied depending on the boat and target species (range: 500m-1000m), but control and experimental pairs were always kept to the same length on each vessel to ensure the trial was truly paired. In one of the three boats, there was a difference of 1 panel between the control and experimental nets.

Figure 9. Operating gillnets with experimental panel © Iván Gutierrez, SPEA

2.1.7. ANALYSIS OF MITIGATION MEASURE EFFECTIVENESS

To test whether the experimental fishing nets had an effect on the number of seabirds caught, we used a hurdle model approach to split the analysis into two separate questions. This approach is appropriate for datasets where a large number of samples have a zero outcome (= no bycatch) that affect normal statistical distributions (Martin *et al.,* 2005, Potts and Elith 2006, Zeileis *et al.,* 2008).

We therefore first examined whether net treatment (control or experimental nets) had an effect on the probability that any seabirds were caught at all. For this question we reduced the bycatch data to a binary indicator variable (0 = no birds caught, 1 = at least 1 bird caught), and compared two generalised linear mixed models (GLMM) using a likelihood-ratio test (Lewis *et al.,* 2011). Each GLMM used bycatch as a response variable with a binomial error distribution and a logit link function, and accounted for the non-independence among sets of fishing nets deployed during the same boat trip by including the set identity as random intercept. This approach is necessary because sets of fishing nets that are deployed together in time and space are more likely to yield a similar outcome than nets deployed in other sets (Bolker *et al.,* 2009). We could conclude that net treatment had a significant effect on bycatch if the likelihood-ratio test comparing the model with the treatment effect to the null model without this effect indicated a better model fit at $p= 0.05$.

In a second step, we analysed the number of bycaught birds per unit effort (BPUE) for those fishing sets in which at least one of the pair (control or experimental) caught at least one bird. BPUE was calculated as the number of bycaught birds per 1000 Net Metre Days (NMD). We used a similar GLMM as above with the same random intercept to account for non-independence among sets, but with a negative binomial error distribution and a log link function. We compared a null model to a model using treatment as a fixed factor and concluded that treatment affected the number of birds caught per unit effort if a likelihood-ratio test indicated a better model fit at $p = 0.05$.

2.2. IMPACT STUDY

In addition to testing experimental mitigation measures for gillnets, this study included an impact assessment covering both economic factors of mitigation and the potential impact of bycatch and mitigation on seabird populations.

If the mitigation measures tested by this study are to be implemented on a wide scale (i.e. national- or EU-fleet level), it is crucial that the measures do not have a significant and negative economic impact on the fishing operations adopting these measures. For example, if gillnets fitted with the mitigation measures resulted in significantly lower catches (and profits) compared to normal gillnets, it is unlikely the mitigation measures would be accepted by the fishing industry. Therefore, the impact study herein sought to evaluate the potential economic impact of the focal mitigation measures on fishing operations. This was explored through an evaluation of three issues: outlay and installation costs of the mitigation measures; impact of mitigation measures on fisheries catches; and, the acceptability of the measures to fishers. Data was collected during the technical study field work and is described below.

2.2.1. ECONOMIC DATA COLLECTION- PORTUGAL

Catch income: The data for landings (volume and value) for each trip is required to be reported in Portugal to Docapesca[3]. Since it was impossible to separate landing volume and value for both experimental and control sets on-board due to space constraints, we measured a sub-sample of fish catch on board. We then estimated fish weight based on length-weigh equations described in the literature and used the first sale prices to get the revenue. Observers on board were able to register all catches. All other data and information was collected by us or given to us by the fishing crew.

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[3] Docapesca is the responsible entity for the first sale in Portugal; submitting landings to them is mandatory.

Energy costs: energy costs were calculated based on information provided by fishers regarding average fuel consumption multiplied by the number of hours and the price of fuel. The latter was provided by the producer organisation, including the fisher's discount.
Crew costs: in Portugal, crew payment is dependent on fish catches and it is expressed in a percentage of total landing value. The percentage is variable between boats and crews. For the boats we worked on, 50% is for boat maintenance (owner). The rest is divided in different percentages to each member of the crew. All captains gave us this information about their boats.
In the final phase of the project, a standardized interview was done with each of the participating three captains to evaluate their opinion about net panel efficiency (see Annex 5).

2.2.2. ECONOMIC DATA COLLECTION- POLAND

In terms of economic data collected for this project, the methodology differed slightly within Poland for the two research areas (Puck Bay and Pomeranian Bay), as well as for individual fishing boats. All information, including costs, comes directly from the fishers and is based on trust.

Catch income: In the course of the mitigation trials, the observers recorded fish catch, broken down by particular nets. In addition, the fish were weighed on land and fishers provided the sale price for catches. Due to small catches, all fish were sold to individual customers immediately after returning to land. In vessels from the Pomeranian Bay, due to limited space on-board and much larger catches, a different procedure was necessary when vessels switched to targeting herring. It was not possible to determine the size of catches by particular nets. For this reason, the total catch in experimental nets and the total catch in control nets was noted and then divided by the number of nets of a particular type.

Energy costs: The energy costs were calculated based on information provided by fishers, regarding the average fuel consumption of their boats expressed as litres per hour, multiplied by the number of hours of fishing operations and by the price of fuel. The fuel prices differed depending on how the boats were supplied (i.e. fishers could buy fuel in a local petrol station or a special cheaper fuel for fishers in a location 35 km away from their port base). The time taken for fishing operations was recorded by the observer or the fisher when nets were being deployed.

Crew costs: Traditionally, crew salary is dependent on catches and it is a constant percentage of its value. However, the fishers in the Pomeranian Bay also received a guaranteed pay amount that was not related to catch results. In Puck Bay, the number of crew was dependent on the CPUE, and due to the very low CPUE during the conducted studies, apart from a skipper, only one fisher usually participated in a fishing trip. In the absence of catches, the fisher did not receive any payment. In the vessels operating from the Pomeranian Bay two crew members were usually employed in addition to the skipper. Due to the higher CPUE, pay for workers on land, employed for fish selection, cleaning and clarifying nets, was also included in the costs.

2.2.3. ANALYSING OUTLAY AND INSTALLATION COSTS

Outlay costs relate to the costs associated with the materials and installation of the focal bycatch mitigation measures (lights and high contrast panels). Evaluating these costs was an important component of this study as the wide-scale implementation of the focal mitigation measures would likely be inhibited if these costs were too high. As a basis for this evaluation, detailed data on the costs associated with the materials and labour required during the gear manufacturing process were collected. The gear manufacturing and installation process consisted of modifying existing bottom-set gillnets to contain lights or high contrast panels (see section 2.1.3). Across Poland and Portugal, a total of ten nets were modified: In Poland, seven nets were modified to contain lights as a mitigation measure; and, in Portugal, three nets were modified to contain high contrast panels as a mitigation measure. The modified nets varied in length, ranging from 174 – 1176 metres. For each net, costs for the raw materials and labour required for the modification were recorded.

Outlay and installation costs were evaluated using the collected data and three methods: a breakdown of the costs to modify each net with the mitigation measures; a comparison between the costs to modify each net and the original manufacturing costs of each gillnet; an extrapolation of the costs to modify nets to respective gillnet fleets in Poland and Portugal. The breakdown of costs presents the costs per metre and total costs incurred to modify each of the nets. The comparison between modification costs and original manufacturing costs determines the additional costs required to modify gillnets with the focal mitigation measures above that of the original manufacturing cost for each net. The extrapolation provides an estimate of the total cost that would be incurred if the mitigation measures were adopted by all vessels using gillnets in the Portuguese and Polish gillnet fleets. The extrapolation uses the data collected from the trials combined with data on vessel numbers (STECF, 2016), and assumptions regarding the average length of gillnet used by each metier, the number of nets used by vessels of different sizes, and the proportion of vessels using gillnets within each metier. Results and assumptions used are presented in section 3.2.1.

2.2.4. ANALYSING FISHERIES CATCHES- INCOME

A key indicator of the economic impact of the focal bycatch mitigation measures on fishing operations is the effect each mitigation measure has on fisheries catches. To determine if the nets fitted with mitigation measures catch less, more, or the same amount of fish compared to normal fishing nets, total fisheries catches (kg) from the control (normal) gillnets and nets containing the mitigation measures were recorded throughout the field trials. A total of 181 and 179 catches were recorded for mitigated and normal gillnets, respectively. Of these catches, 322 were recorded from the trials conducted in Poland across two locations (Puck and Pomeranian Bay) where the mitigation measure applied was lights; whereas 38 catches were recorded from trials conducted in Portugal where the mitigation measure applied was high contrast net panels. To determine if catches were significantly different between normal gillnets and nets containing the bycatch mitigation measures, a Mann-Whitney test was used to compare the catches between these two groups in each location. A Mann-Whitney test was selected as the focal data were non-normally distributed and the test is non-parametric, i.e. it does not require normally distributed data (Field, 2013). Results are discussed in section 4.1.1.

2.2.5. ASSESSING ACCEPTABILITY OF MITIGATION MEASURES

Determining if fishers will accept their normal gillnets being replaced (or modified) with nets containing the focal mitigation measures was a key component of the impact evaluation. During the project's inception phase, it was acknowledged that in addition to the outlay costs and the impact on fisheries catches, a range of additional factors could potentially influence the willingness of fishers to adopt the mitigation measures. For example, if nets containing the mitigation measures were more difficult to set and haul, or if they took significantly longer to repair compared to normal gillnets, then it is likely fishers would resist using these nets. Therefore, to gain a comprehensive understanding of any issues experienced and the overall acceptability of each of the mitigation measures tested by this study, the opinions and experiences of fishers utilising the gears during the field trials were documented using a semi structured questionnaire (Annex 5, Gear Acceptability Questionnaire). Questions asked to participating fishers regarding their experiences related to eight aspects of using the gear: gear set up or manufacture; handling nets at sea; onshore handling and repairs; impact of the mitigation measures on target catches; impact of the mitigation measures on bird bycatch; difficulties or issues encountered with the gear; and acceptability. The questions asked were a mixture of yes/no answers, Likert scales requesting fishers to agree or disagree with statements on each aspect, and open questions requesting explanations for answers to the Likert scales. A total of seven fishers were interviewed, three from Portugal and four from Poland. Results presented in section 5.2.3 discuss fisher's responses to each of the questions and draws out the most important issues relevant to the continued testing of the focal mitigation measures and the wide–scale implementation.

2.2.6. IMPACT OF BYCATCH AND MITIGATION ON SEABIRD POPULATIONS

Our approach to the longer-term analysis of the likely impacts of fisheries bycatch on threatened seabird populations was adapted from the proposed methods, based on the data available from the experimental trials and other information sources.

We initially proposed to estimate total annual bycatch of focal bird populations at the fleet level for three different scenarios: the status quo (no intervention/current bycatch rates); implementation of the bycatch mitigation measures trialled during field work; and implementation of spatio-temporal closures and compare these with estimates of Potential Biological Removal (PBR) through the calculation of impact ratios (Richard & Abraham*.,* 2013). Potential Biological Removal (PBR) is a method that can be used to identify the number of additional mortalities that can be sustained each year by a population.

However, estimation of annual bycatch for focal seabird species was problematic. Bycatch data is currently unavailable for the focal bird species across appropriate spatial and temporal scales in Poland and Portugal, therefore limiting the ability to effectively/accurately account for variability when scaling up estimates across all fishing effort and areas.

Therefore, potential impacts of seabird bycatch in the areas of the technical study, were explored through comparison of already available local/regional annual bycatch estimates (status quo scenario) and bycatch estimates adjusted by results of the mitigation trials where appropriate, with estimates of Potential Biological Removal (PBR) (Dillingham & Fletcher, 2008). The following section provides more detail on focal seabird species for each trial area and Annex 6 presents details of the PBR method and assumptions.

- Focal seabird species

For both regions of the technical study (Poland and Portugal) a focal bird species was selected for the impact study, based on frequency of bycatch in the respective fishery and its conservation status.

  - Poland – Long-tailed duck *Clangula hyemalis*

The long-tailed duck is a globally threatened species classified as 'vulnerable' on the global and European IUCN Redlist (BirdLife International, 2015 & 2016b) and endangered at the Baltic Sea level according to HELCOM[4] (2013 Red List Information Sheet[5]). A large decline in numbers in the Baltic Sea, where the majority of the global population overwinters, has taken place since the mid-1990s, equivalent to a 59% decline in the size of the global population within three generations, even when factoring in uncertainty regarding the sizes and trends of other populations. The European wintering population is estimated at 1,430,000- 3,520,000 individuals (Birdlife, 2016b). This species has previously been reported as one of the most frequently caught species in gillnets in the Baltic (see Table 1 in Žydelis *et al.*, 2009; Skov *et al.,* 2011).

The species has an arctic circumpolar breeding distribution. It winters primarily in coastal waters of North America, northern East Asia and northern Europe. Four biogeographic populations are recognised, two of which occur wholly within the African-Eurasian Waterbirds Agreement (AEWA) region (West Siberia/North Europe and Iceland/Greenland).

Within the African-Eurasian region, the long-tailed duck breeds predominantly in Russia, with smaller populations in Finland, Sweden, Norway, Iceland and Greenland (Hearn *et al.,* 2015). Detailed information on migratory movements is mostly lacking, but existing data suggest that the West Siberia/North Europe population moves predominantly to the south and west, with the vast majority breeding in western Russia and overwintering in the Baltic Sea, but possibly also wintering around Iceland and Greenland (see Figure 10).

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[4] Baltic Marine Environment Protection Commission - Helsinki Commission

[5] HELCOM Red List Information Sheet- long-tailed Duck:

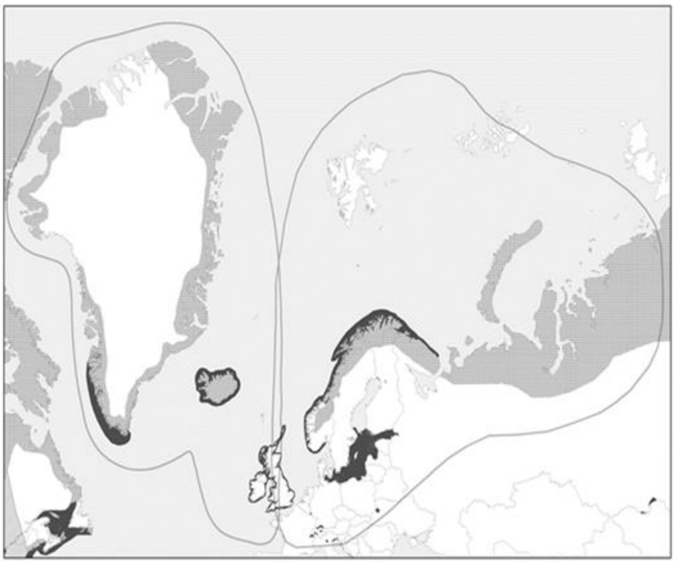

Figure 10. Range of long-tailed duck within the AEWA region. Light grey stippling indicates the breeding area, dark grey indicates regularly used wintering and staging areas. Source: Hearn *et al.*, 2015

- Portugal - Razorbill *Alca Torda*

Razorbill breeds in the temperate North Atlantic and adjacent parts of the Arctic Ocean, on both sides of the Atlantic, as far south as northwest France, north to Svalbard and east to northwest Russia, and wintering along Atlantic coasts as far south as North Africa (Merne & Mitchell, 2004). Razorbill use the Portuguese mainland coast during their migration and as feeding grounds, resting and wintering areas (Oliveira *et al.,* 2015). Many of the razorbills which occur along the Portuguese coast are known to come from breeding colonies in the UK, based on identification of beached/stranded birds with rings (Teixeira, 1986) - though note that this may be a bias of the high ringing effort in the UK and Ireland. The analysis of several bird skins found dead in Portugal suggests that the wintering population belongs mainly (or perhaps exclusively) to the subspecies *A. t. islandicus* (Hope Jones, 1984), which is distributed through Iceland, the Faroe Islands, the British Isles and France (BWP) (Catry *et al.,* 2010).

The European population is estimated at 979,000-1,020,000 mature individuals and was classified in 2015 as 'near threatened' on the IUCN Red list with a currently decreasing population trend (BirdLife International 2016a).

Since 2005, there has been a sharp decline in numbers observed in Iceland, where more than 60% of the European population is found (BirdLife International 2016a). The 2005 decline occurred around the same time that sandeel stocks crashed around Iceland, suggesting that a lack of food may have influenced the decline (Birdlife International, 2017). As a result of the reported decline in Iceland, the estimated and projected rate of decline of the European population size over the period 2005-2046 (three generations) is 25-30% (Birdlife International, 2016a).

Razorbills have been reported as bycatch in Portuguese gillnet and other polyvalent fleets based on fisher interviews (Oliveira *et al.,* 2015; Vingada *et al.,* 2012), observer data (Vingada *et al.,* 2012) and from stranding data (Vingada *et al.,* 2012; Teixeira, 1986; Granadeiro *et al.*, 1997).

3. RESULTS

3.1. TECHNICAL STUDY

3.1.1. OBSERVED TRIPS- POLAND

A total of 74 monitored fishing trips were carried out during the two autumn/winter field seasons (2015/2016 and 2016/2017) and across both field sites. A total of 161 paired fishing sets were observed on these trips, with control nets and experimental nets with lights attached.

3.1.2. BYCATCH OBSERVED DURING TECHNICAL STUDY- POLAND

Out of 161 pairs of fishing sets (n=80 in Puck Bay, n = 81 in the Pomeranian Bay; locations presented in Figures 11 & 12), 35 sets were recorded with at least one event of seabird bycatch (n = 18 in Puck Bay, n = 17 in the Pomeranian Bay). Of these sets, a total of 27 sets were recorded with bycatch of long-tailed ducks (n = 15 in Puck Bay, n = 12 in the Pomeranian Bay).

A total of 106 bycaught birds were recorded during the paired trials, with Long-tailed ducks being the most numerous species recorded (~74% of all bycaught birds). The mean number of bycaught birds in control nets was 0.83 ± 2.0 birds/1000 NMD and for experimental nets it was 0.56 ± 1.53 birds/1000 NMD. The mean number of bycaught long-tailed ducks was 0.67 ± 1.87 birds/1000 NMD in control nets and 0.39 ±1.25 birds/1000 NMD in experimental nets (see Table 1.).

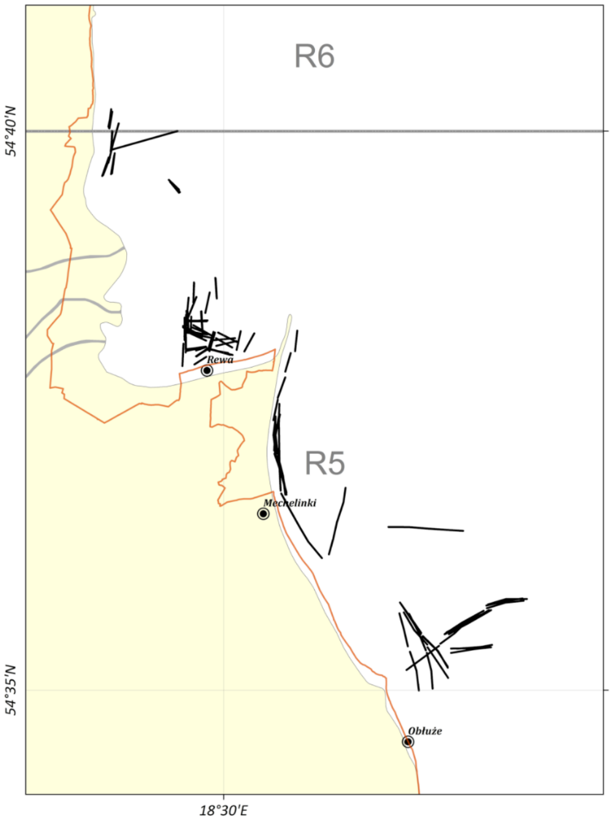

Figure 11. The location of 40 monitored fishing trips in Puck Bay. Black lines indicate positions of deployed sets (experimental and control).

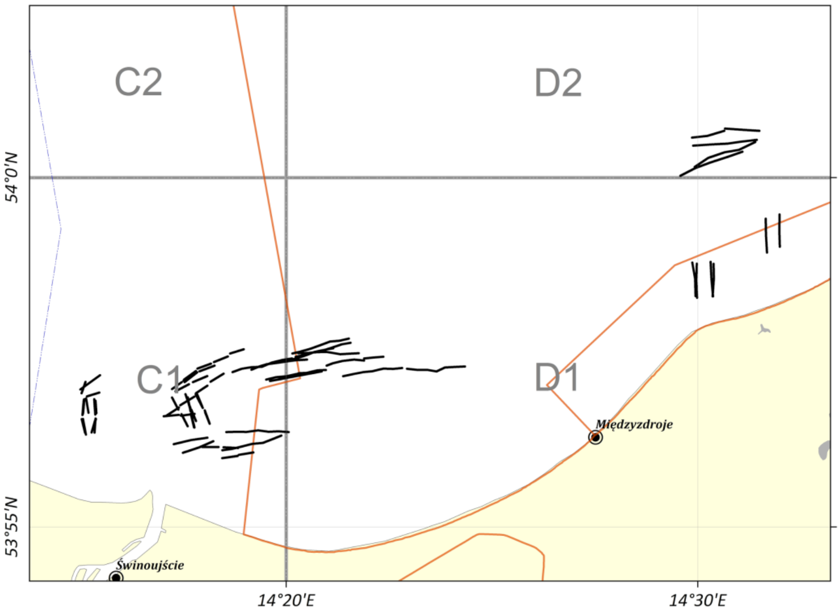

Figure 12. The location of 34 monitored fishing trips in Pomeranian Bay. Black lines indicate positions of deployed sets (experimental and control).

