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Seabird Bycatch Mitigation: Evidence Base for possible UK application and further research

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Summary

Recent studies have provided evidence that identifies the UK **offshore demersal longline** and **< 10 m static net** fleets as the highest priority fleets with which to target further seabird bycatch mitigation measures due to observed seabird bycatch. Preliminary bycatch estimates have been developed from the UK Bycatch Monitoring Programme (BMP), which, although it has small sample sizes and some biases, gives an indication of the possible level of bycatch (fulmar in longlines and guillemot in static nets; Northridge *et al*. 2020) and possible conservation implications at a population level (especially fulmar in longlines and, to a lesser extent, cormorant in fixed nets; Miles *et al*. 2020). Longlines are currently considered the highest priority, considering absolute numbers of birds likely to be bycaught and possible population-scale impacts. Recommendations from this report should be viewed in the light of conclusions of forthcoming research on “bycatch hotspots” in UK waters, commissioned by Defra under the Bycatch Mitigation Initiative.

In the offshore demersal longline fleet, potential focal areas to target monitoring and mitigation trials are the **north-west of Scotland** and **off the Shetland Islands**, due to estimated bycatch levels of fulmar (Northridge *et al*. 2020). For the < 10 m static net fleet, the **southern coast of Devon and Cornwall** and the **north-east coast of England** are likely priorities for trials from the perspective of bycatch incidences (Northridge *et al.* 2020) and population concern (Miles *et al.* 2020).

Given the identified high priority fleets, we recommend research trials be conducted into the efficacy of best practice guidelines on **line-weighting** and **bird-scaring lines** for the UK offshore demersal long-line fleet set-up, as well as the effectiveness of night-setting (noting in particular that this might not be appropriate for fulmar) and **offal management** in reducing bycatch levels. The former two measures need to be tailored for the ‘piedra bola’ system currently in use in UK demersal longline vessels. This would build upon measures already informally trialled and applied by some operators in this fishery.

Mitigation measures for static net fleets are in a much earlier stage of development worldwide, and there are no ‘off the shelf’ methods that can be recommended for widespread roll-out in UK fleets. Therefore, targeted experimental trials are needed for some of the more promising mitigation measures that have been trialled elsewhere, in addition to refinement of techniques already used in the UK in one small-scale fishery.

In addition to targeted mitigation trials in fleets with higher levels of bycatch, increased monitoring is advisable, given the limited and patchy observer data to-date. Optimising existing or planned trials for other groups of protected species (e.g. cetaceans) to include seabirds may be an option. Importantly, engagement with and investigations by the fishing industry into the feasibility, transferability and implications (target catch/financial) of trials or of any subsequent roll out of measures across fleets need to take place before any of the above can be progressed.

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1 Introduction

In July 2018, DEFRA contracted JNCC to develop a UK marine bird bycatch Plan of Action (PoA) to: "Deliver a coherent approach to understand and where necessary reduce marine bird bycatch in UK fisheries, through engagement and dialogue with all interested parties and the implementation of subsequent recommendations". Stemming from that request and subsequent evidence gathering associated with the development of the PoA (Miles *et al.* 2020; Northridge *et al.* 2020; Northridge *et al.* in prep.), this report aims to provide a synthesis of current best practice advice on seabird bycatch mitigation from fisheries throughout the world, but with the greatest applicability to UK fisheries where seabird bycatch is thought to occur. Building on this, the next stage to be explored with the fishing industry is how to incorporate the most applicable of these approaches into clear and practical guidance.

Putting aside the likely effectiveness in reducing bycatch of the various measures discussed, each will have some operational, cost and other impacts on the process of fishing – all of which are recognised as critical considerations but outside the scope of this report to assess.

The following sections (2–6) consider various mitigation options across priority fisheries. Key evidence is summarised in Table 1.

2 "Cross-metier" mitigation measures

These measures can, broadly speaking, be applied to a number of different fisheries and are applicable in most locations.

2.1 Time and area closures

The temporary closure of fisheries in important seabird foraging areas (e.g. areas adjacent to important seabird colonies during the breeding season or non-breeding feeding aggregations) can be a very effective mechanism to reduce bycatch[1,] However, predicting appropriate time/area closures can be difficult due to the mobility of the seabirds, their prey, and fisheries. This is illustrated by a bycatch event in St Ives Bay, Cornwall, in a set gillnet fishery that reportedly caught 163 birds (mostly guillemots), triggering a local byelaw which closed the fishery for 21 days (E. Dunn, RSPB, pers. obs.). However, subsequent to this a large number of birds were reported to have been caught in a neighbouring region outside the byelaw area as the focus of the fishery moved (E. Dunn, RSPB, pers. obs.). Time/area closures to fisheries near to colonies of vulnerable species during the breeding season may be an important mitigation measure to be considered in some circumstances and, technically speaking, relatively simple to implement, but impacts on target catch and associated acceptability with the industry are a vital consideration. They also require extensive knowledge of local conditions and regular monitoring and enforcement, if they are to be effective.