Table 1. Summary of number of birds captured (all species and long-tailed duck (LTD) separately) and BPUE in control and experimental sets, collated across both bays and per bay site. BPUE is calculated as birds/1000 NMD

Treatment	**No. birds caught (all species)**	**No. LTD caught**	**Mean BPUE all sp. Puck Bay**	**Mean BPUE all sp. Pomp Bay**	**Mean BPUE all species**	**Mean BPUE LTD**
Control	61	48	0.90± 1.98	0.75± 2.04	0.83 ± 2.00	0.67 ± 1.87
Experimental	45	30	0.49± 1.35	0.63± 1.70	0.56 ± 1.53	0.39 ± 1.25

3.1.3. BYCATCH COMPARISON- CONTROL & EXPERIMENTAL SETS- POLAND

A binomial generalised linear mixed model (GLMM- see section 2.1.7. Analysis of mitigation measure effectiveness) **examining the probability of catching any seabirds indicated that the treatment effect was slightly negative (e.g. bycatch was lower in experimental sets), but not significantly different from zero ($\bar{x}$ = -0.669; 95% confidence interval -1.393 – 0.018; *p* = 0.056, Figure 13).** Including study area in the model did not alter this conclusion, and there was no significant difference in bycatch between the two study areas ($\bar{x}$= 0.005; 95% confidence interval -1.267 – 1.307; *p* = 0.162). The treatment effect was similar for the probability of catching a long-tailed duck ($\bar{x}$ = -0.758; 95% confidence interval -1.581 – 0.012; *p* = 0.053, Figure 14).

A negative binomial GLMM that examined whether the number of bycaught birds differed between control and treatment sets in sets where at least one bird was caught in any of the nets indicated that the treatment effect was slightly negative, but not significantly different from zero ($\bar{x}$=-0.377; 95% confidence interval -0.908 – 0.137; *p* = 0.151, Figure 15). Including the study area in the model did not alter this conclusion, and there was no significant difference in bycatch between the two study areas ($\bar{x}$ = -0.117; 95% confidence interval -0.631 – 0.395; *p* = 0.322). The mean number of bycaught long-tailed ducks was also slightly lower in the experimental nets, but this effect was also not significantly different from zero ($\bar{x}$ = -0.463; 95% confidence interval -1.088 – 0.135; *p* = 0.130, Figure 16).

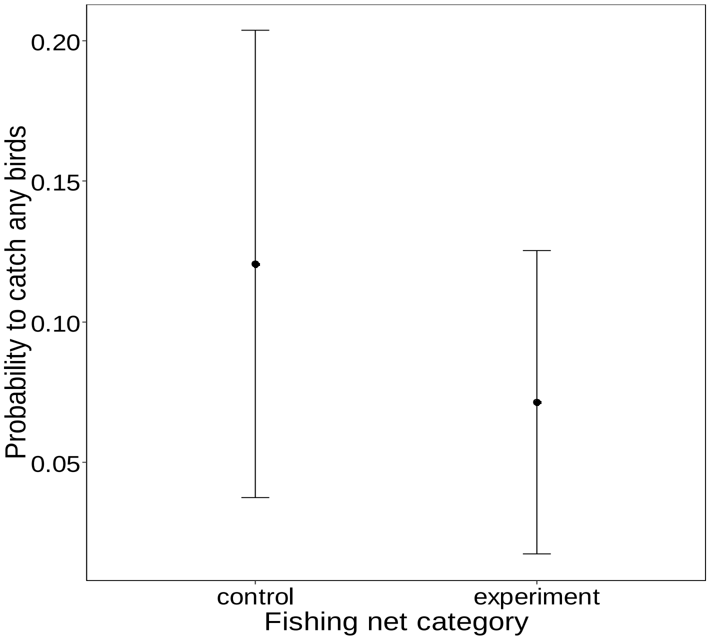

Figure 13. Estimated mean probability (± 95% confidence interval) to catch any birds in paired sets of control or experimental fishing nets in Poland in 2016/2017.

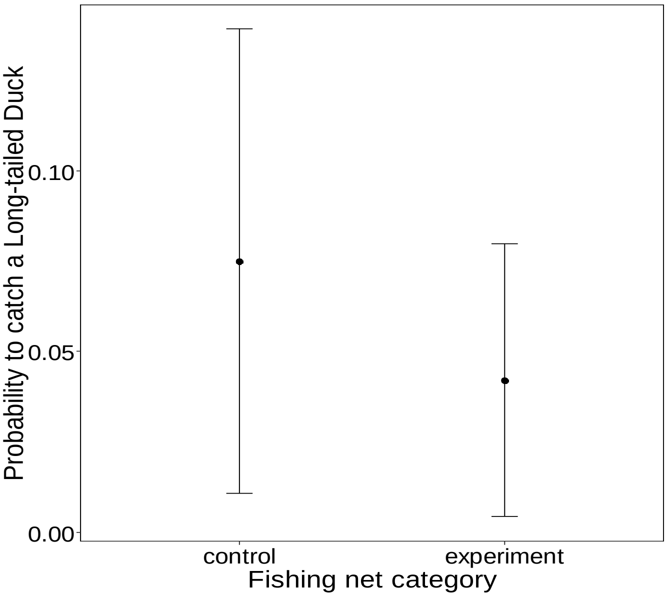

Figure 14. Estimated mean probability (± 95% confidence interval) to catch a long-tailed duck in paired sets of control or experimental fishing nets in Poland in 2016/2017.

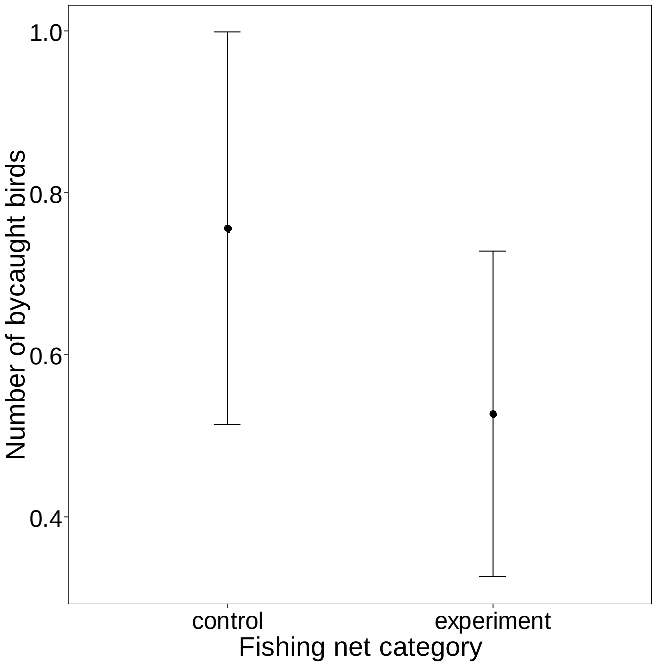

Figure 15. Estimated mean number (± 95% confidence interval) of bycaught birds in paired sets of control or experimental fishing nets in Poland in 2016/2017 where at least one bird was caught in any net.

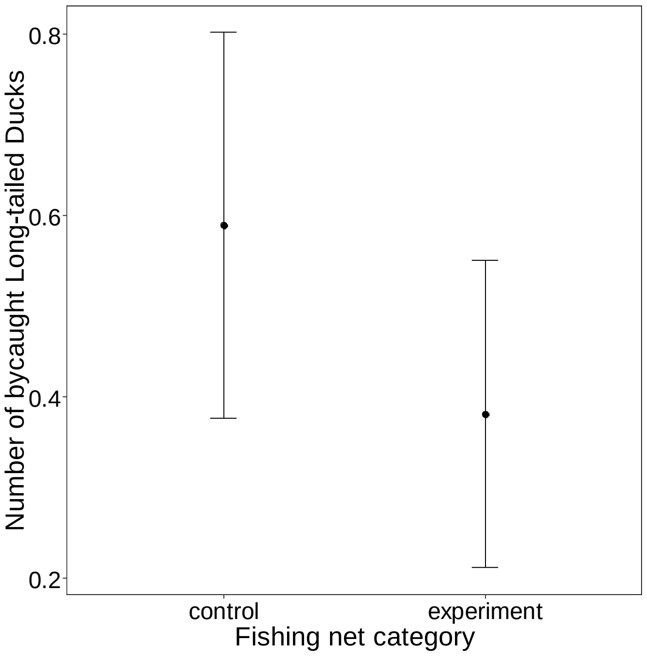

Figure 16. Estimated mean number (± 95% confidence interval) of bycaught long-tailed ducks in paired sets of control or experimental fishing nets in Poland in 2016/2017 where at least one bird was caught in any net.

3.1.4. OBSERVED TRIPS- PORTUGAL

22 fishing trips were monitored during the two field seasons (2015/2016 winter and spring; 2016/2017 winter and spring).

3.1.5. BYCATCH COMPARISON- CONTROL & EXPERIMENTAL SETS- PORTUGAL

The historical and recent evidence of seabird bycatch in gillnets within this region and fishery demonstrates that this area was appropriate for mitigation gear testing. However, no bycatch was recorded during any of the observed trips in either control or experimental sets. Bycatch is episodic by nature and based on observer work by SPEA in this specific fishery, many sets can be observed during which bycatch does not occur, followed by a bycatch event. The relatively few observed trips (caused by poor weather during the field season) means that bycatch could have occurred, just not in the gear of participating vessels or during observed trips. Due to the lack of bycatch in observed trips, an analysis of the difference between control and experimental sets was therefore not possible based on the sample.

3.1.6. IMPACT OF MITIGATION GEAR ON FOCAL SEABIRD POPULATIONS

Due to the lack of bycatch in the technical mitigation trials in Portugal described above, it was not possible to explore the potential impacts of bycatch and mitigation measures trialled on the focal bird species- the razorbill- in Portugal. The team still calculated the PBR results for razorbill, which are provided below.

In Poland, based on the results of the mitigation trials testing lights on nets and the already available bycatch estimates from other studies (e.g. Psuty *et al.,* in prep.), we explored the potential impacts on threatened seaduck populations of adopting the mitigation measures locally in Puck Bay.

3.1.7. STATUS QUO AND MITIGATED BYCATCH ESTIMATES – PUCK BAY

Bycatch estimates are available for Puck Bay from Psuty *et al.,* (in prep.). This work by the Polish National Marine Fisheries Research Institute (NMFRI) investigated the seabird bycatch rates in the Szczecin and Kamienski Lagoons and in Puck Bay with on board observers between November 2014 and April 2015. Generalised linear models (GLM) were used to predict bird bycatch. The optimal model was chosen iteratively based on AIC (Akaike Information Criterion), which allows for the assessment of predictive properties. The selected optimal model predicted by-catch for Puck Bay of 3,359 birds (all species) in 2013/2014 and 3,176 birds in 2014/2015.

During the trials conducted under the current study, 74% of birds caught were long-tailed ducks. **If we assume a similar composition of bycatch to Psuty *et al.,* (in prep) observations, these give estimates of 2,486 and 2,350 long-tailed ducks caught in 2013/14 and 2014/15 respectively.**

In this study, the BPUE observed in the statistical rectangle R5 of Puck Bay for long-tailed ducks in experimental nets was 0.39±1.25 birds/1000 NMD compared to 0.67±1.87 birds/1000 NMD in control sets (See Table 1). **The difference in observed bycatch rates is equivalent to a 42% reduction in bycatch from control to experimental nets (though it is important to note that our result was not significant in this instance).**

Based on this result, had the tested mitigation measures been used in Puck Bay, bycatch estimates for Psuty *et al.* (in prep.), could potentially have been reduced to 1,447 and 1,368 birds respectively for 2013/14 and 2014/15.

3.1.8. POTENTIAL BIOLOGICAL REMOVAL- FOCAL SEABIRD SPECIES

- Long-tailed Duck

Potential Biological Removal (PBR) estimates ranged from 2,919 to 6,849 birds depending on which method was used for calculations (Table 2). These figures represent a theoretical estimate of the number of mortalities additional to natural mortality that can be sustained each year by a population. Using maximum adult survival gave an estimate of 6,849. Using an estimated value for the maximum population growth rate from Schamber *et al.* (2009) gave a more conservative estimate of PBR of 2,919 birds.

Table 2. Potential Biological Removal (PBR) estimates for long-tailed duck *Clangula hyemalis* (western Siberian/northern European populations).

Min Population size N_{min}	**Source of Population estimate**	**Age of first Reproduction** **α**	**Recovery factor** ***f***	**Adult survival** ***s***	**Maximum Population growth rate** λ_{max}	**Potential Biological Removal (PBR)**
939,000	ErLob lower range	3	0.1	0.91[1]	1.1458	**6,849**
939,000	ErLob lower range	NA	0.1	NA	1.06[2]	**2,919**

[1]Koneff *et al.,* 2017; [2]Schamber *et al.,* 2009

- Razorbill

For razorbill, the PBR was estimated at 6,668 birds based on the maximum adult survival estimates from Machias Seal Island. Using the modelled estimate for the maximum population growth rate from Lavers *et al.,* (2009) gave a slightly more conservative estimate of PBR of 6,079 birds (see Table 3).

Table 3. Potential Biological Removal (PBR) estimates for razorbill *Alca torda*

Min Population size N_{min}	**Source of Population estimate**	**Age of first Reproduction** **α**	**Recovery factor** ***f***	**Adult survival** ***s***	**Maximum Population growth rate** λ_{max}	**Potential Biological Removal (PBR)**
643,249	ErLob lower range	5	0.3	0.967[1]	1.0691	**6,668**
643,249	ErLob lower range	NA	0.3	NA	1.063[2]	**6,079**

[1]Lavers *et al*., 2008b; [2]Lavers *et al.,* 2009

3.2. IMPACT STUDY- ECONOMIC

3.2.1. OUTLAY AND INSTALLATION COSTS

Using data collected during the gear manufacturing and installation process, the following section provides a breakdown of the outlay costs (i.e. raw materials and labour) associated with each experimental mitigation measure; a comparison of these costs in relation to the original manufacturing costs of each gillnet; and, an estimation of the total costs of installing the focal mitigation measures across the entire Polish and Portuguese gillnet fleets, using data on vessel numbers presented in the Annual Economic Report (AER) data (STECF, 2016) and assumptions regarding net lengths and the number of nets used per vessel.

The costs of the raw materials per metre and total costs of modification per metre are presented for each net in Table 4. The total cost to modify a net with lights was approximately 0.42 Euro per metre, whereas the total cost to modify a net with high contrast panels ranged from 0.34 – 0.56 Euro per metre. Additionally, data on the modification time for the nets suggests that installing high contrast panels into a gillnet is much more time-consuming than installing lights on a gillnet. For example, comparing the modification time of the nets one and nine (Table 4) suggests that installing lights on a gillnet takes a quarter of the time required to install high contrast panels. This result was somewhat expected; nets modified with high contrast materials required the high contrast material to be attached to the net at four metre intervals; whereas nets modified with lights required the lights to be attached to the nets at ten metre intervals.

Table 4. Break down of costs to equip the ten gillnets used in the field trials with bird bycatch mitigation measures. The length of the nets, materials used, costs of materials, modification time, and costs of labour associated with each of the nets are provided alongside total modification cost and cost per metre. All costs are provided in Euros.

Net	**Net length**	**Materials**	**Cost of materials**	**Cost of material per net metre**	**Modific-ation time (hrs)**	**Cost of labour to modify net***	**Total Cost to modify net**	**Total Cost per net metre**
1	1176	Lamps and batteries	437.90	0.37	4.56	58	495.90	0.42
2	420		158.55	0.38	1.66	21	179.55	0.43
3	224		83.05	0.37	0.87	11	94.05	0.42
4	435		166.10	0.38	1.73	22	188.10	0.43
5	174		67.95	0.39	0.71	9	76.95	0.44
6	261		98.15	0.38	1.02	13	111.15	0.43
7	348		128.35	0.37	1.34	17	145.35	0.42
8	600	High contrast material	281.25	0.47	18	56.9	338.15	0.56
9	1170		384.38	0.33	17.50.	55.3	439.68	0.38
10	500		134.38	0.27	12	37.9	172.28	0.34

*****_Cost of labour in Poland (nets 1-7) represent the actual wages paid to fishers to attach lights to their gillnets. In Portugal (nets 8-10) fishers were paid a flat fee of 400 Euro to attach high-contrast panels to their nets and participate in the trials; therefore, labour costs have been calculated from the time it took fishers to attach panels to their nets (Modification time) multiplied by the current minimum wage in Portugal (3.16 Euro per hour)._

Comparing the costs of installing the mitigation measures to the costs of manufacturing the original gillnets provides valuable insight to the relative financial investment required to install these mitigation measures. Specifically, the costs to modify gillnets with lights represented a 45 – 50% increase in the cost of manufacturing; whereas, the costs to modify gillnets with high contrast panels represent a 26 - 40% increase (see Table 5). When considering implementation of the focal mitigation measures at fleet level, therefore, it should be acknowledged that modifying gillnets will represent a relatively significant increase to the original cost of manufacturing gillnets. However, it should be acknowledged that if these net modifications were implemented on a wide-scale, the price of modifying individual nets with mitigation measures would likely decrease due to bulk purchasing of the materials. Fishermen also suggested that gillnets could have the mitigation mechanism attached at the factory to reduce time.

Table 5. Comparison of costs to manufacture a bottom set gillnet per metre against the costs to modify the same nets with the focal mitigation measures.

	Net length (m)	Original cost to manufacture net per metre	Cost to modify net with mitigation measure per metre	Increase in price per metre for modification (%)
1	1176	0.89	0.42	47.4
2	420	0.95	0.43	45.0
3	224	0.89	0.42	47.2
4	435	0.91	0.43	47.5
5	174	0.87	0.44	50.8
6	261	0.91	0.43	46.8
7	348	0.87	0.42	48.0
8	600	1.4	0.56	40
9	1170	1.03	0.38	36.9
10	500	1.3	0.34	26.2

Extrapolating these costs to the entire Polish and Portuguese gillnet fleets provides an indication of the potential outlay costs that they would incur if the mitigation measures were implemented at a national level. Extrapolations are made using data on the costs per metre (Table 4) and the number of vessels per metier, combined with assumptions on the average length of gill net used by each metier, the number of nets used by vessels of different sizes, and the proportion of vessels using gillnets within each metier[6]. The data and assumptions used to calculate these costs are presented in Table 6. The total number of boats identified to be potentially using gillnets was 587 in Poland and 2,321 in Portugal (STECF, 2016). These boats were spread across metiers which were either drift and/or fixed net vessels (DFN) or polyvalent passive gear vessels (PGP). The following assumptions were made for Poland: All boats belonging to PGP metiers would use gillnets, whereas 50% of vessels belonging to DFN metiers would use gillnets; all vessels used nets with an average length of 50 metres; the number of nets used by vessels of different sizes within each metier was assumed to be 50 nets for vessels below ten metres, 80 nets for vessels between 10-12 metres, and 150 nets for vessels between 12-18 metres (Pers. Comm. NMFRI representative). The following assumptions were made for Portugal: All boats belonging to DFN metiers would use gillnets, whereas 50% of vessels belonging to PGP metiers would use gillnets; all vessels use nets with the same average length of those participating in the field trials (773 metres); the number of nets used by vessels of different sizes within each metier was assumed to be two nets for vessels below ten metres, four nets for vessels between 10-12 metres, eight nets for vessels between 12-18 metres, and twelve nets for vessels between 18-24 metres.

Results of the extrapolation indicate that the estimated cost to fit the Polish gillnet fleet with lights would equal 695,310 Euro; the estimated cost to fit the Portuguese gillnet fleet with high contrast material would equal 1,186,965 Euro. Although these estimates provide a useful indication of the potential costs of modifying the gillnets of fleets on a national level, to contain the focal bycatch mitigation measures, it must be underscored that the figures are based on multiple assumptions which could make the true costs highly variable. To gain a more accurate estimation of the potential costs of the wide-scale implementation of these bycatch measures, it is crucial to obtain robust estimates from respective national fisheries institutes regarding the number of vessels in their fleets using gillnets, the number of nets being used by the fleet, and the length of these nets. Additionally, the wide-scale implementation of the mitigation measures could significantly reduce the cost of the raw materials (lights and high contrast materials) due to bulk purchasing. As a follow on from this study, future research should investigate the potential savings to be made on raw materials.

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[6] Vessels fishing under a polyvalent passive gears (PGP) licence are permitted to use a range of gears may or may not use gillnets consistently throughout the year.

Table 6. Cost estimations of modifying gillnets to contain bird bycatch mitigation measures across the entire Polish and Portuguese fishing fleets. Vessel numbers based on STECF (2016)

Metier	Number of vessels within metier	Assumed proportion boats within the metier using nets	Average length of net (m)	Cost per metre to equip with mitigation measure (EURO)	Cost to modify an average length of net (EURO)*	Number of nets	Total outlay cost per metier
POL A27 PG0010	456	1	50	0.42	21	50	€ 478,800
POL A27 PG1012	97	1	50	0.42	21	80	€ 162,960
POL A27 DFN1218	34	0.5	50	0.42	21	150	€ 53,550
Total Poland	**587**						**€ 695,310**
PRT A27 DFN0010	307	1	773	0.43	332.39	2	€ 204,087
PRT A27 DFN1012	27	1	773	0.43	332.39	4	€ 35,898
PRT A27 DFN1218	66	1	773	0.43	332.39	8	€ 175,502
PRT A27 DFN1824	26	1	773	0.43	332.39	12	€ 103,706
PRT A27 PGP0010	1849	0.5	773	0.43	332.39	2	€ 614,589
PRT A27 PGP1012	12	0.5	773	0.43	332.39	4	€ 7,977
PRT A27 PGP1218	34	0.5	773	0.43	332.39	8	€ 45,205
Total Portugal	**2321**						**€ 1,186,965**

*C*ost to modify average length of net is calculated from the average length of net used by the focal metier multiplied by the cost per metre to equip with mitigation measure.*

3.2.2. IMPACT OF PANEL AND NET LIGHT MITIGATION GEAR ON FISH CATCHES

Results indicate that the total recorded catches across all fishing trips in Poland's Pomeranian Bay were 8,650kg and 8,594kg for the mitigated and control nets, respectively; for Puck Bay, total catches were 41.51kg and 116kg for mitigated and control nets; and, for Portugal, total catches were 50.57kg and 49.33kg for the mitigated and control nets (see Table 7).

Table 7. Summary of fisheries catches from control nets and nets with mitigation measures

	Portugal	Poland - Pomeranian Bay	Poland - Puck Bay
Experimental Nets			
Total catch, all nets (kg)	50.57	8650.48	41.51
Mean catch per net/trip(kg)	2.53	106	0.59
Max catch per net/trip (kg)	12.33	860	3.81
Min catch per net/trip (kg)	0	0	0
Sample size (n)	20	81	81
Control nets			
Total catch, all nets (kg)	49.33	8594.28	116
Mean catch per net/trip (kg)	2.74	106	1.45
Max catch per net/trip (kg)	9.98	550	15.5
Min catch per net/trip (kg)	0	0	0
Sample size (n)	18	81	81

To determine if catches were significantly different between normal gillnets and nets containing the bycatch mitigation measures, a Mann-Whitney test was used to compare the catches between the two groups. Results indicate that the mitigation measures have no impact on catches in two locations, and a negative impact on catches in one location: In Portugal the catches from the control nets (Mdn=0) did not significantly differ from the nets with high contrast panels as a mitigation measures (Mdn=0), U=157.5, p=0.510; similarly, in Pomeranian Bay, catches in control nets (Mdn=80) did not significantly differ from the nets with lights as a mitigation measure (Mdn=62), U=3202, p=0.792; however, in Puck Bay, catches in nets with lights as a mitigation measures (Mdn=0) were found to be significantly less than catches in the control nets (Mdn=0), u=2585.5, p=0.015).

Results indicate that nets with high contrast panels trialled as a bird bycatch mitigation measure in Portugal do not catch a significantly different volume of fish compared to control (normal) gillnets. Therefore, this result provides evidence that the adoption of high contrast panels by gillnet fishers would not negatively (or positively) impact their catches. However, it must be underscored that these results should be interpreted with caution due to the limitations of the study and the resulting data: In Portugal, the sample size for the fisheries catches data set is small (n=38), and the observed fisheries catches in both the normal and nets with high contrast panels are extremely low (see Table 7); both these limitations reduce confidence in the result. Thus, to obtain a more robust result, it is recommended that the sample size of trials involving the high contrast panels is increased. While this study was conducted on the vessels' usual fishing grounds (on which we would expect higher catches), higher catch rates would have assisted in achieving a more robust result.

Trials in Poland provide contrasting evidence regarding the impact of the mitigation measure (lights) on fisheries catches. Results from Pomeranian Bay suggest there is no significant difference between the fisheries catches from nets attached with lights and the control nets. Conversely, results from Puck Bay suggest that fisheries catches are significantly less in the nets with lights attached compared to the control nets. Again, this result must be interpreted with caution as the fisheries catches in Puck Bay from both the control nets and nets with lights are extremely low (see Table 7), suggesting that the trials were conducted in an area with low fish populations. For example, although data from Puck bay indicates that the nets with mitigation measures caught significantly less fish, the difference between the mean catches of the normal gillnets and the nets with mitigation measures in Puck Bay was 1kg; an insignificant amount of fish relative to the economics of a fishing vessel. Considering the limitations of the data obtained from Puck Bay, it is suggested that the results from Pomeranian bay may provide the most robust insight into the impact of the mitigation measure on fisheries catches, due to the large sample size (n=81) and relatively large fisheries catches (**Error! Reference source not found.**see Table 7). If the results f rom Pomeranian bay were to be interpreted alone, it would indicate that the lights installed on gillnets do not negatively (or positively) impact on the ability of these nets to capture fish.

Overall, the mixed results and limited data make it difficult to draw conclusions regarding the impact of the focal mitigation measures on fisheries catches. **It is therefore recommended that more robust data are gathered to improve confidence in the results. It is suggested that the sample size of trials involving the high contrast panels is increased, and that both the mitigation measures are re-tested to obtain higher fish catches.**

3.2.3. ACCEPTABILITY OF MITIGATION GEAR TO FISHERS

- Poland

In Poland, the captains of the four vessels participating in the trials were interviewed separately to document their experiences of utilising nets containing lights as a mitigation measure relative to normal gillnets. When asked about how the modified nets were to set up or manufacture (see Annex 5., questions 5 & 6), all captains gave consistent responses indicating that nets with the mitigation measures were more time consuming to set up compared to normal nets. This was attributed by three captains to the additional time it took for the lights to be attached to the nets.

When asked about how the nets with lights attached were to handle at sea (questions 8 & 9), three captains indicated that the nets with lights were more difficult and took more time to set and haul when compared to normal gillnets. Two captains suggested that the additional weight of the lights increased the likelihood of the nets ‘messing up’, whereas one captain suggested that that setting and hauling had to be done at a slower pace as the lights could damage the nets. One captain indicated they were uncertain about the impact of the lights on handling.

When asked about onshore handling (questions 10 & 11), similar to questions relating to gear set up and manufacture, three of the participating captains indicated that the nets with the mitigation measure were more difficult and time consuming to repair when compared to normal gillnets. Captains associated this increased difficulty and time with the additional process of attaching the lights to the nets. No additional issues were reported by the fishers.

When vessel captains were asked how fisheries catches in the nets with lights differed compared normal gillnets (questions 13 & 14), all captains indicated they were uncertain of the impact of the mitigation measures. Both vessel captains that had participated in the trials in Puck Bay, suggested that the fishing catches were poor (both in normal nets and the nets with mitigation measures) and it was therefore not possible to make judgements about the differences in fisheries catches between the nets. Captains fishing in Pomeranian bay both indicated that the catches varied due to other factors, i.e. any difference in catches between the nets with the mitigation measures and the normal gill nets were not due to the lights.

When asked about bird bycatch in the nets with lights compared to the normal gillnets (questions 15 & 16), three captains suggested that the nets caught a similar amount of birds, whereas one captain suggested that the nets with lights caught more birds than the normal gillnets. Three captains indicated that the birds caught in the nets with lights were usually found close to the lights. Therefore, from the questionnaire, the view of three captains participating in this trial was that the lights had the opposite impact to what was intended; i.e. the lights attracted birds instead of repelling them. The remaining captain was uncertain about the impact of the lights on bird bycatch.

Vessel captains stated that four main issues and difficulties were encountered while using the nets with lights (questions 17 - 21): the lights cause damage to the nets; the lights cause the nets to ‘mess up’ during setting and hauling; the lights add weight to the nets; and, additional time is required to attach the lights and replace batteries in the nets. When asked to clarify and discuss these issues, vessel captains offered limited information; potentially because they considered the stated issues as self-explanatory, or the issues had been previously discussed (see previous paragraphs). Nevertheless, one captain offered important insight, stating that the lights 'hooked' onto the nets during setting and hauling, which, in turn, caused damage and entanglement. Consequently, when captains were asked for recommendations to overcome the issues and difficulties they encountered with the nets, two captains suggested that the lights should be more streamlined to avoid the lights hooking on the nets. One captain suggested that the shape of the lights should be similar to the floats they use to provide buoyancy for the nets. Thus, although the captains provided limited information on the issues encountered as part of question 19, interviews suggest that the main issue with the nets with lights attached is that the lights become hooked on the netting during setting and hauling, causing damage and entanglement. If further trials are conducted using lights as a bird bycatch mitigation measure, it is therefore recommended that the design of the lights is altered to prevent this issue.

The final questions put to vessel captains related to the overall acceptability of the gillnets with lights attached (questions 22 & 23), and if they would replace their normal gillnets with these new nets. Overall, all vessel captains indicated that they would not wish to replace their normal gillnets with the nets with lights attached: All four captains strongly agreed with the statement, 'I would not want to replace my current nets with the new nets (nets containing lights). Furthermore, three captains agreed that replacing their normal gillnets with nets with lights attached would have a negative impact on them as fishers. When asked to explain why they would not want to replace their normal nets with nets with lights attached, two captains suggested the costs of maintaining the nets with lights would be higher than normal nets; one captain stated that the nets were difficult to handle (set and haul); and, one captain stated that the lights cause damage to the nets.

- Portugal

The captains of the three vessels participating in the trials in Portugal were interviewed separately to document their experiences of utilising nets containing high contrast panels relative to normal gillnets. When asked about how the modified nets were to handle at sea (see Annex 5., questions 8 & 9), the captains gave mixed responses: two captains indicated that there was no difference between handling the normal gillnets and handling the nets with high contrast panels. Conversely, the remaining captain suggested that the nets containing the panels were more difficult to handle as the high contrast panels made the nets heavier; consequently, this made the nets more difficult to set and haul compared to normal gillnets.

When asked about the onshore handling and repairs of the new nets compared to normal gill nets (questions 10 & 11), only one captain answered this question, as the other two captains had not repaired their nets during the trial. The captain that had repaired the nets indicated that the normal gillnets and the nets with high contrast panels were similar to repair, but that the nets with high contrast panels took more time to repair than the normal nets. Additionally, the captain stated that they were uncertain whether the new gillnets were more difficult or as practical to repair as the normal gillnets.

When asked about the impact of fisheries catches (questions 13 & 14), all three captains indicated that they did not consider the catches from the nets with high contrast panels to be any different to catches from normal gillnets. Therefore, this result corroborates the previous analysis of fisheries catches (Fisheries catches), suggesting there is no significant difference between the catches of normal gillnets and nets with high contrast panels. Questions relating to the effect of the mitigation measures on bird bycatch rates (questions 15 & 16) were not relevant to the fishers in Portugal as no instances of bird bycatch were recorded during the trials.

When asked about specific difficulties and issues encountered with nets containing high contrast panels (questions 18 – 21), two issues were stated among the three captains: One captain indicated that the nets were difficult to work with in bad weather; and, as previously discussed, one captain suggested that the nets were heavier and therefore more difficult to set and haul compared to normal gillnets. The captain indicating that the nets were difficult to work with in bad weather suggested that the high contrast panels functioned as a barrier which restricted the flow of water through the net. This reportedly led to the nets becoming entangled on the sea floor more easily. This is an important finding; if the nets are unable to be used in bad weather it potentially means that nets with high contrast panels could not be used during winter months. However, when interpreting this result, it should be underscored that only one of the three vessels reported that the nets were difficult to work with in bad weather, despite all vessels in the trial fishing with the gear throughout the winter months. The results of this question suggest that, in future, attempts should be made to reduce the weight and improve the flow of water through the high contrast panels. This would eliminate the issues experienced by fishers during the trials.

When the captains were asked if they would accept replacing their normal gillnets with nets containing high contrast panels (questions 22 & 23), one captain answered positively and two answered negatively. The two captains indicating that they would not replace their nets cited the issues discussed in the previous paragraph as their main reasons for not wanting to replace their nets. This suggests, again, that to make nets containing high contrast panels acceptable to fishers, work should be done to reduce the weight and improve the flow of water through the panels. The captain indicating that they would not have a problem replacing their normal nets with nets containing high contrast panels indicated that the nets had minimal impact on their fishing; however, they voiced concern over the outlay costs of replacing or modifying their nets.

4. DISCUSSION/CONCLUSIONS

4.1. OVERALL ASSESSMENT OF MITIGATION MEASURE EFFECTIVENESS

- Effectiveness of net lights in Poland as a mitigation measure

The success of green LED lights in reducing seabird and turtle bycatch in Peru and Mexico (Wang *et al.,* 2010; Mangel *et al.,* 2014; Ortiz *et al.,* 2016) drove us to examine the effects of the same lighting regime in a geographically distant fishery in Poland, with different bycatch species and environmental characteristics. The results of our trials in Puck Bay and the Pomeranian Bay have not demonstrated a statistically significant reduction in seabird bycatch in illuminated sets. However, a reduction in bycatch is evident (mean overall bycatch is reduced by 32% in illuminated sets), and is more pronounced for long-tailed ducks than for all species collectively. Although the lack of significance means this reduction should not be interpreted as an outright success, it does highlight that net illumination is a worthy avenue for future research.

It may be that the environmental conditions and/or species-specific visual capacities and behavioural responses had a strong role to play in the difference between the results observed in this trial and those in Peru (where reductions of >80% were recorded for guanay cormorants in illuminated sets). A combination of more fundamental work on what European seabirds find aversive (potentially with captive populations) and further trials with the same lights would help to highlight if this was the case (see section 4.8 'Recommendations for future research' below).

- Effectiveness of net panels in Portugal as a mitigation measure

There were no birds caught in the control or the experimental sets during the 22 trips with observers on board in Portugal. This makes it impossible for us to draw conclusions about the efficacy of panels as a gillnet bycatch mitigation measure. The small number of trips (due mostly to weather windows) along with the documented nature of the bycatch events in the area (sporadic but in high numbers) could have influenced our results. The low fish catch reported and the unsuitable sea conditions were additional constraints to the fulfilment of the number of experimental trips initially planned. However, this was an important first opportunity to trial operability of the panels in the Peniche fishing fleet and to examine acceptability of the panels to fishers.

While the lack of bycatch prevented us from examining the efficacy of net panels in reducing the number of seabirds caught, it is useful to report here results from BirdLife International's work in Lithuania, where similar panels were tested in the bottom-set cod fishery. In Lithuania, across two winter (October-April) seasons in 2015/16 and 2016/17, a trained team of observers have conducted paired trials on several fishing vessels. In 2015/16, the number of birds caught in experimental sets was a third lower than control nets, but this result was not found to be statistically significant. In 2016/17, we collected data on bycatch and catch from 80 paired sets, with 20 birds caught in control nets and 20 in experimental nets. These results demonstrate that panels, whilst most likely visible to seabirds (Martin and Crawford, 2015), are not sufficiently aversive to result in birds avoiding nets (Tarzia *et al*., 2017). Given a robust experimental design and the large number of trips conducted, we are confident that net panels have been shown to be ineffective in reducing seabird bycatch in Lithuania.

4.2. IMPACTS ON SEABIRD POPULATIONS

In order to make meaningful comparisons between fisheries bycatch estimates and PBR estimates, accurate estimates of all sources of additional mortality affecting the whole seabird population under consideration are ideally required.

A number of factors are likely to be impacting populations of long-tailed ducks wintering in the Baltic, including changing ecological conditions and increased predation on breeding grounds, due to climate change, and potential carry-over effects from threats in non-breeding areas (Hearn *et al.,* 2015). Direct mortality in non-breeding areas is known to come from recurrent operational oil discharges and hunting as well as fisheries bycatch (Hearn *et al.,* 2015). Mortality from hunting is fairly well documented from bag monitoring systems in the key countries, but the other factors are very difficult to quantify as few data exist.

Here we have only been able to make relatively crude estimates of annual long-tailed duck bycatch caught in one area of the Polish coast, Puck Bay. **However, these estimates represent between 34% and 36%, of the upper estimate of PBR for the European population of long-tailed duck presented in 5.1.8. and between 81% and 85% of the more conservative PBR estimate for this species. It is therefore easy to comprehend why this population is in decline, once all additional mortality across the entire flyway for the European population of long-tailed duck is taken into account.** Reviewing the hunting statistics alone (see Annex 7) gives cause for concern in light of the PBR estimates we present for this species.

Hunting catch estimates across the Baltic and Nordic/Arctic countries from 2008-2012 amount to an annual mortality of 14,806 birds, some 12,000 or so shot in Finland alone. In Finland, long-tailed ducks are now hunted by a relatively small number of hunters, and the harvest statistics and current bag estimate methodology tends to overestimate hunting pressure (Hearn *et al.,* 2015). In all other countries where the bag size trend is known it has declined, though in some the trend has now stabilised at a lower level. However, in Denmark, where the second largest national harvest of long-tailed ducks has been reported, these lower levels (at 1,400 birds) account for approximately 50% of the more conservative estimate of PBR we calculated of 2,919 birds.

As expressed throughout this report, it is exceedingly difficult for us to extrapolate from a very small sample size to broader sea basins to assess the impact of bycatch on seabird populations. In large part, this is because it is difficult to design a study which simultaneously examines the effect of mitigation interventions (for which it is sensible to focus study sites in areas of high bycatch) and assesses baseline bycatch levels (for which it would be best to ensure a representative sample of observations across the fishery). As the primary aim of this study was to develop mitigation measures, we followed the former approach, which has affected our ability to extrapolate bycatch estimates.

In addition, it has not been possible to look at the effect of different mitigation scenarios on seabirds in Portugal because of the lack of bycatch in the Portuguese trials. However, our Lithuania panel work suggests differences in bycatch are unlikely regardless- suggesting that panels are not effective in reducing bycatch in these fisheries at least (Tarzia *et al*., 2017).

The net illumination trials in Poland indicate that this measure could result in seabird bycatch reduction if implemented across a wider area - but the lack of significant result means that further trials and refinement of this measure are prerequisites before rolling out over a broader area (see section 4.8 'Recommendations for future research').

Although our PBR outputs and the bycatch estimate for Puck Bay need to be treated with a degree of caution, the decline in long-tailed ducks is of little surprise given the additive mortality from bycatch, hunting, invasive species and oil pollution. Minimising sources of adult mortality like bycatch and hunting offer some of the most tractable opportunities for reversing this trend. With regard to bycatch, a programme of work to underpin technical mitigation measure development and the identification of spatio-temporal fisheries management measures in the most pressing conservation cases is required. Research priorities along these lines are proposed below.

4.3. IMPACTS OF GEAR ON FISH CATCH

Although a mixed picture is presented in our results on target catch, broadly there are encouraging signs that both the mitigation measures tested do not impact catch, with trials in Portugal and the Pomeranian Bay showing no significant difference in target species catch. However, the small sample size for Portugal, coupled with the results from Puck Bay (which show a lower level of catch, albeit in the context of extremely poor catches in both control and experimental sets) merit further exploration in future trials.

4.4. OPERATIONAL ISSUES

Operationally speaking, several issues were raised by fishers that should inform future development of mitigation measures (see section 3.2.3. for more details). Panels could be improved through a lighter weight design and attachment to the net at the manufacturer. Although the panels are already cut into pieces to allow water flow-through, this aspect of the design also merits closer examination. Net illumination appears to have caused more problems for fishers, with entanglements and slower setting/hauling times being major issues. **Since the lights are actually designed for use in other fisheries, a purpose-built gillnet light (similar in shape to existing floats, as per of one of the fisher's comments) would potentially deal with both of these issues. However, we would recommend that some baseline work is done to understand what light specifications would be the most aversive for the key bycatch species in a given area** (see section 4.8 'Recommendation for future research' below)**.**

4.5. ACCEPTABILITY OF MITIGATION GEAR BY FISHERS

Semi-structured interviews conducted with the vessel captains participating in the trials in Poland suggest that they had a consistent opinion regarding the acceptability of the nets containing lights: the nets are not acceptable to fishers in their current form. Analysis of the questionnaire responses suggest that three main points should be considered for future trials involving nets containing lights as a mitigation measure, and to reduce the potential negative impacts of this bird bycatch mitigation measures on fishers. Foremost, the current design of the nets with lights means that the lights are prone to hooking on the net; this, in turn, causes damage and entanglement. In line with recommendations from fishers, the design of the lights attached to the nets should therefore be altered to prevent this issue. Second, fishers were concerned about the additional costs associated with maintaining the lights attached to the nets. It is therefore recommended that these costs are minimised to increase the acceptability of the bird bycatch mitigation measure to fishers. Finally, captains participating in this study have suggested that the lights used as a bird bycatch mitigation measure potentially attract seabirds to the nets instead of repelling them. However, this is not conclusive and it must be underscored that fishers considered there to be similar bird bycatch rates between normal gillnets and nets with lights attached, which somewhat contradicts the point that birds are attracted to the lights. It is therefore recommended that the opinion of fishers regarding bird bycatch rates in nets with lights is considered alongside the analyses presented in section 4.1 and section 4.2, which indicate that there was no significant difference between the bird bycatch rates between control and experimental nets. Again, it must be highlighted that the sample size for this study was small and further trials are required to accurately determine the efficacy of this bird bycatch mitigation measure.

Acceptability interviews conducted with the vessel captains in Portugal presented a mixed opinion of the nets containing the high contrast panels: Two fishers reported different issues with the gear and one fisher did not report any issues with the gear. The interviews in Portugal presented two important findings: Foremost, all fishers regarded the high contrast panels to have a minimal impact on fish catches, a result which corroborates the analysis conducted in section 4.3.2. Thus, evidence suggests fishers utilising these nets would not incur losses to their income from fisheries catches through reduced fish catches. Second, handling of nets with high contrast panels could be improved by decreasing the weight of the panels and improving the flow of water through the panels. It is therefore recommended that future trials involving nets containing high contrast materials consider this point as nets which are difficult to set and haul are unlikely to be adopted by fishers.

4.6. DISSEMINATION OF RESULTS- WORKSHOP

The results of the study, priorities for research and recommendations based on the study were disseminated through a dedicated lunchtime workshop held in Directorate-General for Maritime Affairs and Fisheries (DG MARE) in September 2017.

4.7. DISCUSSION ON ISSUES/ASSUMPTIONS WITHIN STUDY

The issues and assumptions associated with different elements of this study are raised and addressed throughout this report, but the main overarching issues and assumptions are summarised here for ease of reference. Perhaps the most fundamental issue this study encountered was a lack of data. Not only on bycatch mitigation in gillnet fisheries, but numbers of birds caught in gillnets and basic gillnet effort data. These knowledge gaps create substantial barriers for assessing bycatch impacts on populations and measuring change - a number of recommendations are targeted to address these issues.