2.2 Night and twilight setting

Setting longlines at night is effective at reducing incidental mortality of many seabirds in a range of fisheries because the majority of vulnerable seabirds are diurnal foragers[1,2]. A study in the Mediterranean of a demersal longline hake fishery (i.e. similar in respect of gear-type

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[1] https://acap.aq/en/resources/bycatch-mitigation/mitigation-advice/3496-acap-2019-review-and-best-practice-advice-for-reducing-the-impact-of-demersal-longline-fisheries-on-seabirds/file (18/11/19)
[2] https://www.acap.aq/en/resources/bycatch-mitigation/mitigation-fact-sheets/1824-fs-05-demersal-pelagic-longline-night-setting/file (18/11/19)

to that which occurs in some Scottish waters where Northridge *et al.* (2020) estimated significant fulmar bycatch is likely) found that night-setting was the most effective mitigation measure in calm conditions, as bird-scaring lines (BSL) were not as effective under these conditions (Cortés & González-Solís 2018). However, unlike in the UK setting, that study was done in a highly coastal, artisanal fishery with many Balearic shearwaters but few northern fulmars. Furthermore, a study in Alaska showed that night-setting increased fulmar bycatch rates by 40%, which led to its abandonment as a measure to reduce bycatch in that species (Melvin *et al.* 2019). Therefore, we caution against night-setting as a method to reduce fulmar bycatch in the UK, until further evidence is gathered.

Auk bycatch in a surface driftnet fishery in a study in Washington State, US, was reduced by 25% by avoiding dawn and dusk setting (Melvin *et al.* 1999). There is evidence that auk (guillemot and razorbill) and shag feeding activity in the UK is very low at night but often peaks at dawn and dusk (Cleasby *et al.* in prep.), so avoiding setting at this time in UK fisheries is advisable.

The extent to which UK fleets use night-setting as a means of avoiding seabird bycatch is not known. Further research is required to identify the extent to which UK gillnet and longline fleets set at night, before recommendations can be made on this mitigation measure. Anecdotally, UK registered offshore demersal longlines tend to haul in the day, but not all setting is done at night (A. Kingston, University St Andrews, pers. obs.). The issue of long days during UK summertime is another complicating factor. There may also be health and safety issues with continuous night setting, particularly on smaller vessels where all the baiting is done on deck.

2.3 Deck lighting

Attraction of birds to artificial sources of light at night on fishing vessels has been recorded in at least 21 species of albatrosses and petrels, as well as several other seabird groups, and has a detrimental effect on some globally threatened seabird populations (Reed *et al.* 1985), notably shearwaters (e.g. Day *et al.* 2003, from a study in Hawaii). Light-induced seabird collisions are difficult to quantify but up to tens of thousands have been observed in a single collision event in the NW Atlantic (Montevecchi 2006). In one incident the lights of one fishing vessel were estimated to attract *c.* 6,000 crested auklets (Dick & Davidson 1978), but it is not known the extent to which attraction to deck lighting of fishing vessels attracts UK seabirds, nor the extent to which (following attraction to the vicinity) birds continue to forage behind the vessel whilst gear is being set and consequently at threat from entanglement during the night. Evidence from Scotland regarding puffins (Harris & Wanless 1998) and Manx shearwaters (Syposz *et al.* 2019) shows that their fledglings are attracted to artificial light from buildings so there is the potential for some level of attraction of UK seabirds to artificial lighting on fishing vessels.

Deck lighting management is possible, but there are safety issues meaning that some lighting will always be required at night. Anecdotally, there are reports of different coloured filters being applied to deck lights to try to alter the colour, although the results of these are unknown; red and green filters have been tried, with mixed success (M. Hermida, Hooktone, pers. obs.).

2.4 Offal management

Seabirds are attracted to offal/fish waste that is discharged from vessels and the practice may increase bycatch rates at these times. Ideally offal should be retained onboard for processing/disposal onshore but if that is not possible, offal should not be discharged while setting and hauling lines and nets, wherever possible[1]. If this is not possible, a mitigation could be to ensure offal is discharged on the opposite side of the vessel to line hauling (assuming hauling is not done from vessel stern).

It is reported (M. Hermida, Hooktone, pers. obs.) that in parts of the northern UK offshore demersal hake longline fishery, offal management is used in the form of a large container on deck into which all offal is placed during fish processing. This is then discharged from the vessel once lines are set or fully retrieved. The prevalence of containers on all boats (and therefore the potential scope for adopting this practise) is not known. If offal management is not currently implemented on all vessels, this would be a relatively simple and effective mitigation measure to adopt to reduce bycatch, assuming sufficient space is available of the vessel.

2.5 Gear switching

In some limited instances, a mitigation option may be to alter the gear set-up of a fleet. For example, gillnets targeting cod specifically, may be able to switch to traps which also catch cod but which are less likely to cause seabird bycatch (A. Kingston, pers. obs.; Meintzer *et al.* 2018). But the diversity of target species that can be caught with traps is likely limited compared to nets, and so transferability might be an issue. Further research into which target species can be caught in traps (and other alternative gears) is needed before this can realistically be considered a mitigation measure. For many vessels, gear switching would require extensive changes, not only to the gear, but potentially the vessel as well. Many vessels are configured for a particular type of fishery and switching gear may not be practically or economically viable. This mitigation option would need extensive research before it could be implemented. Research into the feasibility of gear, determining whether catch remains high, determining fisher appetite for gear switching, investigations into feasibility and cost of gear switching, and impacts to non-target species would all be required.

2.6 Safe handling of caught birds

In many instances, birds are bycaught during gear setting (i.e. trawl or longline) and in these circumstances, mortality is almost certain. However, there are instances where birds are caught as gear is being retrieved. In longline retrieval birds can be caught on hooks as the gear is being brought onboard (*c.* 4% of offshore demersal longline bycatch in UK reported by Northridge *et al.* (2020), though higher live proportions have been reported by RSPB) and in gillnets birds can be caught as the net is being retrieved. In these instances, the optimal situation is that any live birds are released quickly and with minimal stress (i.e. appropriate handling) to ensure their chances of survival remain high. There is currently a large data gap on how many birds are caught alive and are released, as well as what the survival rates are of birds post-release, though a recent study of wandering albatrosses at South Georgia (Phillips & Wood 2020) estimated their survival to be only 40% of that expected for the wider population. Clear guidelines on the safe handling and release of trapped birds can be considered an appropriate mitigation tool in any toolkit for fishers[3] (Zollett & Swimmer 2019).

3 UK Demersal Longline Fishery

There are two different demersal longline fisheries operating in the UK. One fishery involves large vessels (over 20m) fishing offshore in the northern North Sea and western waters, targeting hake and ling, while a much smaller inshore fishery operates in the English

[3] https://www.acap.aq/en/documents/working-groups/population-and-conservation-status-working-group/population-and-conservation-status-wg-meeting-1/2086-pcswg1-doc-07-acap-guidelines-on-hook-removal-from-seabirds/file (03/12/19).

Channel and North Sea, targeting various species, including cod and ray (Northridge *et al.* 2020). Northridge *et al.* provide estimates only for the former fishery, within which bycatch rates (and overall numbers) are much greater in the north (ICES Divisions 4a and 6a) than the south. The number of days at sea fished by the inshore fleet is *c*. 10% that of the offshore fleet (Northridge *et al.* 2020) and total effort will be considerably less than that, given boat size is small. Estimates indicate that there may be 2,200–9,100 fulmars killed incidentally each year in the UK-registered demersal longline fleets in UK and adjacent waters and an estimated 0-600 gannets, along with smaller numbers of three other species (Northridge *et al.* 2020). Therefore, fulmar represents the largest component of bycatch in the UK-registered fleet, for which mitigation measures could have the potential to result in substantial population gains relative to the likely trajectory with no mitigation (Miles *et al.* 2020). While some mitigation measures are in place on some UK-registered vessels (M. Hermida, Hooktone, pers. obs.) the extent and efficacy are poorly understood, though a preliminary study on line sink-rate has recently been completed, highlighting the likely limited benefits of traditional mitigation measures (e.g. Bird Scaring Lines) in use in this fishery to prevent seabird bycatch (Rouxel, in prep.). That said, there are several proven seabird bycatch mitigation devices for demersal longline fisheries, predominantly trialled in the Southern hemisphere, discussed below.

3.1 Line weighting

Lines should be weighted to get the baited hooks rapidly out of the range of feeding seabirds. Weights should be deployed before line tension occurs to ensure that the line sinks rapidly out of reach of seabirds[1]. Both the mass of weights applied to lines, and the spacing between weights, are equally important. The optimal sink rate is thought to be 0.3 m/sec (Nyengera & Angel 2019). To achieve a uniform sink rate, weight should be evenly distributed along the entire line[4]. When the distance between weights is too great, the hook line tends to loft immediately before the deployment of a weight; this leaves hooks vulnerable to seabird attack.

In traditional demersal longline fisheries (e.g. for cod) the use of steel weights is considered best practice. For this type of fishery, the mass should be a minimum of 5 kg at 40 m intervals[1]. However, for the UK hake long-line fishery, which use a ‘piedra bola’ system, the gear set-up includes ‘lofted’ demersal longlines, where the line is floated off the seabed (also known as semi-pelagic longlines) (Figure 1). This poses a challenge, as the floats on the line counteract the line weights and result in lofting of the line behind the vessel for extended periods, exposing seabirds to the risk of being bycaught. Experiments suggest that 3 kg of weights every 100 m is optimal for this particular gear set-up (Rouxel in prep. – see below), and further research is being undertaken to identify improved configurations (M. Hermida, Hooktone, pers. obs.).

[4] https://www.acap.aq/en/resources/bycatch-mitigation/mitigation-fact-sheets/762-fs-02-demersal-longline-line-weighting-external-weights/file (18/11/19); https://www.seafoodinnovation.fund/projects/developing-a-floated-demersal-longline-design-that-minimises-seabird-bycatch-fs031/