The wide scope of this study also presented a challenge - it is difficult to design a study that simultaneously develops mitigation measures (which requires directing data collection towards areas of known high bycatch to obtain large enough sample sizes) and assesses bycatch in gillnet fisheries at a broader (i.e. country) scale (which requires stratified, non-biased sampling across space and time). Alongside the data gaps noted above, this restricted our ability to assess the potential population-level effects that mitigation measures might have. Bycatch assessment and mitigation testing are important elements of tackling this problem, but they need to be dealt with in different ways.

The changes to seabird populations, at-sea distributions and the effects of a host of threats (climate change, oil pollution, hunting, invasive species) make it difficult to disentangle the importance of individual threats. This is a further complicating factor in assessing the influence of bycatch on seabird populations. That said, it is clear that birds are being killed in substantial numbers in EU gillnet fisheries, and for species like long-tailed duck, action to assess and tackle the threat is urgent, particularly to build resilience into populations to deal with threats that are more difficult to solve, like climate-mediated changes to prey availability.

4.8. RECOMMENDATIONS FOR FUTURE RESEARCH

The results and barriers noted in this project point to some research priorities to advance technical seabird bycatch mitigation in gillnets:

- Additional testing of LED lights, including refined designs and different light colours and specifications (potentially based on some of the below research projects)
- Further work in determining aversive stimuli for the most susceptible species of seabird (velvet scoter, long-tailed duck, razorbill, Guillemot, common eider, great cormorant) (i.e. work with captive birds to discern what 'scares' them effectively)
- Based on the output of this work, design audio and visual (including light) alerts and test behavioural responses to these in active fisheries
- Collaborate with oceanographers to understand the environmental characteristics of key sea basins at the time of highest bycatch (i.e. Baltic/Atlantic in the winter)

In addition, further research into seabird distribution and habitat use at sea - combined with research into fish behaviour, catch rates and efficiency - would assist in better design of temporal and spatial fisheries management to minimise economic impacts and bycatch at the same time. For example, conducting detailed telemetry studies of seabirds to determine timing and use of key habitats, linked to censuses that show broader-scale distribution, may help to refine our understanding of how to manage protected areas, based on the times and locations (e.g. foraging areas) when birds are most vulnerable. Further collaborations between NGOs and academia and fisheries experts such as ICES is needed in order to fill the many remaining data gaps.

Linked to the above point, better bird distribution data needs to be matched with improved data collection/reporting systems for the small-scale fleets, and accessibility of that data for this type of study (as noted under 5.7). The currently limited understanding of effort in these fleet sectors is severely impacts more instructive analysis and, in turn, effective and proportionate management measures.

It is expected that the ‘path of least resistance’ in terms of achieving uptake of bycatch mitigation is to minimise the changes required to the gear, vessels, or operating methods. However, as large numbers of threatened seabirds continue to be caught, particularly in the Baltic, the need to find solutions becomes ever-more pressing. While gear-switching represents a more fundamental change for fishers, further research in this area is also essential. In particular, the catch efficiency of cod pots seems to be improving (Hedgärde *et al.,* 2016; L. Kindt-Larsen, pers comm.) and could be a viable option for some fishers. Financial support for such changes - whether mitigation measures or wholesale gear changes - is clearly critical.

All of these research avenues require significant financial and institutional support in order to address one of the major issues of sustainability for gillnet fisheries. To date, the priority and finance afforded to seabird bycatch has not met the scale of the challenge - a step change is required if the problem is to be addressed without reliance on punitive measures. This project marks a first step forward the reduction of seabird bycatch in gillnets operating at European waters. However, some continuity must to be guaranteed in order to meet the urgent needs.

4.9. IMPLICATIONS FOR FISHERIES MANAGEMENT IN NATURA 2000 SITES

Effective management of fisheries is vital to ensure the implementation of the Habitat and Birds Directives (including Natura 2000 sites), as well as the Common Fisheries Policy and Marine Strategy Framework Directive.

The three sites where experimental trials took place (Puck and Pomeranian Bays in Poland; Berlengas in Portugal) are part of the Natura 2000 marine network- designated as Special Protection Areas (SPA) for the seabird populations therein[7]. Bycatch of protected species is known to occur within these areas due to the spatial/temporal overlap with gillnet fishing gear, with significant bycatch recorded during the technical study observer work in both Polish sites. Berlengas Archipelago SPA has defined conservation objectives, and the management plan is being developed through a current LIFE project (LIFE BERLENGAS). In Poland, the conservation objectives and management plan have not yet been finalised. For sites in both countries, appropriate assessments for fishing activities occurring within the sites have not been conducted. Therefore, the impact of fishing on the integrity of the sites for seabird species (and their populations) has not been adequately defined. This means that fisheries management measures have not been specifically agreed and implemented for these sites. The results of this study further corroborate that the development of a management plan and fisheries management measures is of high importance for these specific sites- and for marine Natura 2000 sites across the EU.

This study illustrates that there needs to be more systematic data collection of incidental catches of seabirds (within and beyond Natura 2000 sites) as well as detailed information of gillnet fishing effort, where this would benefit management of these Natura 2000 areas. In particular, small scale vessels require systematic monitoring, particularly when operating within Natura 2000 sites. A VMS/AIS system and potentially self-reporting log book system could assist in monitoring small scale gillnet fisheries, allowing for fine scale understanding of fishing effort.

In addition, monitoring programmes for marine Natura 2000 sites are needed to collect data on seabird species (presence/absence, fine scale distribution, abundance), with a priority on those species which are most susceptible to bycatch. This is particularly important in regions where climate change is affecting the distribution and timing of seabird movements (and prey), which could open up new interactions with gillnet fisheries.

Furthermore, although an effective mitigation measure still requires further research and development, given the urgent need to manage this issue (particularly in the context of high concentrations of susceptible seabirds in Natura 2000 sites) all the available management options require examination (e.g. temporal/spatial closures, gear switching to traps/pots etc.).

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[7] Puck Bay in Poland is also a Site of Community Importance- SCI

4.10. POLICY RECOMMENDATIONS BASED ON OUTCOMES OF THIS STUDY

The Birds and Habitats Directives afford strict protection to seabird species. Where interactions occur with human activities, these need to be managed. The Common Fisheries Policy includes the overarching objective to minimise and, where possible, eliminate fisheries impact to the wider environment (e.g. impact of incidental catches of seabirds). Therefore, developing technical solutions (i.e. mitigation measures) is a fundamental part in achieving this objective for gillnet fisheries.

This study has produced some useful outputs towards identifying effective solutions for gillnets, however it is overwhelmingly clear that further research investment is required to test potential solutions in areas of high bycatch risk over longer time periods. Across EU coastal member states national research programmes should be established to provide greater understanding of the use of gillnet gear modifications and other technical mitigation measures.

Furthermore, with the adoption of a revised data collection framework regulation (EU 2017/1004) and its implementing act (EU) 2016/1251, Member States are now obliged to collect data on the impact of fisheries to the wider environment, including the impact on seabirds. This study has highlighted the need for systematic, fine-scale data collection from small scale fleets, including both recording of bycatch and fishing effort. In many EU countries, the gillnet fleet includes a high proportion of small scale vessels, where remote monitoring (e.g. VMS, AIS) is not currently utilised. This means that the level of spatial/temporal overlap of gillnet fisheries with the distribution of vulnerable seabirds is not possible to accurately map, and furthermore, that gillnet bycatch estimates cannot be extrapolated out to fleet level scale without the possibility of either under or over-estimating bycatch.

4.11. POLICY RECOMMENDATIONS EXTERNAL TO OUTCOMES OF STUDY

In relation to the EMFF, the EU Member States should promote the use of this fund to investigate gillnet bycatch and mitigation measures- particularly in countries with high bycatch risk. In some countries, under their EMFF operational programmes, the eligibility rules applied by national authorities to access funding to test innovative solutions to mitigate the impact of the fishing sector on seabirds is overly restrictive on the type of organisation/institution which can apply even though the EMFF regulation itself is not. Therefore, some leaders in this field (e.g. NGOs) find it increasingly difficult to access funds to carry out the necessary work. In some cases, national authorities feel inclined to only allow for NGOs to apply for financing when it directly relates to a marine protected area. This, however, limits the testing of mitigation gears only within marine protected areas.

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ANNEX 1. LIST OF SEABIRD SPECIES IN EUROPE, THEIR GLOBAL RED LIST STATUS AND THEIR SUSCEPTIBILITY TO BEING CAUGHT IN GILLNETS (ADAPTED FROM ZYDELIS *ET AL*. 2013).

Species scientific name	Species common name	Global Red List status	Susceptible to Gillnets (y=yes, Possibly, Unknown)	References
Alca torda	razorbill	NT	**Y**	Strann *et al.*, 1991; Murray *et al.*, 1994; Stempniewicz, 1994; Fangel *et al.*, 2011; Bellebaum *et al.*, 2012
Alle alle	little auk	LC	**Y**	Stempniewicz, 1994; Benjamins *et al.*, 2008; Artukhin *et al.*, 2010; Merkel, 2011
Ardenna gravis	great shearwater	LC	**Y**	Piatt and Nettleship, 1987; Benjamins *et al.*, 2008
Ardenna grisea	sooty shearwater	NT	**Y**	Piatt and Nettleship, 1987; Taylor, 2000b; Majluf *et al.*, 2002; Benjamins *et al.*, 2008; Artukhin *et al.*, 2010; Mangel *et al.*, 2011;
Aythya marila	greater scaup	LC	**Y**	Stempniewicz, 1994; van Eerden *et al.*, 1999; Klinge and Grimm, 2003; Bellebaum *et al.,* 2012
Bucephala clangula	common goldeneye	LC	**Y**	Stempniewicz, 1994; Žydelis *et al.*,,2009; Bellebaum *et al.*,, 2012
Bucephala islandica	barrow's goldeneye	LC	**Y**	
Bulweria bulwerii	bulwer's petrel	LC	Possibly	
Calonectris borealis	cory's shearwater	LC	**Y**	Benjamins *et al.,* 2008; Oliveira, *et al.* 2015.
Calonectris diomedea	scopoli's shearwater	LC	**Y**	Based on cory's shearwater references and recent taxanomic split.
Catharacta skua	great skua	LC	Possibly	
Cepphus grylle	black guillemot	LC	**Y**	Piatt and Nettleship, 1987; Stempniewicz, 1994; Benjamins *et al.*,

				2008; Žydelis *et al.*, 2009; Fangel *et al.*, 2011; Merkel, 2011; Bellebaum *et al.*, 2012
Chlidonias niger	black tern	LC	Unknown	
Clangula hyemalis	long-tailed duck	VU	**Y**	Stempniewicz, 1994; Dagys and Žydelis, 2002, Žydelis *et al.*, 2009; Bellebaum *et al.*, 2012
Fratercula arctica	atlantic puffin	VU	**Y**	Piatt and Nettleship, 1987; Strann *et al.*, 1991; Rogan and Mackey, 2007; Benjamins *et al.*, 2008; Fangel *et al.*, 2011
Fulmarus glacialis	northern fulmar	LC	**Y**	Carretta *et al.*, 2004; Soczek, 2006; Benjamins *et al.*, 2008; Artukhin *et al.*, 2010; Fangel *et al.*, 2011
Fulmarus glacialis	northern fulmar	LC	**Y**	Coram *et al.* 2015
Gavia adamsii	yellow-billed loon	NT	**Y**	Stempniewicz, 1994; Artukhin *et al.*, 2010
Gavia arctica	arctic loon	LC	**Y**	Stempniewicz, 1994; Žydelis *et al.*, 2009; Artukhin *et al.*, 2010; Bellebaum *et al.*, 2012
Gavia immer	common loon	LC	**Y**	Piatt and Nettleship, 1987; DeGange *et al.*, 1993; Stempniewicz, 1994;Merkel, 2011
Gavia stellata	red-throated loon	LC	**Y**	Stempniewicz, 1994; Dagys and Žydelis, 2002; Manly 2009; Žydelis *et al.*, 2009; Artukhin *et al.*, 2010; Bellebaum *et al.*, 2012
Gelochelidon nilotica	common gull-billed tern	LC	Unknown	
Histrionicus histrionicus	harlequin duck	LC	**Y**	Manly, 2007 (in Zydelis *et al*., 2013)
Hydrobates castro	band-rumped storm-petrel	LC	Unknown	
Hydrobates leucorhous	leach's storm-petrel	LC	Unknown	
Hydrobates monteiroi	monteiro's storm-petrel	VU	Unknown	
Hydrobates pelagicus	european storm-petrel	LC	Unknown	

Hydrocoloeus minutus	little gull	LC	Unknown	
Hydroprogne caspia	caspian tern	LC	Unknown	
Larus argentatus	european herring gull	LC	Possibly	Piatt and Nettleship, 1987; Fangel *et al.*, 2011; Coram *et al.* 2015
Larus audouinii	audouin's gull	LC	Possibly	
Larus cachinnans	caspian gull	LC	Unknown	
Larus canus	mew gull	LC	Unknown	
Larus fuscus	lesser black-backed gull	LC	Possibly	
Larus genei	slender-billed gull	LC	Unknown	
Larus glaucoides	iceland gull	LC	Unknown	
Larus hyperboreus	glaucous gull	LC	Possibly	Artukhin *et al.*, 2010
Larus ichthyaetus	pallas's gull	LC	Unknown	
Larus marinus	great black-backed gull	LC	Possibly	Piatt and Nettleship, 1987
Larus melanocephalus	mediterranean gull	LC	Unknown	
Larus michahellis	yellow-legged gull	LC	Unknown	
Larus ridibundus	black-headed gull	LC	**Y**	Oliveira, *et al.* 2015
Larus thayeri	thayer's gull	LC	Unknown	
Melanitta fusca	velvet scoter	VU	**Y**	Piatt and Nettleship, 1987; Stempniewicz, 1994; Dagys and Žydelis 2002; Žydelis *et al.*, 2009; Bellebaum *et al.*, 2012
Melanitta nigra	black scoter	LC	**Y**	Stempniewicz, 1994; Dagys and Žydelis, 2002; Žydelis *et al.*, 2009; Bellebaum *et al.*, 2012
Melanitta nigra	common scoter	LC	**Y**	Oliveira,*et al.*., 2015.
Mergus merganser	common merganser	LC	**Y**	Stempniewicz, 1994; Žydelis *et al.*, 2009; Bellebaum *et al.*, 2012
Mergus serrator	red-breasted merganser	LC	**Y**	Stempniewicz, 1994; Žydelis *et al.*, 2009; Bellebaum *et al.*, 2012
Morus bassanus	northern gannet	LC	**Y**	Piatt and Nettleship, 1987; Benjamins *et al.*, 2008; Fangel *et al.*, 2011; Oliveira *et al.* 2015

Morus bassanus	northern gannet	LC	**Y**	Oliveira, *et al*., 2015.
Oceanites oceanicus	wilson's storm-petrel	LC	Possibly	
Oceanodroma leucorhoa	leach's storm-petrel	LC	Possibly	Piatt and Nettleship, 1987; Artukhin *et al*., 2010
Pagophila eburnea	ivory gull	NT	Unknown	
Pelagodroma marina	white-faced storm-petrel	LC	Unknown	
Pelecanus onocrotalus	great white pelican	LC	Possibly	
Phalacrocorax aristotelis	european shag	LC	**Y**	Louzao and Oro, 2004; Fangel *et al.*, 2011
Phalacrocorax carbo	great cormorant	LC	**Y**	Stempniewicz, 1994; Lanza and Griffin, 1997; van Eerden *et al.*, 1999; Žydelis *et al.*, 2009; Merkel, 2011; Bellebaum *et al.*, 2012
Phalaropus fulicarius	red phalarope	LC	Possibly	
Phalaropus lobatus	red-necked phalarope	LC	Possibly	
Podiceps auritus	horned grebe	VU	**Y**	Stempniewicz, 1994; van Eerden *et al.*, 1999; Bellebaum *et al.*, 2012
Podiceps cristatus	great crested grebe	LC	**Y**	Stempniewicz, 1994; van Eerden *et al.*, 1999; Žydelis *et al.*, 2009; Bellebaum *et al.*, 2012
Podiceps grisegena	red-necked grebe	LC	**Y**	van Eerden *et al.*, 1999; Žydelis *et al.*, 2009; Bellebaum *et al.*, 2012
Podiceps nigricollis	black-necked grebe	LC	**Y**	van Eerden *et al.*, 1999; Žydelis *et al.*, 2009
Polysticta stelleri	steller's eider	VU	**Y**	Dagys and Žydelis, 2002; Žydelis *et al.*, 2009
Pomarine Jaeger	stercorarius pomarinus	LC	Unknown	
Pterodroma deserta	desertas petrel	VU	Unknown	
Pterodroma madeira	zino's petrel	EN	**Y**	
Puffinus lherminieri	audubon's shearwater	LC	**Y**	

Puffinus mauretanicus	balearic shearwater	CR	**Y**	Oliveira, *et al.* 2015
Puffinus puffinus	manx shearwater	LC	**Y**	Rogan and Mackey, 2007
Puffinus yelkouan	yelkouan shearwater	VU	**Y**	ICES, 2008
Rhodostethia rosea	ross's gull	LC	Unknown	
Rissa tridactyla	black-legged kittiwake	LC	Possibly	Piatt and Nettleship, 1987; Artukhin *et al.*, 2010; Fangel *et al.*, 2011; Merkel, 2011
Somateria mollissima	common eider	NT	**Y**	Piatt and Nettleship, 1987; Stempniewicz, 1994; van Eerden *et al.*, 1999; Benjamins *et al.*, 2008; Merkel, 2004, 2011; Bellebaum *et al.*, 2012
Somateria spectabilis	king eider	LC	**Y**	Merkel, 2004, 2011
Stercorarius longicaudus	long-tailed jaeger	LC	Possibly	Artukhin *et al.*, 2010
Stercorarius parasiticus	arctic jaeger	LC	Unknown	
Stercorarius pomarinus	pomarine jaeger	LC	Possibly	Artukhin *et al.*, 2010
Sterna dougallii	roseate tern	LC	Unknown	
Sterna hirundo	common tern	LC	Unknown	
Sterna paradisaea	arctic tern	LC	Unknown	
Sternula albifrons	little tern	LC	Unknown	
Thalasseus bengalensis	lesser crested tern	LC	Unknown	
Thalasseus sandvicensis	sandwich tern	LC	Unknown	
Uria aalge	common guillemot	LC	**Y**	Piatt and Nettleship, 1987; Falk and Durinck, 1991; Strann *et al.*, 1991; Stempniewicz, 1994; Melvin *et al.*, 1999; Benjamins *et al.*, 2008; Manly, 2007, 2009; Artukhin *et al.*, 2010; Fangel *et al.*, 2011; Merkel, 2011; Bellebaum *et al.*, 2012

Uria lomvia	thick-billed guillemot	LC	**Y**	Piatt and Nettleship, 1987; Strann *et al.*, 1991; Manly, 2007; Benjamins *et al.*, 2008; Artukhin *et al.*, 2010; Fangel *et al.*, 2011;
Xema sabini	sabine's gull	LC	Unknown	

ANNEX 2. SEABIRD BYCATCH IN GILLNETS- ESTIMATES IN EU MEMBER STATES

Summary of the current estimates of seabird bycatch available in each country based on peer reviewed literature and other sources.

Country	**Annual bycatch estimate in literature**	**Species recorded as bycatch**	**References & notes**
Belgium	No information available	Unknown	
Denmark	No complete estimate available. Estimates for island of Aero- 840 birds	red-throated diver; black-throated diver; red-necked; great-crested grebe; slavonian grebe; great cormorant; tufted duck; greater scaup; common eider; long-tailed duck; common scoter	Žydelis *et al., (*2009)
Estonia	Gulf of Finland- Estonian coast region ~5000 Gulf of Finland- 2154	long-tailed duck; great cormorant; steller's eider; common merganser; black guillemot	M. Vetemaa unpublished data in Žydelis *et al., (*2009) Dagys *et al., (*2009)
France	No complete estimate-	razorbill; northern gannet; shearwater spp.	Bugot & Boue (2012)
Finland	No separate estimate available- see Estonia/Gulf of Finland		M. Vetemaa unpublished data in Žydelis *et al., (*2009)
Germany	3000; 15800 2800 (greater scaup)	long-tailed duck; common scoter; red-throated diver; common eider; greater scaup; red-breasted merganser	Žydelis *et al., (*2009);
Ireland	No current estimate available		
Latvia	2500-6500		

Lithuania	2500-5000	long-tailed duck; velvet scoter; red-throated diver; black-throated diver; (steller's eider)	Dagys and Žydelis (2002), Žydelis (2002), Žydelis *et al., (*2009)
Netherlands	50,000 12,000	greater scaup; red-breasted merganser; great-crested grebe;	van Eerden *et al.,* (1999) Witteveen and Bos (2003)
Poland	21,000* possibly an over-estimate due to lack of fishing effort information		17,500 birds in Gulf of Gdansk (Stempniewicz 1994); 3750 birds Puck Bay; Kies´ and Tomek (1990). New studies pending: I. Psuty *et al.,,* in prep
Portugal	No annual estimate available, further quantification of fishing effort needed.	common scoter; balearic shearwater; northern gannet; great cormorant; lesser black-backed gull; common guillemot; cory's shearwater; sandwich Tern; razorbill; yellow-legged gull; european Shag; black-backed gull; black-headed gull; razorbill	Oliveira *et al., (*2015)
Spain	3000 European shags / Cormorants; 2000 auks	european Shag great cormorant Alcids (razorbill, Guillemot)	Galicia region- F.Arcos in Žydelis *et al., (*2013)
Sweden	18,000	red-throated loon; Black-throated Loon; Great cormorant; Common eider; Long-tailed duck; common goldeneye; Red	Lunneryd *et al.,* (2004)

		breasted Merganser; common merganser; razorbill; common guillemot;	
United Kingdom	No current estimate available for all of UK,	common guillemot, razorbill, northern Fulmar, northern gannet, great cormorant, herring gull.	Filey Bay (RSPB 2012); Sussex and Cornwall Coast (Coram *et al.,* 2015)

ANNEX 3. SUMMARY OF GILLNET FISHING VESSELS BY EU COUNTRY

Summary of number of gillnet vessels (large scale and small scale) registered to fishing ports in each EU country (EU Fishing Fleet Register on the Net, accessed March 2016).