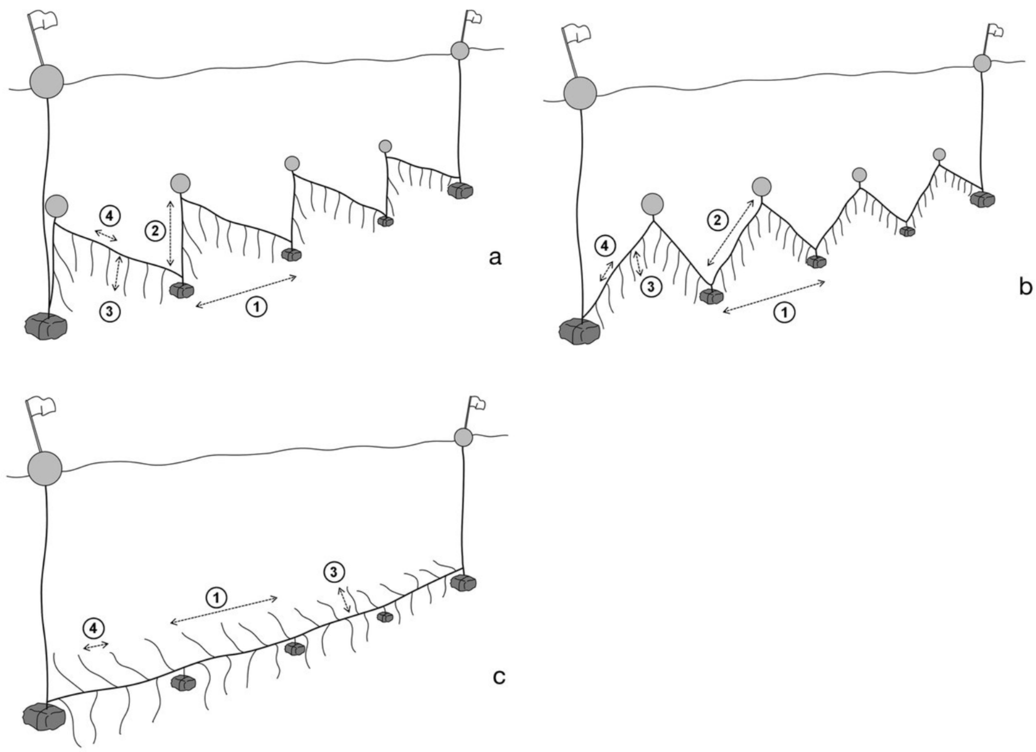

Figure 1. Longline configurations used by the demersal fleet: (a,b) the Piedra−Bola system (a = PB-zigzag, b = PB-pyramidal) and (c) the bottom longlines (bottom-weights). 1 = distance between weights; 2 = minimum distance between the weight and the float; 3 = length of branch lines; 4 = distance between hooks. Drawing by Toni Mulet (taken from Cortes *et al.* 2017).

Petersen *et al.* (2005) experimented with semi-pelagic longlines targeting hake in South Africa. They found a threshold above which adding further weight had little effect on sink rates. They recommended reducing the distance between weights to achieve a faster, more even sink rate[4]. However, this is likely to affect the performance of the gear resulting in lower catch of target species and higher fish bycatch. In semi-pelagic lines, seabirds are far more likely to be caught on hooks positioned near floats than elsewhere. Seco Pon *et al.* (2007) found over 93% of all birds killed in the Argentine semi-pelagic kingklip fishery were caught within 30 m of a float. Removing hooks adjacent to floats or increasing the length of the line connecting the float to the hook line would help to reduce seabird mortality in these fisheries[4].

Reports from the UK demersal hake longline fishery involve skippers placing weights closer to floats to increase line sink rate in an effort to reduce seabird bycatch, so improved line weighting regimes are already in place on some vessels (M. Hermida, Hooktone, pers. obs.). These trials were not undertaken in experimental conditions and so designed experimental trials should be conducted.

As a first step towards this, RSPB and Hooktone, through the UK Seafood Innovation Fund, examined the sink profile of the demersal longline fishery and propose a new design that could minimise interactions with seabirds through enhanced sink rates (Y. Rouxel, in prep.). Deployment of Time-Depth Recorders (TDRs) and computer simulation work suggested that current gear configurations have very low sink rates, with only the hooks closest to the weight-lines reaching the minimum recommended sink rate. This means that in the most extreme cases (near the floats), hooks can still remain close to the surface up to several hundred meters behind the stern (Rouxel, in prep.). Additionally, this is likely to increase the risk of entanglement between gear and bird scaring lines, leading to practical issues. Therefore, even with the inclusion of bird scaring lines (see Section 3.2), a large number of hooks would remain available to seabirds and this low sink rate is therefore suggested to be the main driver of seabird bycatch in floated demersal longlines in UK waters.

The feasibility study used computer simulations to identify potential modifications to the gear to increase the sink rate of the hooks and therefore reduce bycatch whilst also minimising the level of change required to fishing gear and practices. A suite of modifications was identified:

- Increase the length of float lines
- Modifications to weights (their shape and potentially weight)
- Incorporate a ‘no-hook’ buffer zone around the floats
- Change floats from traditional design to ‘hydrodynamic’ floats to decrease water resistance

This feasibility study identifies at-sea trials of the recommended modifications as the next step. Such a trial would compare rates of target-fish catch and seabird bycatch between current gear and an experimental gear type incorporating the recommended modifications.

3.2 Bird-scaring lines (BSL)

Bird scaring lines (also known as tori lines) are designed to provide a physical deterrent over the area where baited hooks are sinking. Sufficient drag must be created to maximise aerial extent and maintain the line directly behind the vessel during crosswinds. This may be achieved using either towed devices or longer in-water sections. Current best practice advice on deployment of bird-scaring lines in demersal longline fisheries (based on international experience) is found below[1].

Large vessels (≥ 24 m in length)

Two (paired) bird scaring lines should be used simultaneously. The design of the bird scaring lines should include the following specifications:

- The attachment height should be at least 7 m above sea level.
- The lines should be at least 150 m long to ensure the maximum possible aerial extent.
- Streamers should be brightly coloured and reach the sea-surface in calm conditions and placed at intervals of no more than 5 m.

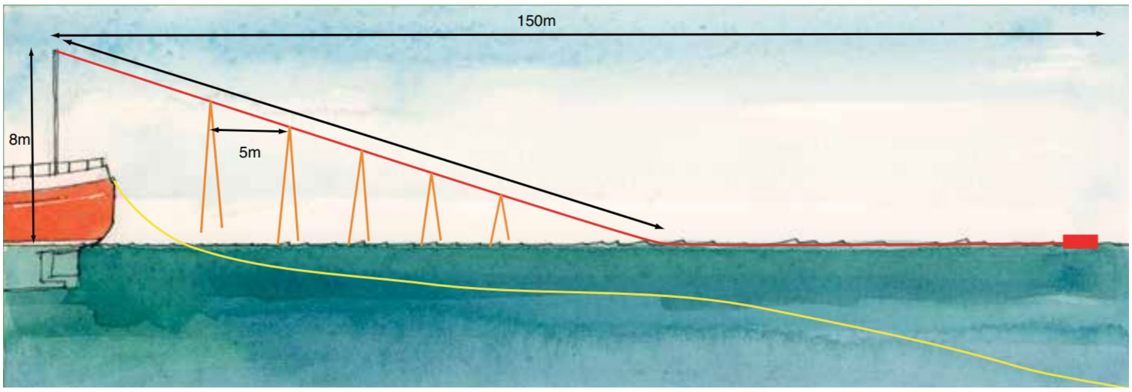

Figure 2. Bird-scaring line configuration for large demersal longline vessels (≥ 24 m in length)[5].

[5] Illustration taken from ACAP factsheets. https://www.acap.aq/en/resources/bycatch-mitigation/bycatch-mitigation-fact-sheets/1912-fs-01-demersal-longline-streamer-lines/file (13/01/20)

Small vessels (< 24 m in length)

One or two (paired) bird scaring lines should be used.

The design of the bird scaring lines should include the following specifications:

- The attachment height should be at least 6 m above sea level.
- The lines should achieve an aerial extent of at least 75 m when setting at ≥ 4 knots, or 50 m if setting at speeds < 4 knots.
- Streamers should be brightly coloured and reach the sea-surface in calm conditions and placed at intervals of no more than 5 m. Streamers may be modified over the first 15 m to avoid tangling.

It is possible that the advice on bird-scaring lines for small vessels (< 24m in length) may be applicable to the small UK demersal cod longline fishery. However, there may be issues applying the large vessel specifications to the UK demersal longline hake fishery, due to their particular gear set up (as described above). The 'lofting' effect of the floats (which keep the hooks off the seabed during fishing) result in a slower sink rate of the line, meaning that the baited hooks can extend beyond the protection afforded by the bird-scaring lines, if these are not long enough.

Results from the US west coast sablefish fishery found that bird-scaring lines were sufficient to protect bait from bird attacks on longlines without floats, but not bait on longlines with floats (Gladics *et al.* 2017). Longlines with floats sank below the reach of albatrosses (2 m depth) at a distance astern (157.7 m ± 44.8 95% CI) that was 2.3 times farther than longlines without floats (68.8 m ± 37.8 95% CI). The floated longline distance was well beyond the protection afforded by BSLs (in this case c. 40 m of aerial extent). Black-footed albatross attacked floated longlines at rates ten times more (2.7 attacks/1,000 hooks, 0.48–4.45 95% CI) than longlines without floats (0.20 attacks/1,000 hooks, 0.01–0.36 95% CI) (Gladics *et al.* 2017).

That said, bird-scaring lines are reportedly in use on at least 8 out of 15 vessels in the UK-registered demersal hake longline fishery and are reported to be effective in keeping birds away from lines (M. Hermida, Hooktone, pers. obs.) It is not clear whether single or the ACAP-recommended (for larger vessels) double lines are used. Formal mitigation trials are needed to confirm their effectiveness.

We do not know the extent to which existing best practice bird-scaring line specifications are used and/or transferable to UK demersal longline fleets. Trialling of existing best practice bird-scaring lines set-ups is advised, with the expectation that specifications may need to be modified to work appropriately in UK fleets.

Questions to be raised in the trialling of bird-scaring lines to UK offshore hake longline fleet are:

a) is the attachment height sufficient (based on the ones currently in use)?

b) is the length of the bird-scaring lines sufficient to provide coverage for the sinking baited hooks?

c) are two bird-scaring lines being used on vessels over 24 m in length?

d) are there entanglement issues (between BSL and fishing line)? and

e) how best to ensure that best-practise guidelines are actually implemented/followed?

3.3 Bird Exclusion Device (BED)/Brickle curtain

During hauling operations birds can accidentally become hooked as gear is retrieved. A Bird Exclusion Device (BED) consists of a horizontal support several metres above the water that encircles the entire line hauling bay. Vertical streamers are positioned between the support and water surface. The seabird deterrent effectiveness of this streamer line configuration can be increased by deploying a line of floats on the water surface and connecting this line of floats to the support with downlines. This configuration is the most effective method to prevent birds entering the area around the hauling bay, either by swimming or by flying[1]. Crucially this device must be used in conjunction with other mitigation measures (i.e. line weighting, night-setting and bird-scaring lines).