Country	No. medium-large vessels >12m using set gillnets	No. small ≤12m using set gillnets	Total no. vessels using set gillnets
Belgium	**8**	**1**	**9**
Denmark	**371**	**2796**	**3167**
Estonia	**11**	**1461**	**1472**
France	157	1000	1157
Finland	22	2499	2521
Germany	48	1632	1680
Ireland	**73**	**619**	**692**
Latvia	8	614	622
Lithuania	8	125	133
Netherlands	**48**	**192**	**240**
Poland	**84**	**653**	**737**
Portugal	**337**	**2441**	**2778**
Spain	**656**	**6086**	**6807**
Sweden	**51**	**838**	**889**
United Kingdom	**55**	**1618**	**1673**
Total vessels registered	**1937**	**22575**	**24577**

ANNEX 4. GILLNET FISHING AND BYCATCH SUMMARY BY EU COUNTRY

1. Belgium

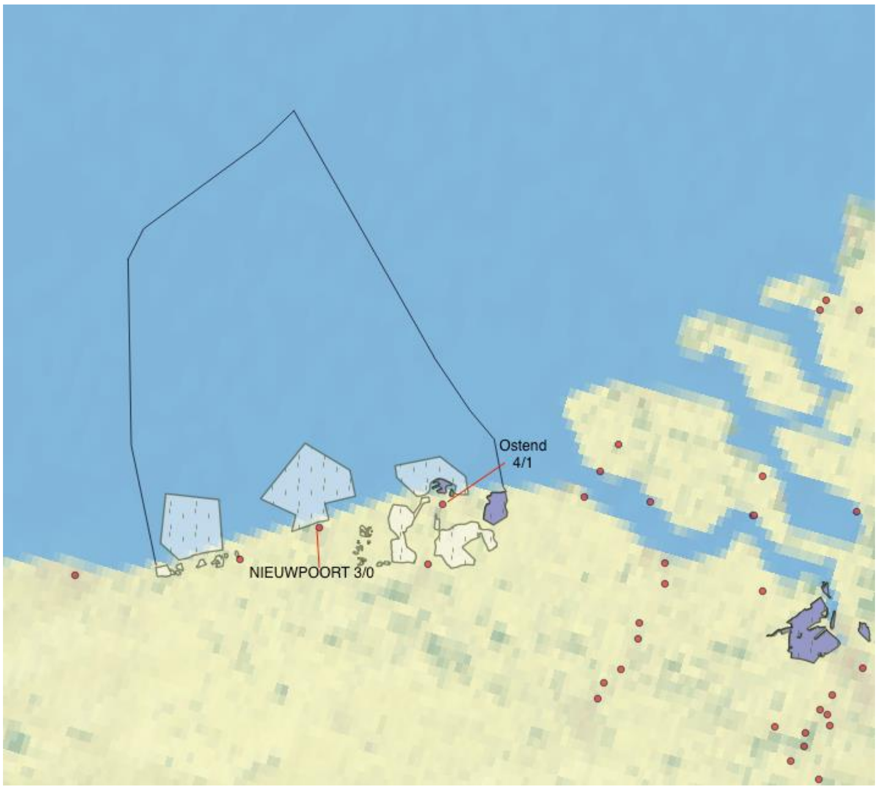

Figure A41: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

There are no published reports on gillnet bycatch for the Belgian fleet. The EU fishing vessel register lists only 9 vessels using this fishing gear (Annex 3). Belgium has 3 marine IBAs identified along its coast (although offshore areas have not yet been identified) and only one site has been identified for a species that is susceptible to gillnet bycatch (great-crested grebe) (see map). More information is needed on both offshore seabird distribution and on the fishing effort of the fleet. However, it is likely that there is a lower risk from the relatively few vessels using this gear.

2. Denmark

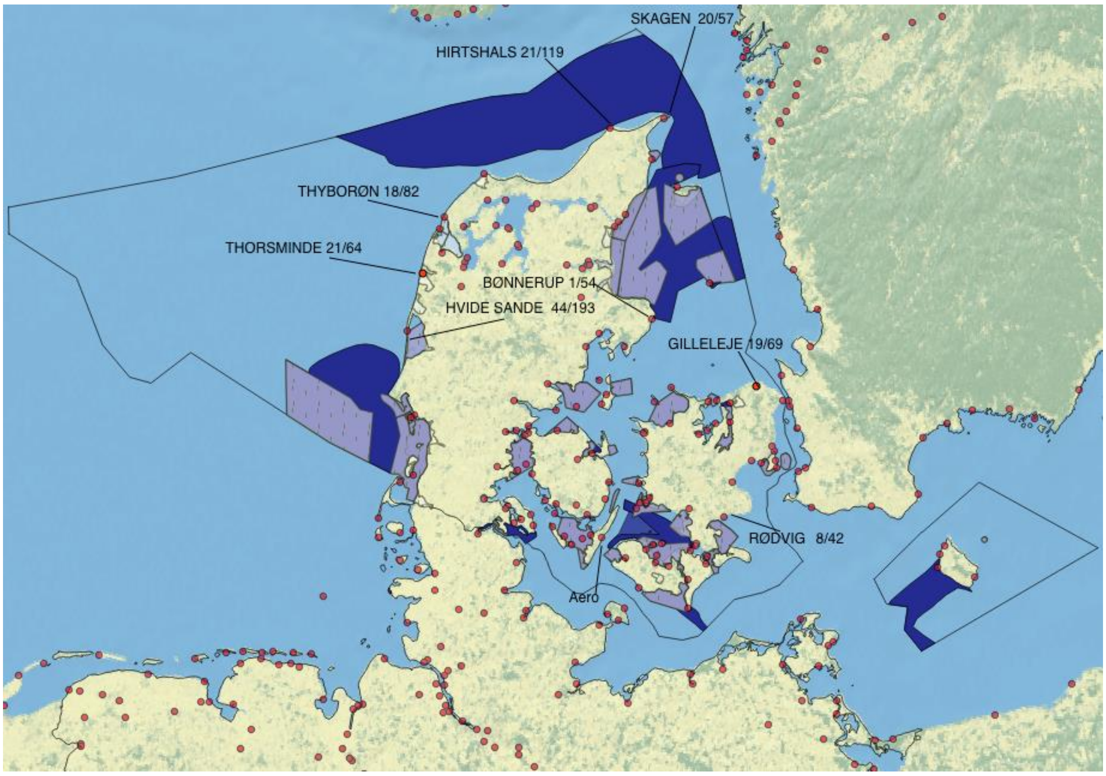

Figure A42: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

There are 371 large scale vessels registered in the EU fleet register, and 2796 small scale vessels which use set gillnets as either primary or secondary gear (see Annex 3) across the North Sea and Baltic Sea coasts. The concentration of fishing ports with vessels using set gillnets is quite high in the Kattegat Sea as there are many small fishing ports with small numbers of small scale vessels. Within the North Sea and the Skagerrak Sea there are fewer ports, but the numbers of vessels in each is much higher (e.g. Hirtshalls 100 small scale vessels- see map). The large-scale vessels operate out of 82 ports whilst the small-scale vessels operate out of 322 ports across Denmark. It is probable that the small-scale fleet, particularly the very small vessels, remain closer to the coast when fishing.

There are 41 marine Important Bird Areas (IBAs) identified in Danish waters, and they all hold significant populations of susceptible species to gillnet bycatch (see map), including Divers, common eider *Somateria mollissima*, great cormorant, common goldeneye. The non-breeding wintering period is likely to a high risk to a large number of species and birds, although the presence of breeding colonies for black guillemot (Site, Hirsholmene in the Kattegat) and of great cormorant means that there is a possible year-round risk of bycatch in this fishing gear. There are 56 coastal and marine SPAs in Denmark, which overlap a number of marine IBAs, particularly in the Kattegat (see map). The proximity of high densities of small vessels to marine IBAs and SPAs may therefore be an indication of areas of high risk for gillnet bycatch. However, no information was available for mapping the Danish gillnet fishing effort and there is currently no published bycatch rate estimates for the Danish set-gillnet commercial fleet. A study by Degel *et al.* (2010) around the island of Ærø estimated that 841 birds caught in in 2001–2003, mostly common eiders. Further information is needed in order to spatially overlap gillnet fishing effort and at sea distribution of seabirds to identify key risk areas, as well as seabird bycatch observations from gillnet vessels.

No published information was found on gillnet bycatch estimates within the Danish North Sea area, although Durinck *et al.,* (1993 in Žydelis *et al.,* 2009) reported that 340 common scoters and velvet scoters drowned in the Danish part of the North Sea in one night in March 1987.

Understanding the potential for gillnet bycatch of susceptible species in this area of Danish waters is an important gap which requires filling. The breakdown of the vessels by port was not separated between North Sea and Baltic Sea, due to the inability of knowing where vessels were fishing regardless of home port, however some of the ports with the highest densities of small scale vessels are in the North Sea (see map).

3. Estonia

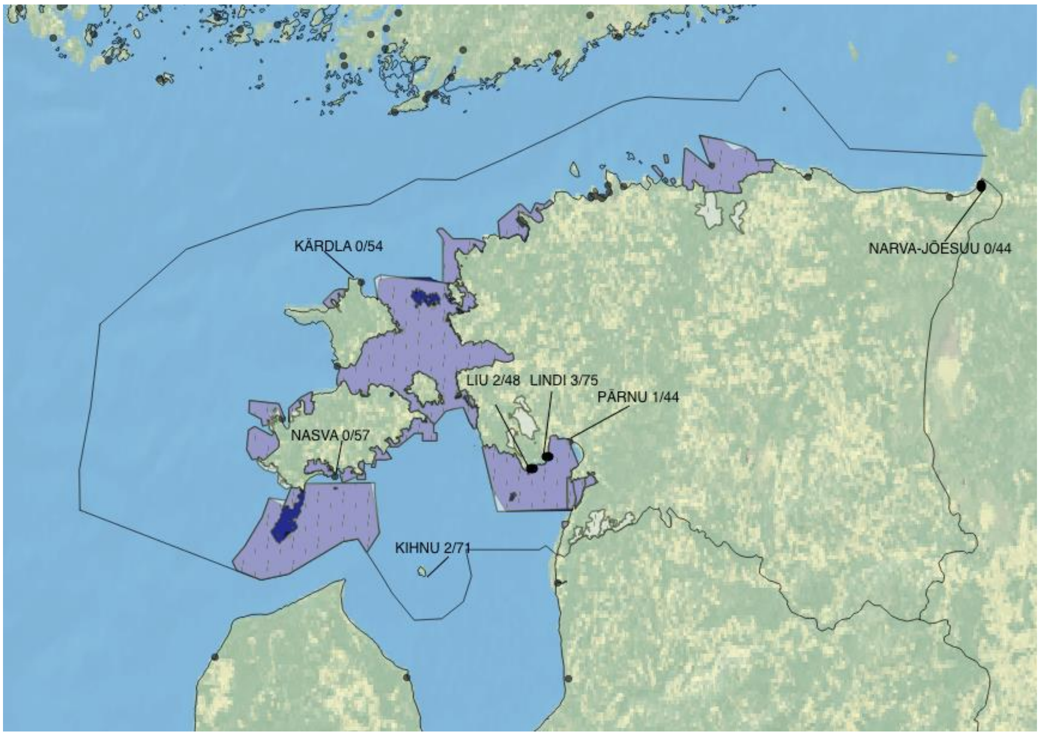

Figure A43: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

There are 11 large scale vessels and 1461 small scale registered as using set gillnets in Estonia (primary and secondary gear). The small-scale vessels are based out of 142 fishing ports and harbours in relatively low densities. The ports in Kihnu, an island in the Gulf of Riga and Lindi on the south western coast have the highest number of small scale gillnet vessels. The fleet targets species such as Pike Perch, Perch *Perca fluviatilis*, Pike *Esox lucius*, Flounder *Platichthys flesus*, Herring *Clupea harengus* and Garfish, *Belone belone* as well as Sea Trout *Salmo trutta*, Salmon *Salmo salar* and Whitefish *Coregonus maraena* (Dagys *et al.,* 2009). In the Gulf of Finland, the most widespread gill net mesh size in commercial fisheries is 50– 60 mm for targeting Sea Trout, Salmon and Whitefish (Dagys *et al.,* 2009). In other areas, the mesh size is smaller (36–50 mm) but up to 50–60 mm in vessels targeting Flounder (Dagys *et al.,* 2009). Fishing effort is limited by weather and ice during colder months, with most fishing activity taking place from spring-autumn (Dagys *et al.,* 2009). Fishing effort is required to be recorded by fishers and submitted to the Fisheries Monitoring Centre which stores aggregated information in electronic form at relatively fine spatial scales. The information on the fleet's fishing effort was not available for this review.

A study by Dagys *et al.,* (2009) found that the area and season of highest bycatch was the Gulf of Finland during autumn, with mesh sizes of 50-60mm. The most regularly caught species was the long-tailed duck, although catches were also recorded for another 12-species including Steller's and common eider, Loons, Grebes, Mergansers, black guillemot and razorbill.

Estonia has 21 marine IBAs and 20 of these sites were identified for species which are susceptible to gillnet bycatch (see map). Dagys *et al.,* 2009 found that although gillnet fishing occurred in the area of Väinameri (large marine IBA between the islands of Sareema and Hiiuma) there was not a great temporal overlap with susceptible bird species with fishing activity taking place during summer.

Further information is needed on the temporal and spatial overlap of the gillnet fleet and susceptible seabirds and ongoing observer work is needed to confirm fishers' bycatch recording.

4. Finland

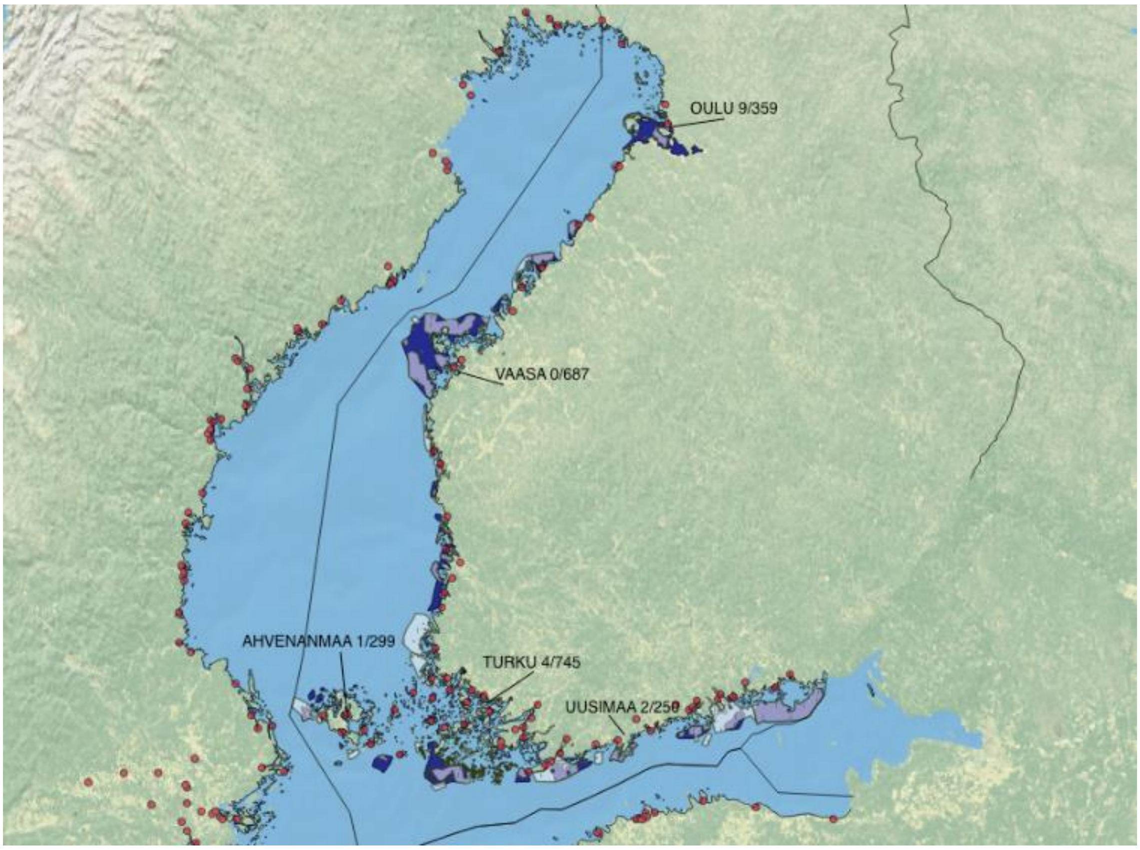

Figure A44: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

There is an extensive set gillnet fishing fleet in Finland with 22 large scale vessels registered and 2499 small scale vessels operating out of seven fishing ports (see Annex 3). It is not known how many of the small vessels are used for full time fishing, and further information is needed to determine if vessels are fishing in inland waters rather than in the coastal region, as historically inland waters have been intensively fished using static gears (Hario in Scott, 1998). The gillnet fleet target species such as European Whitefish *Coregonus lavaretus* and Pike Perch *Sander lucioperca* with mesh sizes between 43-45mm (Heikinheimo *et al.,* 2006).

The majority of small scale vessels are registered along the Bothnian Sea coast out of fishing ports in Ahvenanmaa (Aland Islands), Oulu, and Vaasa, with large numbers also operating from Turku in the Gulf of Finland. There have been no published bycatch estimates for Finland (Korpinen & Braeger 2013) although there are unpublished estimates for the Gulf of Finland (Estonian coast) which indicate that this region is problematic for bycatch (Žydelis *et al.,* 2009). Furthermore, a review of bycatch by Hario (in Scott, 1998) suggested bycatch of black guillemot and razorbill was regularly occurring based on birds ringed in Finland. It was also noted, however, that bycatch of birds had not been considered as a serious conservation threat.

There are 32 marine IBAs in Finland including breeding colonies and wintering congregations (see map). 27 sites have been identified for species which are susceptible to gillnet bycatch, including razorbill, black guillemot, common merganser, Red-breasted Merganser, long-tailed duck, common goldeneye, steller's eider and common eider. There are 98 coastal and marine SPAs designated, which, whilst often smaller than the IBAs, are located in many of the same locations, particularly in the Gulf of Finland and around the islands in the south-west of the country. A number of marine IBAs and SPAs overlap with the fishing ports with high densities of small scale gillnet fishing vessels (see map). Information on the spatial overlap of susceptible species and gillnet fishing activity is urgently needed, as is detailed collection of on-board observation of fishing activity to monitor bycatch.

5. France

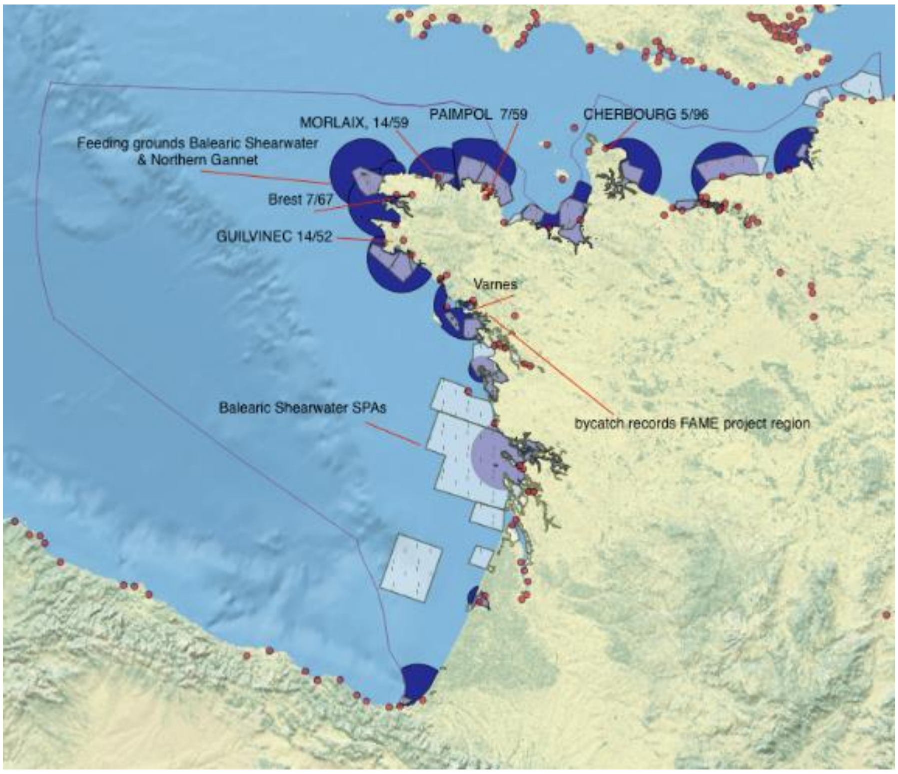

Figure A45: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

The French set gillnet fleet numbers 157 large scale vessels and 1000 small scale vessels from 31 fishing ports (excluding the Mediterranean fleet) (Annex 3). The ports with the most numerous small scale fishing boats include those in the North Sea; such as Cherbourg and Boulogne, and in Brittany; Brest, Paimpol and Guilvinec.