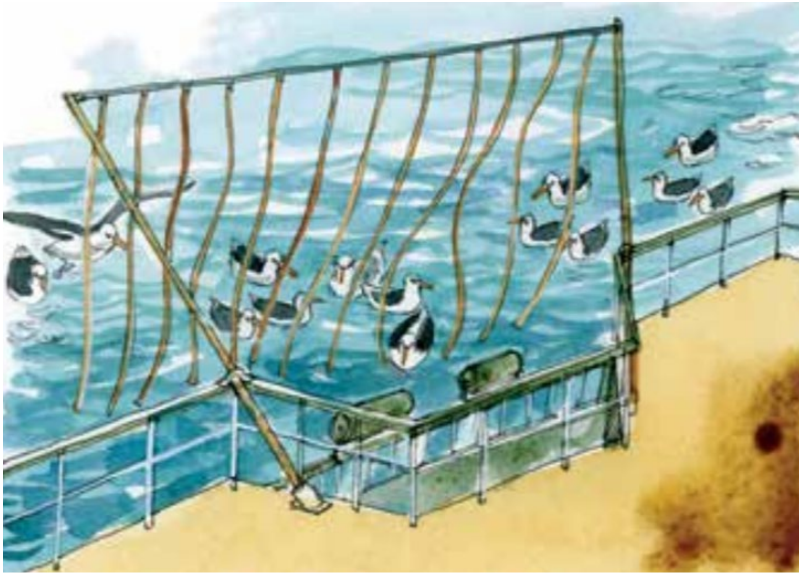

Figure 3. The Bird Exclusion Device or 'Brickle Curtain' is a deterrent that forms a protective barrier around the hauling hatch[6].

4 UK Static Net Fishery

Northridge *et al.* (2020) indicated that approximately 78% of the *c*. 3,000 birds they estimated to be bycaught annually in the UK-registered static gillnet fisheries comprised of guillemot. Cormorant was estimated to be the next most bycaught in static nets (11% of total). Both these are pursuit-diving species, likely caught in gillnets when attempting to catch prey around them or, especially in the case of guillemot, may drift into the net more passively. Miles *et al.* (2020) identified that, of the UK bird populations most likely to benefit from future fixed-net mitigation efforts, cormorant might be expected to benefit more in population terms than guillemot, despite them incurring lower annual bycatch than guillemot.

However, there are an extensive number of different types of gillnet fisheries around the UK. Most fisheries use monofilament nets, but gear can vary between gillnet, tangle net and trammel net[7]. The extent, number of vessels involved, and complexity of the UK static net fleet makes mitigating the impacts of seabird bycatch extremely difficult, and no one mitigation measure is likely to work in all scenarios.

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[6] Illustration taken from ACAP factsheets. https://www.acap.aq/en/resources/bycatch-mitigation/bycatch-mitigation-fact-sheets/1907-fs-12-demersal-pelagic-longline-haul-mitigation/file (13/01/20)

[7] https://www.seafish.org/media/Publications/SeafishGuidanceNote_StaticGear_201102.pdf (13/01/20)

For example, there is a demersal offshore static net fishery, off the south-west of England, targeting hake and turbot, which uses > 10 m vessels (K. Borrow, Mindfully Wired, pers. comm.). There is also an inshore mid-water static net fishery in the southern North Sea using < 10 m boats (K. Borrow, pers. comm.). Cumulatively, the < 10 m vessels are thought to contribute *c*. 95% of the guillemot and cormorant fixed net mortality per year (Northridge *et al.* 2020). It is not clear whether this is because smaller boats tend to fish inshore and are therefore more likely to encounter seabird aggregations, or whether other factors are at play. However, as those authors acknowledge, the observer data, from which these numbers are estimated, are limited, so biases are likely to exist - at least until improvements to monitoring are in place.

4.1 Filey Bay sea-trout fishery

There is also a small static gillnet fishery for sea-trout in Filey Bay (NE England), close to extensive seabird colonies. It is seasonal and opens April to the end of August (K. Borrow, Mindfully Wired, pers. comm.; Quayle 2015). There has historically been quite high levels of seabird bycatch from such a small fishery, due to its proximity to seabird colonies, but it is thought that this has been dramatically reduced in recent years due to mitigation efforts by local fishermen (*c*. 700 down to 4–5 birds per year caught) (K. Borrow, pers. comm.; Quayle 2015), though uncertainty remains as to the absolute and relative effectiveness of the various measures taken and of the role of factors such as weather and number of birds in the area . The fishery has 4–5 licenses, with most fishermen now using mitigation measures throughout the season. Various measures have been trialled, with varying success:

4.1.1 Net attendance

One of the most effective mitigation measures in Filey Bay has been 100% attendance of nets by fishermen while the nets are in the water, which is thought to deter birds from the area immediately adjacent to the net due to the presence of the fishermen (K. Borrow, pers. comm.). It also allows birds to be immediately released from entanglement by fishermen. Whilst this has the potential to be used in other small, inshore, surface gillnet fisheries, very few similar to this exist in the UK. This measure is considered unlikely to be feasible in larger demersal gillnet fisheries, where nets have a substantial soak time. The depth at which mid-water and demersal gillnets are set at (and their length) means that bycatch could occur despite net attendance (A. Kingston, University of St. Andrews, pers. obs.).