There has not been any systematic analysis of gillnet bycatch along the French coast, however the League for the Protection of Birds (LPO, BirdLife Partner in France) carried out fisher surveys within the central Atlantic region (Charente-Maritime, Gironde and Vendée) which included those using gillnets as primary fishing gears (Bugot & Boue, 2012). These fishers identified at a coarse scale the areas where the they operate the most regularly. Although the total reporting of bycatch for gillnets was low for gillnets, species caught included Shearwater species (possibly Balearic Shearwater), common guillemot and razorbill (Bugot & Boue, 2012). It is possible that the Balearic Shearwater could be regularly caught in this fishery, in much the same manner as has been demonstrated in Portugal (Oliveira *et al.,* 2015).

6. Germany

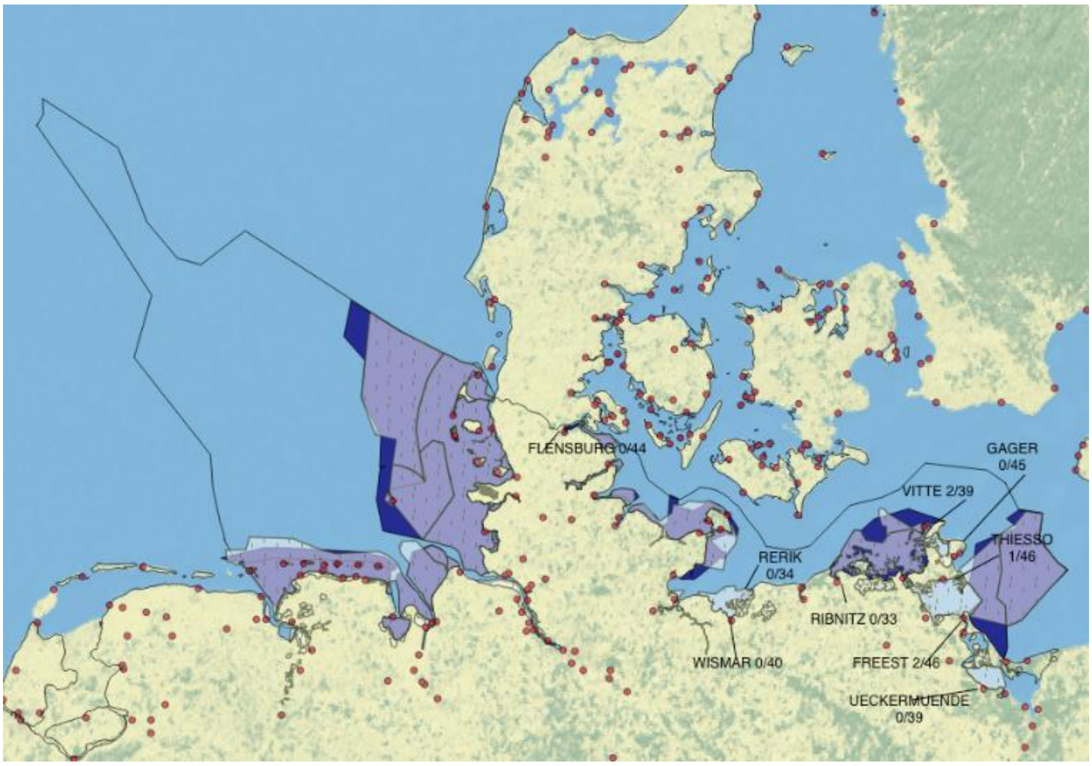

Figure A46: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

The German set gillnet fleet is relatively large, extending over both the North Sea coastline and Baltic Sea marine area. 48 large scale vessels are registered using set gillnets and 1632 small vessels use this gear (Annex 3) operating out of 139 fishing ports and harbours. Within the Baltic Sea the fishery mainly targets Atlantic cod *Gadus morhua*, Atlantic herring *Clupea harengus*, Pike perch *Sander lucioperca*, flatfish, and salmonids (Sonntag *et al.,* 2012).

Seabird bycatch in gillnets is a known issue in Germany, particularly within the Baltic Sea area with a number of studies carried out in the last thirty years (summarised in Žydelis *et al.,* 2009 and Sonntag *et al.,* 2012). Kirchhoff (1982) estimated a bycatch rate of 5.2 birds/study site/day between 1977-85 along the Schleswig–Holstein coast, suggesting 15,800 bird mortalities annually. common eider and common scoter were the most commonly caught. Grimm (1985) investigated bycatch in Wismar Bay from 1983-1985, finding greater scaup and common eider to be the most regularly caught bird species, estimating 2800 greater scaup caught annually. Schirmeister (2003) investigated bycatch around Usedom Island, and between 1989–2005 estimated a bycatch rate of 38.4 (8–186) birds/ fisherman/winter, or 3000 birds caught annually. Bycatch consisted mostly of long-tailed duck, common scoter, and red-throated loon (*Gavia stellate*). Mentjes and Gabriel (1999) collected bycatch data from around Fehmarn during 1996-1998 and calculated a bycatch rate of 1.2 birds/1000 Net Metres/Day, predominantly common eider. Beached bird surveys in the western Pomeranian coast by Bellebaum and Schulz (2006) also indicated bycatch of Great cormorant, Long-tailed duck, greater scaup and common merganser. Bellebaum *et al.,* (2013) analysed bycatch in the Usedom coast with on board observations and questionnaires between 2006 and 2009 and estimated that annual bycatch of all 440 commercial fishermen using set nets in the study area was 17 551 birds. Their analysis included a long-term examination of bycatch rates, which they assessed to have decreased over time- potentially due to the reduction in numbers of long-tailed duck (the most commonly caught species) within the region (Bellebaum *et al.,* 2013).

The range of metrics used for bycatch rates in these studies from Germany alone emphasise one of the difficulties in determining overall bycatch levels - the lack of consistent and comparable datasets across projects. Irrespective, these studies have helped to characterise gillnet bycatch in Germany, identifying key species impacted and important locations.

Germany has a total of 16 marine IBAs, of which 10 are found in the Baltic Sea. These sites are all overlapped by the Natura 2000 network (SPAs). All sites include species which are susceptible to gillnet bycatch (see map). Sonntag *et al.,* (2012) mapped the potential conflict between seabirds and set-gillnets, finding that the risk of overlap between gillnets and seabirds was highest in winter and spring. The most at-risk areas were around the Pomeranian Bight including Adlergrund, during spring in the Greifswald Lagoon (where spring herring spawn) and along the coast of Usedom (where Schirmeister's 2003 study & Bellebaum *et al.,* 2013 indicated high bycatch). It was also predicted that there was a year-round risk to seabirds in the Pomeranian Bight, particularly around the Odra Bank due to the presence of moulting sea ducks and grebes during summer months (Sonntag *et al.,* 2012).

No published information was found on gillnet bycatch estimates within the German North Sea area. Although bycatch is assumed to be much higher in the Baltic Sea, this is an important gap which requires filling. The breakdown of the vessels by port was not separated between North Sea and Baltic Sea, due to a lack of knowledge of where vessels fish (regardless of home port).

7. Ireland

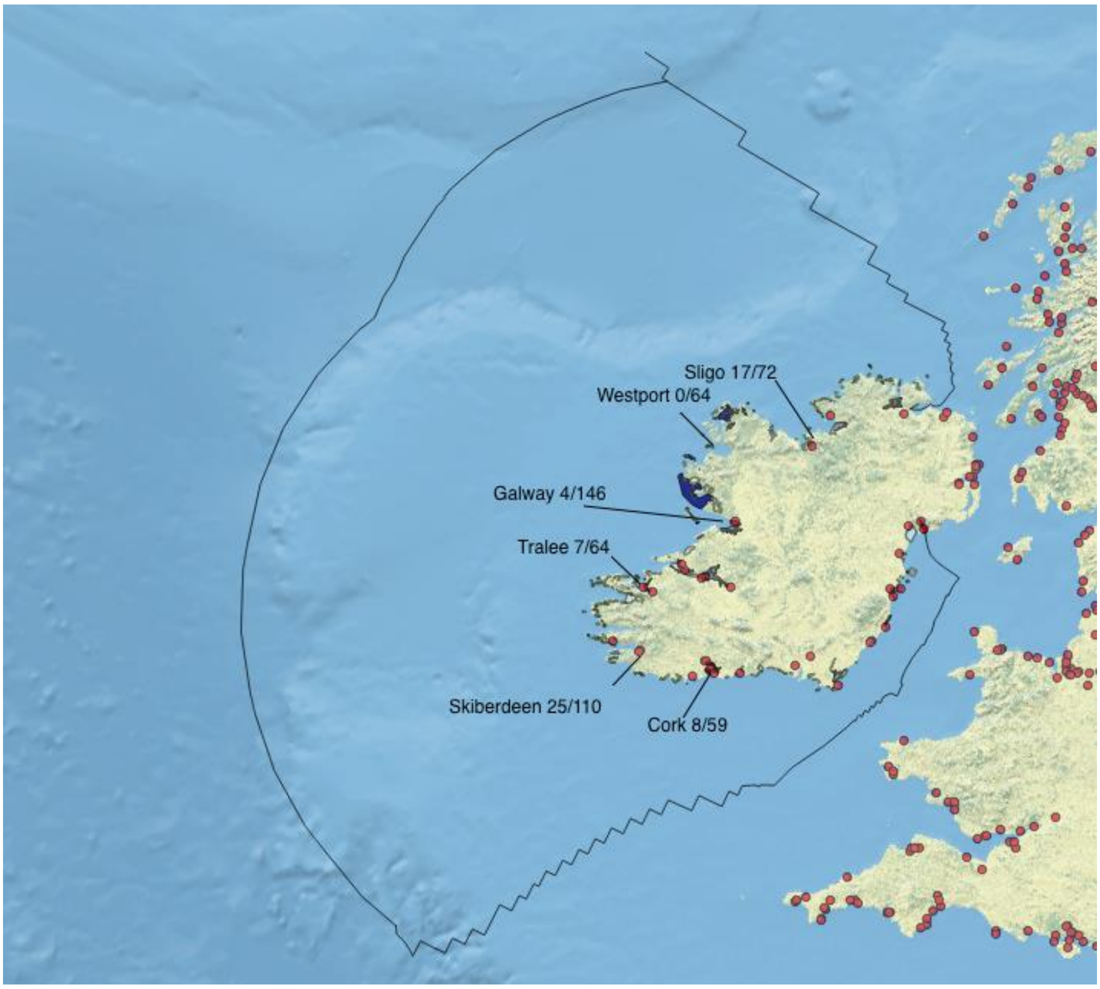

Figure A47: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

The Irish gillnet fleet has 73 large scale gillnet vessels and 619 small scale vessels operating out of 12 fishing ports and harbours (Annex 3). Cork, Galway and Skibbereen, Sligo and Tralee have the highest number of small scale vessels registered. There are no published estimates for set gillnet bycatch, although Ireland has important populations of susceptible seabird species. Although the marine IBA network is mostly terrestrial/coastal, the areas around seabird colonies are likely to be at risk (see map). It is important that further work is carried out to assess the possible risks to seabirds from the gillnet fishing fleet, including temporal and spatial mapping of fishing effort.

8. Latvia

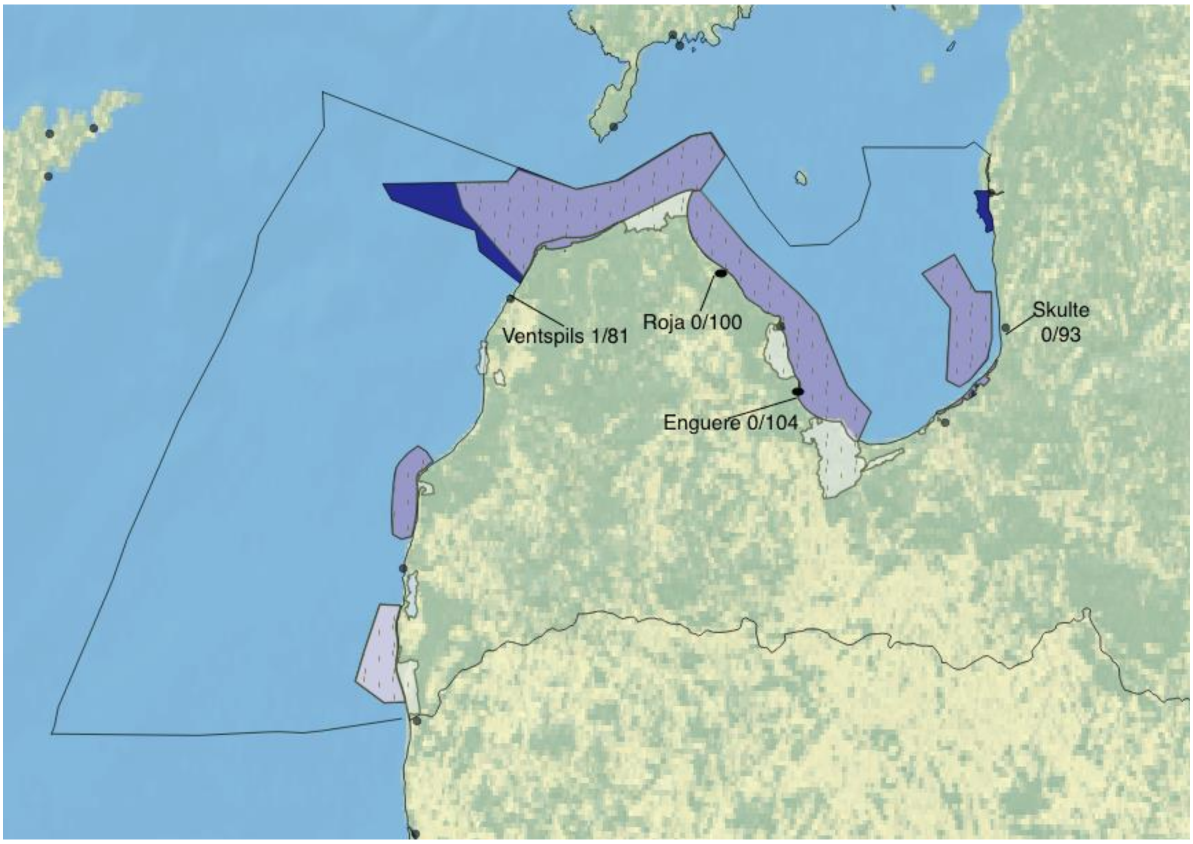

Figure A48: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

Only a few studies have examined the Latvian gillnet fleet and its risk to seabirds, and there is a lack of up to date, dedicated research. A study by Urtans and Priednieks (2000) used fishermen as observers and recorded 576 bycaught seabirds between 1995 and1999, which Žydelis *et al.,* 2013 estimated to be 2,500-6,500 birds per year for the fleet. More recent work, between 2000 and 2007 (Dagys *et al.,* 2009), estimated a bycatch rate of 0.37–0.66 birds per 1000 Net Metre Days. In both studies, long-tailed duck was the most frequently caught species, alongside red-throated loon and Black-throated Loon (*Gavia arctica*), with auks caught during their autumn migration.

The current set gillnet fleet consists of 8 large scale and 614 small scale vessels (Annex 3). These vessels are registered to ten fishing ports along the coast, with the highest numbers of small scale vessels in Engure, Liepaja, Roja and Skulte. According to Urtans and Priednieks (2000) the Gulf of Riga is where fishing effort and bycatch are highest, particularly for long-tailed duck and Loon species. The Gulf of Riga fishery primarily targets Herring, although there are also fisheries for Cod and Plaice/Flounder (Dagys *et al.,* 2009). The offshore fishery targets sprat, and is responsible for the majority of captures of auk species. Fishing activity is recorded as being highest in the shallow inshore area (~10m depth) and bycatch is highest during spring (March-May) and autumn/winter (October/November) (Urtans & Priednieks, 2000). Latvia has 9 marine IBAs (see map) identified for seabirds, and each include susceptible species to gillnet bycatch. The Natura 2000 network (16 coastal and marine SPAs) overlaps very closely with these areas.

9. Lithuania

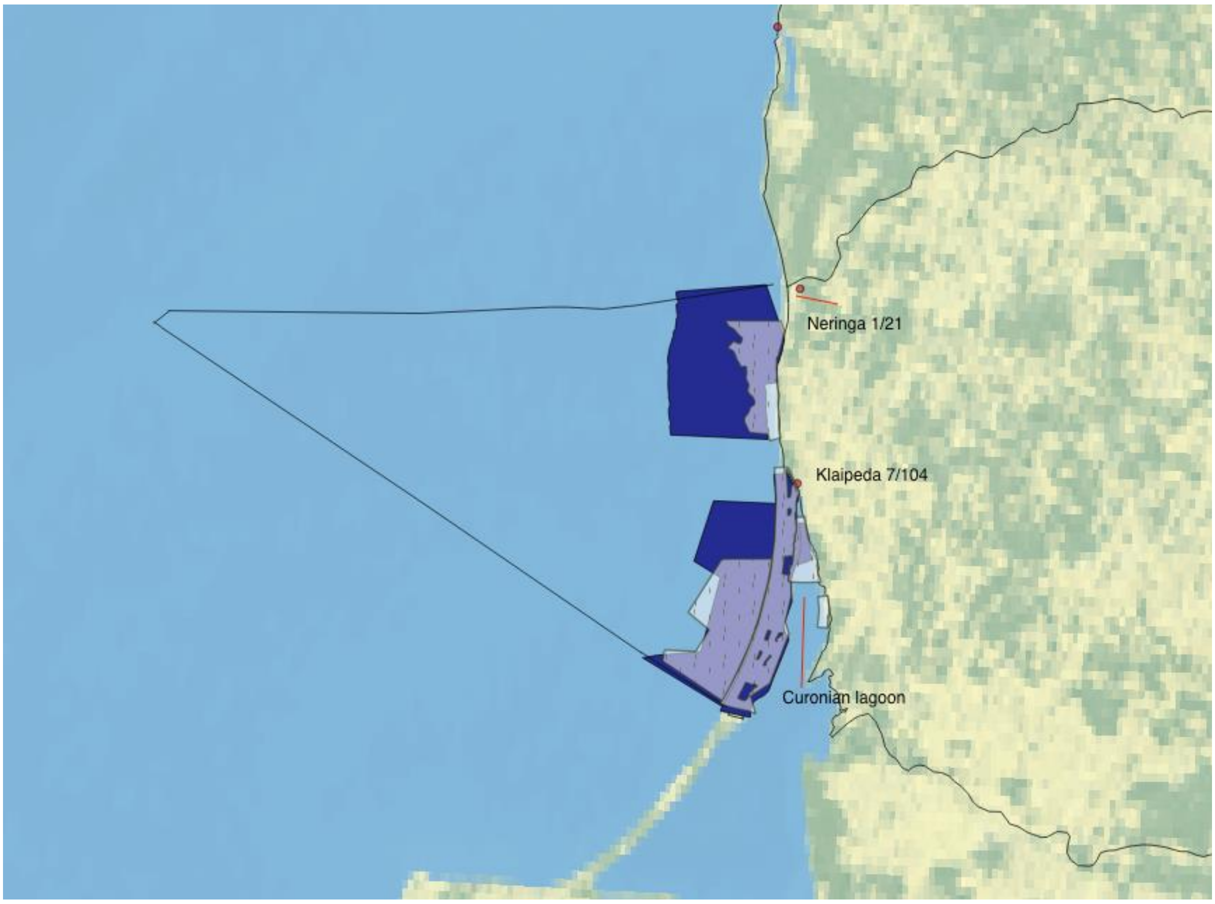

Figure A49: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

Gillnet bycatch is comparatively well-understood in Lithuania compared to other countries in the Baltic Sea, with several targeted studies on the subject (Dagys & Žydelis 2002; Dagys *et al.,* 2009, Žydelis *et al.,* 2009, BirdLife International, unpublished). Seabird bycatch in gillnets is known to regularly occur during autumn, winter and spring, when there are large numbers of wintering or migrating seaducks present (Dagys & Žydelis 2002; Dagys *et al.,* 2009, Žydelis *et al.,* 2009, BirdLife International, unpublished).

There are 8 large vessels registered using set gillnets, and 125 small scale using this gear as primary or secondary gear (Annex 3). Within the small scale sector, there are both vessels of ~10-12m and very small inshore vessels (~3-6m). The inshore gillnet fishery is divided into fishing blocks, which are defined zones where individual license holders can fish. Intensive fishing activity from the small-scale fleet (including the large 10-12m vessels) occurs along the Curonian Spit and around Palanga. There is also intensive gillnet fishing from the very small scale inside the Curonian Lagoon, a brackish semi-enclosed water body (BirdLife International, unpublished). The fishing areas overlap to a large extent with five large marine IBAs identified for susceptible species (see map).

The gillnet fleet fishing within Lithuanian waters targets Cod, Pike Perch (*Sander lucioperca*), Plaice/Flounder and Smelt throughout the year. Mesh sizes change according to target catch. The current understanding is that mesh sizes of 50-60mm (for Cod and Pike Perch Sander lucioperca) are responsible for the highest numbers of birds caught (Dagys and Žydelis, 2002; BirdLife International unpublished) as this fishery also coincides with overwintering seaduck species such as long-tailed duck and velvet scoter. The large mesh size used for flounder is likely to pose less of a risk as it used during the summer months when most vulnerable seabirds are not present in Lithuanian waters. The small mesh size used for smelt is also known to catch birds, however from Dagys and Žydelis (2002) this is believed to produce a much lower bycatch rate and therefore be less of a risk to birds- potentially as the total net length deployed is shorter (Bellebaum *et al.,* 2012). Further research is likely to be needed to determine if this is actually the case.

In Dagys and Žydelis (2002) research, the species most commonly caught were long-tailed duck (61% of recorded bycatch), with common scoter, velvet scoter, red and black-throated loons, and steller's eider also recorded. The combined bycatch rate for all birds was estimated to be 0.61/1000 Net Metres/Day. In Žydelis *et al.,* (2009), the bycatch rate was further increased to 0.97 birds/1000 Net Metres/Day, based on additional information suggesting that 2500-5000 birds were being caught annually. Current work by BirdLife International and the Lithuanian Ornithological Society has found that velvet scoters make up the majority of bycatch records in the bottom-set cod fishery, although long-tailed ducks were also caught in high numbers. Other species caught have included common guillemot, great cormorant, common scoter, great-crested grebe (*Podiceps cristatus*), and red-throated loon. As these are preliminary findings, further work and detailed analysis is needed to determine bycatch rates, estimated levels across the fleet, identify the fine scale differences in seabird distribution (including depth profiles where bycatch occurs) and to further understand the spatial distribution of fishing effort within the fishing blocks.

10. Netherlands

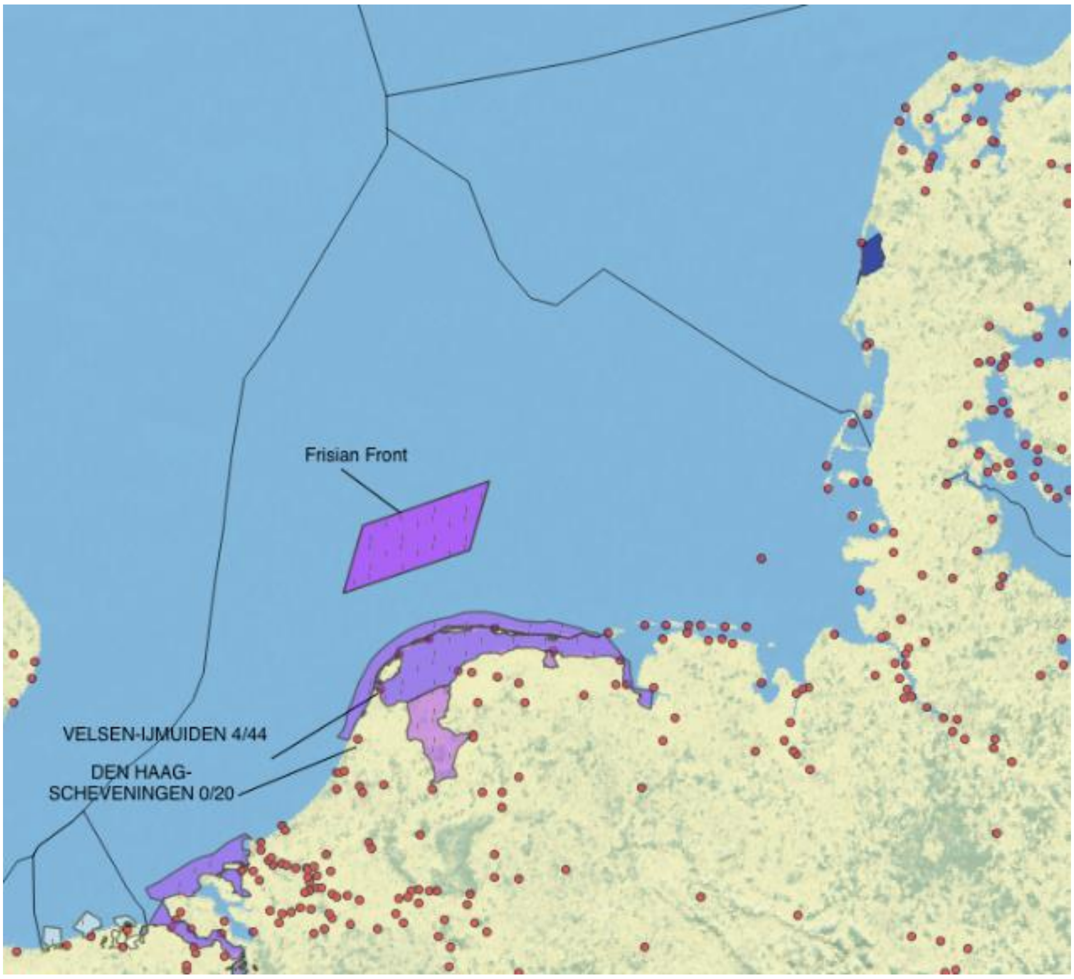

Figure A410: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

The Dutch gillnet fleet includes 48 large scale vessels and 192 small scale vessels from 30 ports and harbours (Annex 3). The port of Velsen-ijmuiden has the highest number of small scale vessels. There has been very little research on gillnet bycatch in the Netherlands, although Dutch waters hold significant numbers of susceptible species. Van Eerden *et al.,* (1999 in Žydelis *et al.,* 2009) worked with fishermen in the inshore lakes of IJsselmeer and Markermeer to collect bycatch data and estimated a rate of 0.64 birds per 1000 Net Metre Days. This led to an estimate of up to 50,000 birds caught annually. The most frequently caught species from that study were the Tufted Duck (*Aythya fuligula*), greater scaup, red-breasted merganser and the great-crested grebe. In the same area, Witteveen and Bos (2003 in Žydelis *et al.,* 2009) estimated the same bycatch rate, but based on a reduction in fishing effort this produced an annual estimate of 12,000 birds.

There are 19 marine IBAs which have been identified for susceptible species (see map) including common merganser, Black Scoter, common eider, greater scaup and great cormorant. Further research is needed to understand both the fishery, the spatial and temporal fishing effort and the likelihood of bycatch.

11. Poland

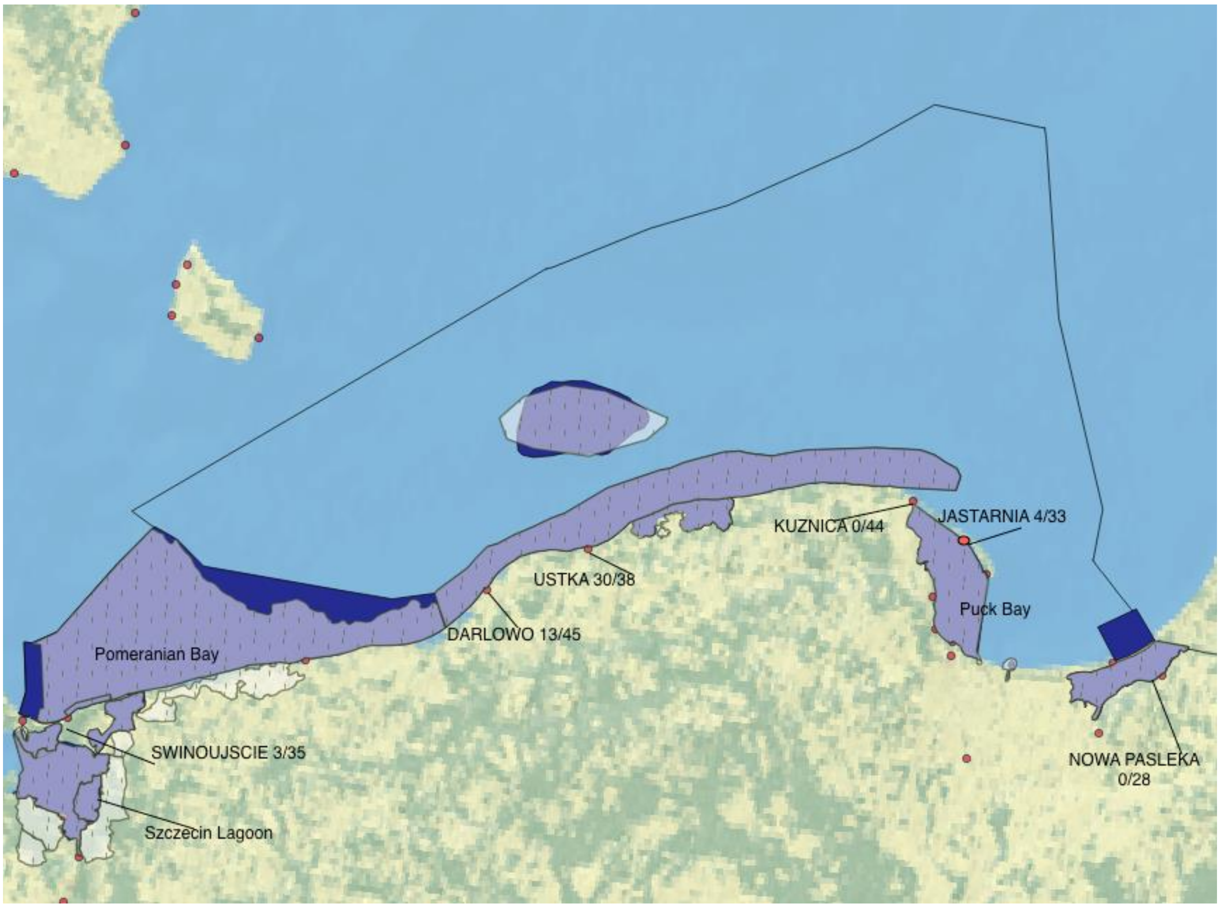

Figure A411: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

There are 84 large scale vessels and 653 small scale vessels registered as using set gillnets in 64 ports and harbours (see Annex 3). Fishing effort for set gillnets has been recorded as consistently high along the coast. Particularly important gillnet fishery areas are in the Puck Bay and Gulf of Gdańsk, in the proximity of river mouths and fishery bases along Polish coasts and in the transitional waters of coastal lagoons - Szczecin and Kamieński Lagoon and Vistula Lagoon.

The measurement of effort (across ~400km2) remains at a coarse scale, and its reliability is of concern, with some known areas of fishing activity not appearing on the fishing effort map (Linkowski pers. comm.). The areas of high fishing activity coincide with areas identified as marine IBAs. Poland has ten marine IBAs, covering most of the coastline, river mouths and coastal lagoons and hold significant populations of susceptible species to gillnet bycatch (see map). These sites are designated Natura 2000 sites.

A number of studies have been published which examine the scale of seabird bycatch in Poland, although there remains disagreement among experts on the estimates and the calculation of fishing effort used. Stempniewicz (1994) acquired data on bycatch from fishers from one fishery based in the Gulf of Gdansk between 1972–1976 and 1986– 1990 and estimated a bycatch rate of 8–81 birds/boat/winter leading to an annual estimate of 17,500 (in Žydelis *et al.,* 2009). Within the observed bycatch, Long-tailed duck made up 48% Velvet scoter 23% and Greater scaup 8%. Within the Pomeranian Bay, Kowalski and Manikowski (1982) collected data recorded by fishers in

1977/1978 from one fishing port and estimated that 2.4 birds/boat/day were being caught, predominantly long-tailed duck, velvet scoterand common guillemot. In Puck Bay, a single fisher from one fishing port collected data and questionnaires by Kies´ and Tomek (1990) led to estimates of 3.7 birds/1000 Net Metre Day or the equivalent of 250 birds/boat/year. This produced an annual estimate of 3,750 birds caught. It has to be mentioned, that Polish gillnet effort was significantly reduced after these studies (2004-2010) due to boat number reduction after accession into the EU.

More recently, work by the Polish National Marine Fisheries Research Institute (NMFRI) has investigated the seabird bycatch rates in the Szczecin and Kamienski Lagoons and in Puck Bay with on board observers. Within the Szczecin and Kamienski Lagoons, bycatch was estimated to be 2,487 in 2013/2014 and 2930 birds in 2014/2015 (Psuty *et al.,* in prep). In Puck Bay, the annual bycatch was estimated to be 3,359 birds in 2013/2014 and 3,176 in 2014/2015 (Psuty *et al.,* In prep). The above cited calculations (Stempniewicz 1994; Kies´ and Tomek 1990) were made/based on the assumption that the bycatch data obtained from one harbour could be easily extrapolated across the remaining vessels of that fleet segment. However, the most recent observations on fishing effort of coastal fisheries show that such manner of bird bycatch calculations leads to serious overestimations as many boats indicate zero or minimal (only a few days) activity during the winter season (Psuty *et al.,* in prep.).

12. Portugal

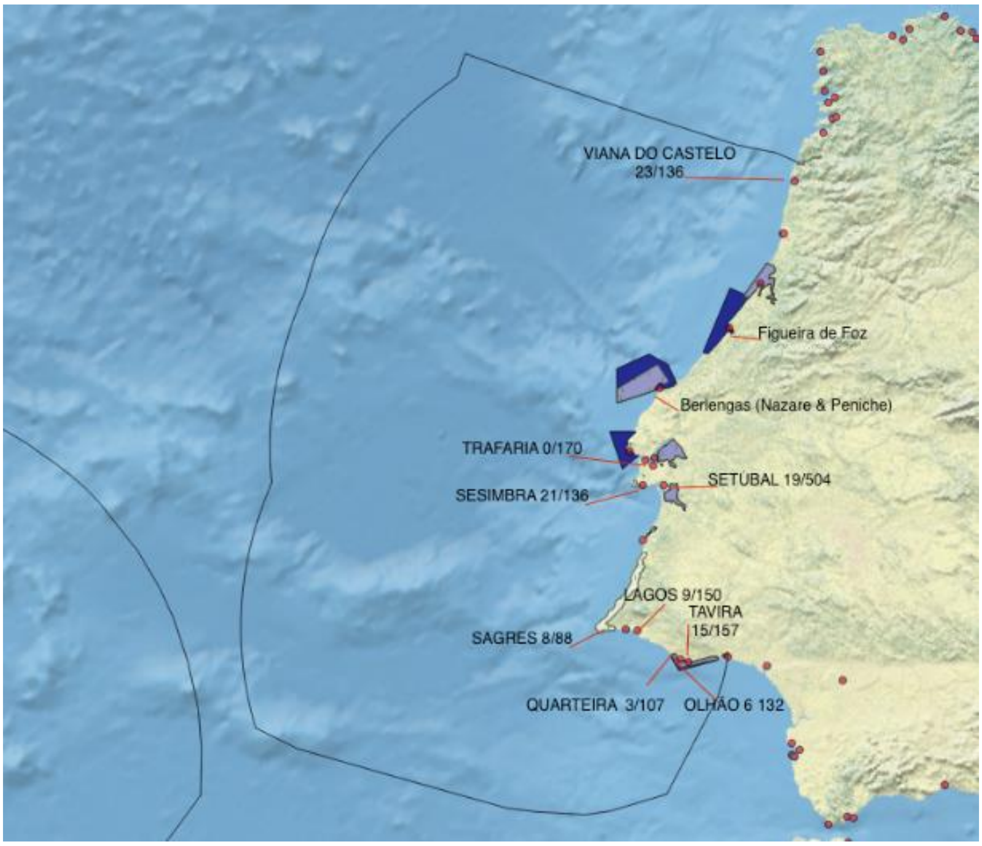

Figure A412: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

There has been recent work (EU funded FAME & MARPro projects) focused on seabird bycatch in the Portuguese small-scale fleet a proportion of which is polyvalent (Oliveira *et al.,* 2015). There are 337 large scale vessels and 2441 small scale vessels registered as using set gillnets as their primary or secondary gear. There is some discrepancy with the nationally registered number of gillnet fishing licences- which numbers around 2199 (A. Almeida pers. comm), demonstrating the difficulty in understanding even the most basic elements of this fishery.

When using set gillnets the small scale fleet is mainly targeting the following species with the following gear configurations (A. Almeida, pers.comm)

- Bottom gillnet (1 net 50-59 m): Witch flounder/Torbay Sole (*Glyptocephalus cynoglossus*)
- Bottom gillnet (1 net 60-79 m): Surmullet (*Mullus surmuletus*), Squid (*Sepia officinalis*), Pouting (*Trisopterus luscus*), Grey Gurnard (*Eutrigla gurnardus*), Sparidae, Blackbelly rosefish (*Helicolenus dactylopterus*), Bastard Sole (*Microchirus azevia*) Thornback Ray (*Raja clavata*)
- Bottom gillnet (1 to 3 nets 80-99mm): European Seabass (*Dicentrarchus labrax*), Whiting (*Merlangius merlangus*), Turbot (*Psetta maxima*), European place (*Pleuronectes platessa*), Common sole (*Solea vulgaris* (solea)), European hake (*Merluccius merluccius*)
- more than 220mm: Anglerfish (*Lophius piscatorius*)

An analysis of beached bird surveys and fisher interviews identified that the areas along the Portuguese mainland where bycatch occurs most often are Nazaré-Peniche and around Figueira da Foz (Henriques *et al.,*2013). These are areas with marine IBAs and Natura 2000 sites. In Figueira da Foz the area has been identified as important for the Balearic Shearwater. In the region around Nazaré-Peniche the Berlengas holds significant numbers of breeding Cory's Shearwater, migrating Balearic Shearwater and wintering razorbill.

Fisher questionnaires distributed to 75 gillnetters had 61 positive responses to gillnet bycatch and a combined total of 5013 birds were reported to be caught by respondents (Oliveira *et al.,* 2015). On board observers (Vingada *et al.,* 2012, Oliveira *et al.,* 2015) recorded bycatch of 13 different species, with the most regularly caught species the razorbill (444 records, and a bycatch rate of 0.34 birds per trip). The Northern Gannet was also caught in high numbers (189 records, 0.036) although the rate was lower and at the same level as the Balearic Shearwater.

13. Spain

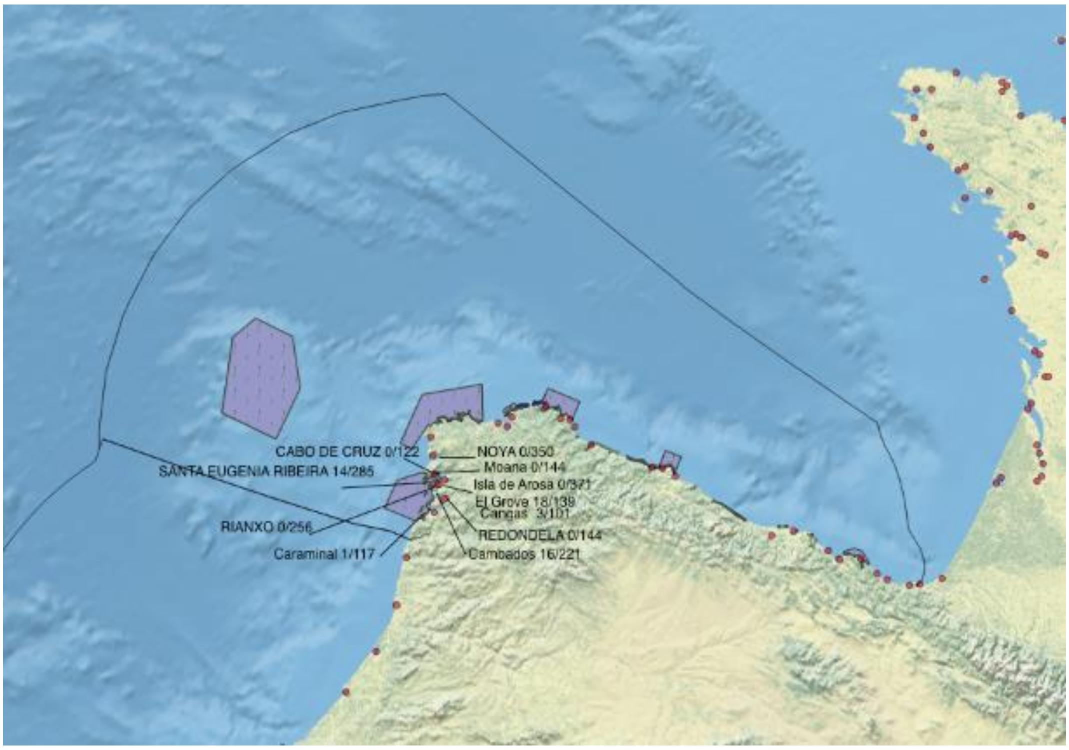

Figure A413: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

Spain's gillnet fleet (excluding the Mediterranean fleet) includes 656 large scale and 6086 small scale vessels operating out of 125 fishing ports and harbours (Annex 3). Ports within the Galician region has the highest density of small scale fisheries.

There are 6 marine IBAs within the region that hold susceptible seabird species (see map), notably the Balearic Shearwater, European Shag, Common Loon and common scoter. It was estimated Arcos (in Žydelis *et al.,* 2013) that up to 3000 European Shags and great cormorants could be caught each year, and 2000 auks (razorbill, common guillemot). More information is needed to quantify and map the spatial and temporal fishing effort and overlap this with known seabird movements and distribution.