4.1.2 High Visibility Sections of the Leader Line

The fishermen of Filey Bay have trialled replacing sections of the leader line from monofilament (which is nearly invisible) to black nylon netting (which is visible). The gillnets are set in a J-shape, and the current structure means that the trout approach the visible net, swim along it to avoid the visible part of the net and are caught in the monofilament section at the end of the J-shape. This design is also thought to have been effective in reducing seabird bycatch. High visibility white nylon has also been trialled but was viewed as less effective (K. Borrow, pers. comm.).

4.1.3 Coloured Floats

The use of different coloured floats on the top of the net has also been trialled at Filey Bay. The efficacy of this mitigation measure is not yet proven – further trials are necessary to assess if it is a useful mitigation tool in these types of fisheries. However, this technique is thought to only be applicable in fisheries where the upper line of the net is set at the water surface.

4.1.4 Looming Eyes Buoy

In a new approach to mitigation (trying to keep birds from approaching the wider vicinity of the net), the RSPB designed a prototype 'Looming Eyes' buoy. This device acts as a scarecrow, with painted eyes of different sizes rotating on a floating buoy, to give birds the impression of a predator approaching them from a distance (Hausberger *et al.* 2018). This has only recently gone to pilot trials in conjunction with Filey Bay fishermen, so it is not known how effective it may be as a mitigation measure for inshore static gillnets. Tests in Estonia have shown that the buoy was effective in reducing Long-tailed Ducks presence within a 50 m radius, and that the buoys have now been sent to Lithuania for testing in a fishery (fish traps) setting, with the aim to do further follow up testing in gillnet fisheries. (Y. Rouxel, RSPB, pers. comm.).

4.2 Acoustic Pingers

Acoustic pingers are used in the static gillnet fishery (on vessels > 12 m) operating off south-west UK due to documented cetacean bycatch, particularly harbour porpoise and common dolphin (K. Macleod, JNCC, pers. comm.). Fishermen need a licence to deploy pingers if use is not mandatory (e.g. if the vessel is < 12 m there is requirement for a licence, in SW England). The deployment of pingers has the potential to effect seabird interactions with static gillnets. The efficacy of it as a mitigation measure for diving seabirds is not yet fully understood, as little is known about the auditory capacity of seabirds underwater. Melvin *et al.* (1999) undertook trials of acoustic pingers deployed on the float line (of surface driftnet fishery in Washington State, US) every 50 m (13 pingers per net). These were tuned to the generic audiogram of birds (*c.* 1.5 kHz). Pingers were found to reduce bycatch of Common Murre (Common Guillemot) by 50% but had no significant effect on Rhinoceros Auklet bycatch rates (Melvin *et al.* 1999). In their study, nets with pingers were found to attract significantly more seals, presumably due to association with fish caught in the net (Melvin *et al.* 1999).

As the only trial of pingers to reduce seabird bycatch was from a surface driftnet fishery, it is not known how transferable this mitigation might be to other forms of static gillnet. Moreover, the results indicate that the efficacy of pingers may be species-specific. Further research will be needed to determine transferability and to explore whether pingers work with some species groups better than others. Also, consideration needs to be given to the potential for non-target effects from pinger deployment, such as increased catch depredation by seals (though there are already pingers on the market that are not audible to seals – Omeyer *et al.* 2020).

4.3 Net Illumination (LEDs)

A few trials have looked at the efficacy of net illumination to reduce seabird bycatch in static gillnets, using light emitting diodes (LEDs) of various colours, with varying success. Trials in a demersal set net fishery in Peru, concluded that constant green LED light reduced bycatch of Guanay cormorants (Mangel *et al.* 2018). In this trial LEDs were placed every 10 m along the float line of a 600 m long net. They concluded a reduction of 85% of Guanay cormorant bycatch. This trial is significant in a UK context because the population level gains that could potentially be achieved by bycatch mitigation could be relatively high in cormorants (Miles *et al.* 2020) even though the total number of cormorants bycaught in static nets in the UK fishery are perhaps one tenth that of guillemot, for which population-level impact is thought to be less.

Field *et al.* (2019), in the Baltic Sea, found that neither Long-tailed Duck nor Velvet Scoter bycatch was reduced by steady green or flashing white LEDs placed at intervals along the float line of the net. Long-tailed Ducks were caught in greater numbers in nets with flashing white LEDs than none at all, suggesting a potential attractant factor. Field *et al.* (2019) suggest that the type of seabird species potentially affected is important, with cormorants being visual pursuit predators (potentially more likely to use visual cues) while sea ducks exploit tactile information to detect benthic prey and (in the case of the Baltic Sea) are in a high turbidity/low visibility environment. Hence, why visual alerts to reduce bycatch may not work well in these circumstances.