14. Sweden

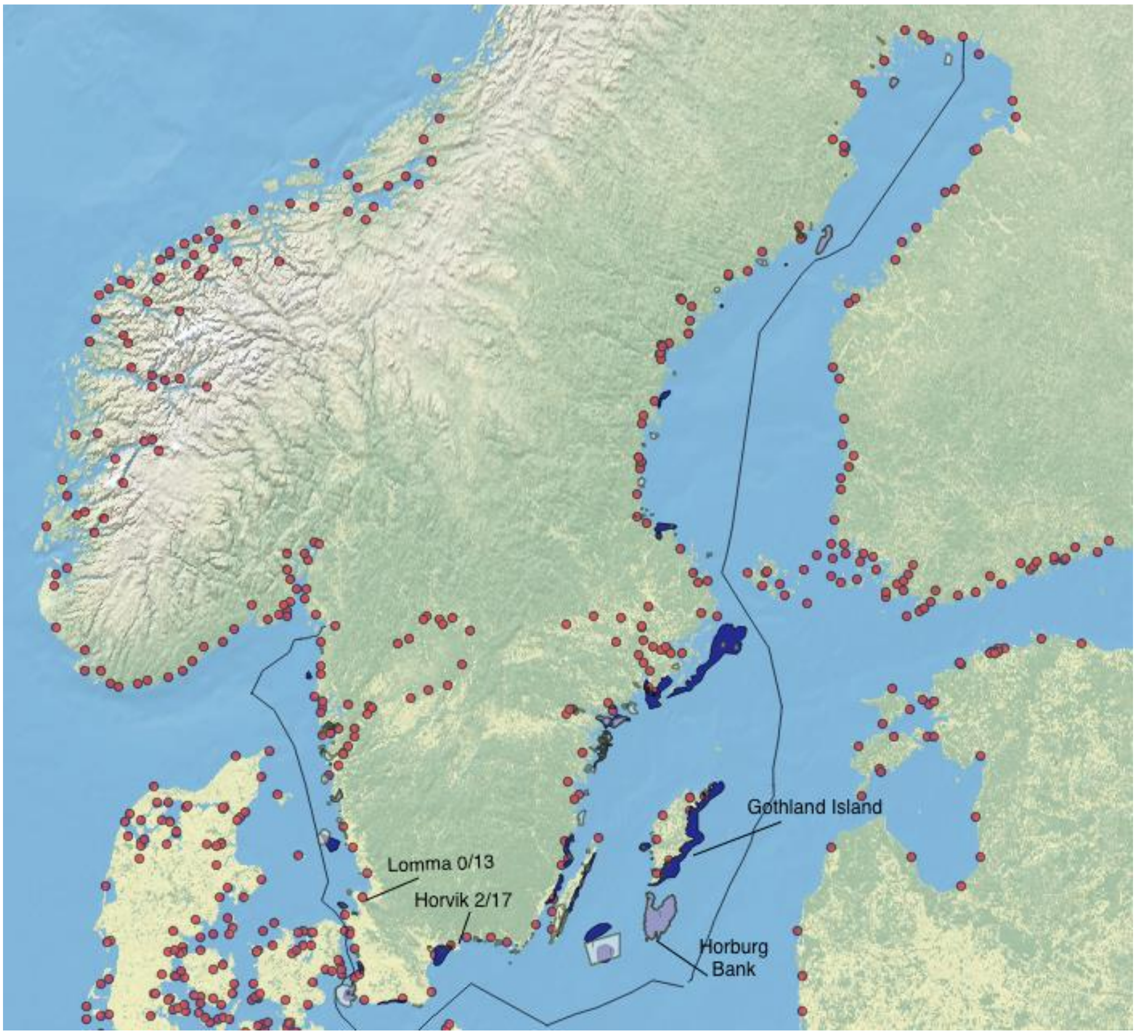

Figure A414: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

The Swedish gillnet fleet is composed of 51 large scale vessels and 838 small scale vessels registered using this fishing gear (see Annex 3). Vessels are registered across 352 different fishing ports and harbours with mostly very low densities in each port. Ports with higher numbers of small scale vessels include Horvik and Nogersund near Pukavik Bay, Lomma (near Malmo), Simrishavn (near Hano Bay) and Trelleborg on the southern coast.

Very few gillnet bycatch-focused studies have been conducted in Sweden. As a result, information on the fishing fleet, including the spatial and temporal effort, is sparse. A study in the 1980s by Oldén *et al.,* (1988) estimated that 500-6500 seabirds (majority common guillemot *Uria aalge*) could be caught along the southern Swedish coast. A more recent study based on fisher replies to questionnaires by Lunneryd *et al.,* (2004) estimated that up to 18,000 birds could be caught annually across Swedish waters, particularly great cormorant, common eider and common guillemot. A study on gillnet bycatch in the turbot fishery around the island of Gotland (eastern coast) and the Horburg Banks recorded bycatch of common eider, great cormorant, black guillemot and common guillemot (Bardtrum *et al.,* 2012). The turbot fishery operates at different depths between May and October, following the Turbot migration to shallower and then deeper water, potentially impacting the species composition and level of bycatch. The east coast of Gotland is a marine IBA, identified for common eider, greater scaup and long-tailed duck, the west coast hosts breeding colonies of common guillemot and black guillemot. The Horburgs Bank is a marine IBA for black guillemot and long-tailed duck during winter.

It is likely that other marine IBAs will have temporal and spatial overlap with gillnet fisheries, as there are 27 marine IBAs in Sweden (see map) which hold species susceptible to gillnet bycatch. According to the report Contribution to the preparation of a Plan of Action for Seabirds (MRAG Ltd., 2011) seabird bycatch is potentially low in Sweden due to the deeper depths at which nets are set, and gillnet fishing is declining across the country. More information is needed, however, to understand the fishery through dedicated on-board observation and fisher questionnaires to determine areas where bycatch is occurring.

15. United Kingdom

Figure A415: Marine Important Bird Areas for susceptible seabird species, Natura 2000 network and fishing ports with high densities of small scale fleets indicated. Marine IBAs= Dark blue, SPA overlapping marine IBA= purple hatch, SPA without marine IBA= grey hatch. Fishing ports identified with number of large scale/small scale vessels.

The entire UK gillnet fleet (North Sea & Celtic Sea region) numbers 55 large scale vessels and 1618 small scale vessels (Annex 3). High densities of small scale vessels are registered along the southern English coast (English Channel) such as in Brixham, Dartmouth, Folkestone, Littlehampton, Newhaven, Plymouth and in Falmouth, Fowey and Penzance.

Very little information is available on seabird bycatch in UK gillnet fisheries, and particularly in the North Sea. Bycatch of razorbills and Guillemots is known to occur in the salmon gillnet fishery in Filey Bay (north Yorkshire coast), although this fishery is decreasing steadily and bycatch levels appear to have declined significantly in recent years (R. Crawford, pers. comm.).

Reports of bycatch off the Cornish coast (St Ives) include episodic events of 200 common guillemots and razorbills caught in one night (RSPB, 2012). More recently a report was published examining the gillnet fishery along the southern English coast (Coram et al., 2015). Collection of information on fishing effort suggested that the coastal areas of Sussex, Kent, east Hampshire and the Cornish coasts have relatively high levels of fixed net effort (Coram et al., 2015). 144 birds were recorded by the observers as bycatch (all static gears), producing an estimate of 1 bird caught every 51 net deployments. The most common species caught were common guillemot and great cormorant.

The marine IBA network is not complete in the UK, and at sea marine Natura 2000 are also lacking (see map). However, the North Sea coastline, particularly around Firth of Forth (Scotland) and northern England (Northumbria), the Orkney Islands, Fair Isle and Shetlands Islands there are important colonies of Atlantic Puffin, razorbill and common guillemot and Red-throated Loon. There are 13 IBAs (mostly terrestrial sites) which contain susceptible species to gillnet bycatch, and so the areas surrounding these sites (and feeding areas) would be of increased risk for gillnet bycatch.

ANNEX 5. GEAR ACCEPTABILITY QUESTIONNAIRE

Questionnaire to determine acceptability of new gillnets / mitigation measures

Introduction

A. Thank you for taking part in this survey. It is a crucial part of the gillnet mitigation project which aims to test the impact of gillnet modifications on seabird bycatch.
B. Today I would like to gather your thoughts on the gillnet mitigation measures you used during the field trials. Specifically, how the nets were to set up, handle, repair, how they influenced catches, and if you had any specific issues with the gear.
C. The questionnaire will be delivered in a semi-structured interview format in Portuguese or Polish. It should take no longer than 20 minutes to complete.
D. All thoughts and opinions you provide will be used in the reporting for this project. Your inputs will be anonymised to the greatest extent possible.

A. Introduction	
1. Which new type of net/mitigation measure did you use?	
☐ Panels	☐ Lights
2. How many fishing trips did you make with the gear?	
3. What was your role on the vessel? (e.g. captain or crew)	

B. Gear set up or manufacture	
4. Were you involved in the setting up or manufacturing of the new gillnets (gear with lights or high contrast panels?	
Yes ☐ (If yes answer question 5)	No ☐ (If no, skip to question 7)
5. How does setting up the new gillnets (nets with panels or lights) compare to setting up normal gillnets? (Please indicate the extent to which you agree or disagree with the following statements).	

Statement	Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
The new gillnets took the same amount of time to set up/manufacture as the normal nets.	☐	☐	☐	☐	☐
The new gillnets were difficult to set up/manufacture compared to the normal nets.	☐	☐	☐	☐	☐

6. Please explain your answers to the previous questions. E.g. if you think the nets were more difficult to set up, why were they more difficult to set up?	

C. Handling (at sea)

7. Did you handle the new gillnets during fishing (gear with lights or high contrast panels)?

Yes ☐ (If yes answer question 8)	No ☐ (If no, skip to question 10)

8. How does handling the new gillnets (panels or lights) compare to handling normal gillnets?
(Please indicate the extent to which you agree or disagree with the following statements)

Statement	**Strongly disagree**	**Disagree**	**Uncertain**	**Agree**	**Strongly agree**
The new gillnets were more difficult to handle compared to normal gillnets.	☐	☐	☐	☐	☐
Hauling and setting the new gillnets took the same amount of time as normal gillnets.	☐	☐	☐	☐	☐
The new gillnets were easier to handle at sea than normal gillnets.	☐	☐	☐	☐	☐

9. Please explain your answers to the previous questions. E.g. if you think the nets were more difficult to handle, why were they more difficult to handle?	

D. Repairs and on-shore handling

10. Were you involved in repairs and on-shore handling of the new gillnets (gear with lights or high contrast panels)?

Yes ☐ (If yes answer question 11)	No ☐ (If no, skip to question 13)

11. How does repairing the new gillnets (panels or lights) compare to repairing normal gillnets? (Please indicate the extent to which you agree or disagree with the following statements)

Statement	Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
The new gillnets were as practical to repair as the normal gillnets.	☐	☐	☐	☐	☐
The new gillnets were more difficult to repair compared to normal gillnets.	☐	☐	☐	☐	☐
Repairing the new gillnets took less time than normal gillnets	☐	☐	☐	☐	☐

12. Please explain your answers to the previous questions.	

E. Effect on target catches

13. How did catches of target species from the new gear compare to catches of fish from your normal gillnets? (Please indicate the extent to which you agree or disagree with the following statements)

Statement	Strongly disagree	Disagree	Uncertain	Agree	Strongly agree
The new gillnets caught more fish than the normal nets	☐	☐	☐	☐	☐
The new gillnets caught different species of fish compared to the normal nets	☐	☐	☐	☐	☐
Catches from the new gillnets were similar to the normal gillnets	☐	☐	☐	☐	☐
The new gillnets caught less fish than the normal nets	☐	☐	☐	☐	☐

14. Please explain your answers to the previous questions.	

F. Effect on bird bycatch

15. How did the bycatch of birds from the mitigated gear compare to your normal gillnets?
(Please indicate the extent to which you agree or disagree with the following statements)

Statement	**Strongly disagree**	**Disagree**	**Uncertain**	**Agree**	**Strongly agree**
The new gillnets caught more birds compared to the normal nets	☐	☐	☐	☐	☐
The new gillnets caught different types of birds (species) compared to the normal nets	☐	☐	☐	☐	☐
Catches of birds from the new gillnets were similar to the normal gillnets	☐	☐	☐	☐	☐
The new gillnets caught less birds compared to the normal nets	☐	☐	☐	☐	☐

16. Please explain your answers to the previous questions.	

G. Difficulties and issues

17. Did you encounter any specific difficulties with the new/mitigated gear that you don’t have with normal nets? Please list all the difficulties you encountered:

Yes ☐ (If yes answer question 18)	No ☐ (If no, skip to question 22)

18. If yes, please list all the difficulties you encountered:

a)	b)
c)	d)
e)	f)
g)	h)

19. Please explain each of the difficulties encountered by providing examples of each of these difficulties:
20. Can you recommend ways to overcome any of the difficulties given above? Please provide these below:
21. Do you see any other issues you or other fishers may encounter when using the new / mitigated nets?

H. Acceptability

22. Is the new fishing gear acceptable to you? (Please indicate the extent to which you agree or disagree with the following statements)

Statement	Strongly disagree	Disagree	Uncertain	Agree	Strongly agree

I would not want to replace my current nets with the new nets (lights or panels)	☐	☐	☐	☐	☐
Replacing my normal nets with the new nets would have minimal impact on my fishing	☐	☐	☐	☐	☐
Replacing my normal nets with the new nets would have a negative impact on the money I make from fishing	☐	☐	☐	☐	☐
I would voluntarily replace my current nets with the new nets	☐	☐	☐	☐	☐
If I replaced my normal nets with the new nets (lights or panels) this would have a significant impact on my fishing	☐	☐	☐	☐	☐

23. Please explain your answers to the previous questions.	

ANNEX 6. POTENTIAL BIOLOGICAL REMOVAL- METHOD & APPLICATION

Potential Biological Removal- explanation of method & application to focal species in study

Potential Biological Removal (PBR) is a method that can be used to identify the number of additional mortalities that can be sustained each year by a population. It may be calculated given an estimate of the population size, the maximum annual recruitment rate (R_{max}), and a management objective (Dillingham and Fletcher, 2008).

This harvest theory approach was developed initially to address marine mammal bycatch in the US (Wade, 1998); but more recently has been applied to a number of seabird species vulnerable to bird bycatch in fisheries (Richard and Abraham, 2013; Žydelis *et al.*, 2009; Dillingham and Fletcher; 2008, Niel and Lebreton, 2005).

PBR is estimated as follows:

$$PBR = N_{min} \, \frac{1}{2} \, R_{max} f$$

Where $\boldsymbol{N_{min}}$ is the minimum estimate of the current population size and is an estimate of the number of animals in a stock that is based on the best available scientific information on abundance incorporating the precision and variability associated with such information, and provides reasonable assurance that the stock size is equal to or greater than the estimate (Wade, 1998). Wade (1998) suggests that the lower bound of a 60% confidence interval is appropriate.

Dillingham and Fletcher (2008), provide a means of approximating $\boldsymbol{N_{min}}$ when population variance estimates are not available:

$$N_{min} \; = \; \widehat{N} exp(Z_{0.2} \, CV_{\widehat{N}} \,)$$

and suggest a CV of 0.5 for imprecise population estimates.

$\boldsymbol{R_{max}}$ is the maximum annual recruitment rate and is calculated as:

$$R_{max} \; = \; \lambda_{max} - \; 1$$

$\boldsymbol{\lambda_{max}}$ is the maximum annual population growth rate of a species existing in optimal conditions, i.e. without limiting factors and at low population density (Niel and Lebreton, 2005).

Applying Niel and Lebreton's (2005) Demographic Invariant method (DIM), $\boldsymbol{\lambda_{max}}$ can be estimated for long-lived bird species using only annual adult survival probability (s) and the age of first reproduction (ɑ):

$$\lambda_{max} \approx \frac{(s\alpha - s + \alpha + 1\,) + \sqrt{(s - s\alpha - \alpha - 1\,)^2 \; - \; 4s\alpha^2}}{2\alpha}$$

There are a number of assumptions implicit within this method. Firstly, it assumes constant fecundity from the age of first reproduction (ɑ) and this is almost certainly not the case. Based on simulations, Dillingham and Fletcher (2008) suggest that using a midpoint value of ɑ produces similar results to modifying the population model to allow for increasing fecundity over time; low estimates may be reasonable if age at first breeding is density-dependent and conditions are non-optimal, while high estimates of ɑ produce the most conservative PBR.

Secondly, survival is implicitly tied to fecundity and generation length, i.e. birds with the highest survival rates (e.g. long-lived species such as albatrosses) have the lowest fecundities. This inverse relationship means that counter-intuitively, a higher survival estimate is associated with lower annual growth, and in addition λ_{max} quickly decreases as s approaches 1; this means that an underestimate of survival results in an overestimate of PBR (Dillingham and Fletcher, 2008). In addition, as most survival obtained from field studies are derived in non-optimal conditions (i.e. they include natural and unnatural sources of mortality that the sampled birds experienced), field estimates generally do not meet the assumption of representing the maximum annual survival probability; hence, conservative (i.e. high) survival estimates should be used to avoid over-estimation of λ_{max} and PBR (Dillingham and Fletcher, 2008).

f= is a recovery factor between 0.1 and 1.0 which is generally set as 0.5 for large and stable populations, *f* = 1 for rapidly increasing large populations, but *f* = 0.3 for small populations fulfilling the criteria for the "Near Threatened" classification by the IUCN (2014) and *f* = 0.1 for species classified "Threatened" (Vulnerable, Endangered, or Critically Endangered; IUCN 2014).

3.2.2.3 Parameters used for Long-tailed duck

Long-tailed duck is considered to be a threatened species (Birdlife, 2016b), so a value of 0.1 was assigned for f based on Dillingham and Fletcher (2008).

The lower range of European wintering population estimate of 1,430,000 birds (European Red List of Birds ERLoB) was used to estimate N_{min} with a CV of 0.5 to allow for the uncertainty in this estimate.

No estimates of age at first breeding or adult survival are available for the western Siberian/northern European populations of Long-tailed duck.

Age at first breeding from Alaskan birds is 2.5 years according to Robertson and Savard (2002). We rounded-up this value to 3 to provide a more conservative estimate.

Some published estimates of survival from Alaska (Schamber *et al.,* 2009) and population modelling (Koneff *et al.,* 2017) are given in Table 1, but these are estimated from declining wild populations. Given that these estimates are unlikely to represent maximum survival rates, we used the upper bounds of these estimates, to calculate a maximum annual population growth rate to calculate PBR.

Table 1. Estimates of adult survival rates for Long-tailed duck (*Clangula hyemalis*)

Adult survival rate and variability	**Scale and/or location**	**Source**
0.74, 95% CL 0.57-0.86	Local (Alaska)	Schamber JL, Flint PL, Grand JB, Wilson HM, Morse JA. Population dynamics of long-tailed ducks breeding on the Yukon-Kuskokwim Delta, Alaska. Arctic. 2009:190-200.
0.81 95% CL 0.58 -0.91	n/a	Koneff MD, Zimmerman GS, Dwyer CP, Fleming KK, Padding PI, Devers PK, *et al.,* (2017) Evaluation of harvest and information needs for North American sea ducks. PLoS ONE 12(4): e0175411. https://doi.org/10.1371/journal.pone.0175411

For comparison, we also derived PBR directly from an estimate of population growth rates available in Schamber *et al.,* (2009). The authors used a matrix-based population model to examine the relative importance of demographic parameters such as clutch size, nesting success, duckling survival, and apparent adult female survival on population growth rate (λ). The stochastic model estimate for λ was 0.81 (95% CI: 0.61–1.06) l; we used the upper confidence interval as a maximum annual growth rate to calculate PBR.

3.2.2.4 Parameters used for razorbill

Razorbill is classified as Near Threatened, so a value of 0.3 was assigned for f.

The lower range of the European population estimate (979,000, Birdlife (2016a)) was used to estimate N_{min} with a CV of 0.5 due to the uncertainty in the population estimate.

Age at first breeding for razorbills from Gannet Island, New Brunswick, Canada is estimated at 4.5 years in Lavers *et al.,* (2008a). We rounded-up this value to 5 to provide a more conservative estimate.

The highest estimate of adult survival that we found in published literature was 0.967 ±0.028 for birds studied at Machias Seal Island, New Brunswick, Canada, which is located at the southern extent of the razorbill's breeding range and supports 592 pairs (Lavers *et al.,* 2008).

Although other studied razorbill populations in the UK were found to have lower age at first breeding and adult survival estimates (Horswill and Robinson 2016), we used these higher, maximum estimates from Canada to calculate the maximum annual population growth rate.

We also calculated PBR directly from a modelled estimate of population growth rate based on demographic parameters from Machias Seal Island birds (Lavers *et al.,* 2009). The intrinsic growth rate (λ) of the stochastic matrix population model based on vital rates from Machias Seal Island was 1.058±0.005.

ANNEX 7. HARVEST STATISTICS FOR LONG-TAILED DUCK IN RANGE STATES

Key harvest statistics for long-tailed duck in each Principal Range State (Hearn *et al.,* 2015)

Principal Range State	Season	Annual harvest	Harvest trend
Denmark	1 Oct – 31 Jan; no bag limit	Mean 2008-12: 1,440	Stable
Estonia	20 Aug – 30 Nov; no bag limit	Mean 2000-12: 68 (annual maximum 223)	2000-12: decline
		Mean 2008-12: 25 (annual maximum 70)	2008-12: stable
Faroe Islands (to Denmark)	Not hunted	Not hunted	n/a
Finland	1 Sep – 31 Dec; occasional spring hunting permitted but none since 2011 (and banned in 2013)	Mean 1996-2013: 14,419 (range 6,200-35,500)	1996-2013: -53%
		Mean 2009-13: 12,220	2001-13: +50%
Germany	Not hunted	Not hunted	n/a
Greenland (to Denmark)	1 Sep – 28/29 Feb	<1,000 birds p.a.	Unknown
Iceland	1 Sep – 15 Mar	Mean 1995-2012: 1,364	Decline
		Mean 2008-12: 816	
Ireland	Not hunted	Not hunted	n/a
Latvia	16 Sep – 30 Nov; also limited in Aug (3 days per week from 2nd week)	Unknown, but thought to be very small	Unknown
Lithuania	Not hunted	Not hunted	n/a
Norway	10 Sep – 23 Dec; no bag limit	Mean 1992-2012: 960	1992-12: decline
		Mean 2008-12: 260	2008-12: stable
Poland	Not hunted	Not hunted	n/a
Russian Federation	Autumn - mid Aug until freezing (Sep-Nov)	Unknown	Unknown
	Spring - 10 days, period varies regionally		
	Summer - unregulated subsistence		
Sweden	Varies regionally; typically mid Aug – end Nov or end Jan	In 1950-90 *c.*7000 p.a.	Decline
		Very few since 2000	
United Kingdom	Not hunted	Not hunted	n/a

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