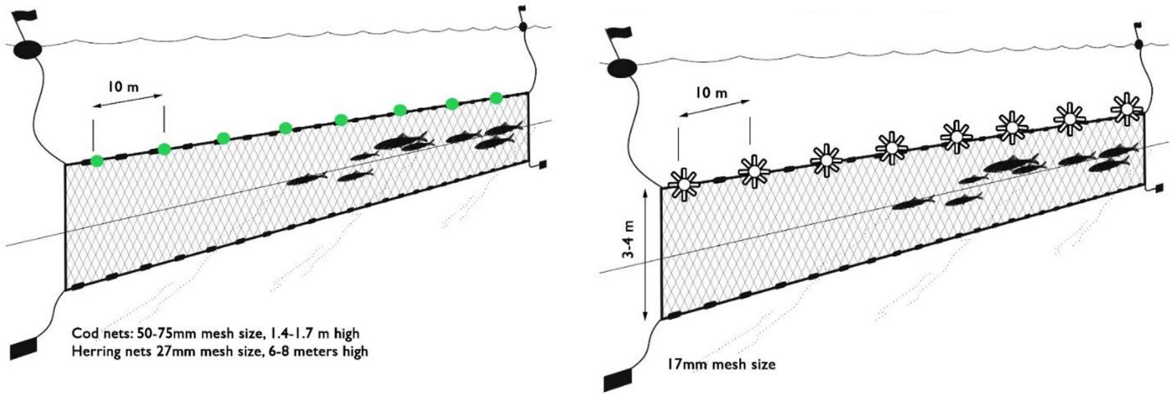

Figure 4. a) Green constant lights used in Polish trials, every 10m along the headline; b) Flashing white lights, used in Lithuanian waters, every 10m along the headline. (Illustrations taken from Field *et al.* 2019).

As the main species of seabird caught in UK gillnets are guillemot and cormorant (visual pursuit diving species) (Northridge *et al.* 2020) it is possible that visual alerts could prove effective, depending on the depth and turbidity of water nets are set in. Some ad hoc data may be collected during the UK Defra funded CEFAS trials currently going on in south-west England, which are looking at the efficacy of LEDs to reduce cetacean bycatch. However, targeted experimental trials for seabirds are needed in a UK context before this can be considered a realistic mitigation measure for UK gillnet fleets. Questions that need answering are:

a) what type of net illumination works for UK seabirds (particularly guillemot and cormorant)?;

b) what species respond well to this mitigation measure?; and

c) how transferable is it to gillnets working at different depths and turbidity?

4.4 High Visibility Mesh Panels

Several studies have trialled using different types of high visibility sections of the gillnet mesh interspersed with the traditional gillnet material (usually monofilament). This is intended to visually alert the seabird to the presence of a net, without causing a reduction in target fish catch. For example, a Lithuanian trial used 0.6 x 0.6 m panels, composed of vertically orientated alternate black and white strips (60 mm wide) made of nylon, attached every 4 m along the net and centrally in the vertical plane. This study concluded that high visibility mesh panels were not successful in reducing bycatch of sea ducks in the Baltic (Field *et al.* 2019). They also concluded that catch rates of commercial fish were not affected by net lights or net panels placed within the nets.

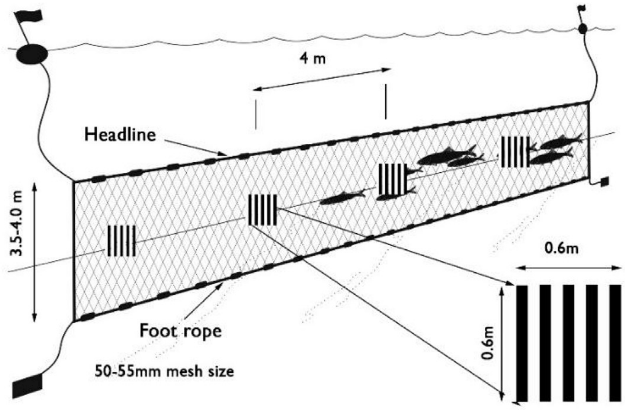

Figure 5. Net panel used in Lithuanian bycatch mitigation trials. Panels measured 0.60 x 0.60 m and were attached every 4 m along each net, equidistant from the head and bottom lines. (Illustrations taken from Field *et al.* 2019).

In Puget Sound (US west coast) thick white sections of mesh were introduced into the top of the net (Melvin *et al.* 1999). This was effective in reducing bycatch of auks, but simultaneously reduced target salmon catch (Melvin *et al.* 1999). Field *et al.* (2019) ascribes the different results of the two studies to the fact that the Puget Sound study was of a surface salmon driftnet fishery, where auks raft towards the net on currents and then their dive-escape response results in capture. The high visibility mesh at the top of the net is thought to deter them from diving down from the surface into the net (i.e. this may be very different from birds pursuit-dive foraging and getting caught in a demersal gillnet whilst hunting for prey).

Common Murre bycatch was reduced by 40% and 45% in the 50 mesh and 20 mesh visual alert nets, respectively. Rhinoceros Auklet bycatch was reduced by 42% only in nets with deeper visual alerts (i.e. 50 mesh) (Melvin *et al.* 1999). The varying efficacy of bycatch mitigation by species is important to note. We recommend that efficacy in UK fisheries should be trialled.

4.5 Net Colour

Hanamseth *et al.* (2017) tested the ability of little penguins to differentiate between different coloured netting materials under controlled conditions, to ascertain if changes in gillnet colour could facilitate a potential mitigation measure by improving visibility of nets. Gillnet filament colours tested were clear, green and orange. Orange coloured monofilament lines resulted in lower collision rates (5.5%), while clear and green monofilament lines resulted in higher rates of collision (35.9% and 30.8%, respectively). This suggests that orange-coloured lines were more apparent to the birds. Constructing nets of orange-coloured material may be effective in reducing bycatch in gillnets set in shallow waters and high light levels where seabirds are able to identify fine colour differences. However, it is important to note this behaviour was displayed only for one species of penguin and under experimental conditions, where light and turbidity of the water column was not an issue (potentially unrealistic in UK waters). The study also did not test for the effect of gillnet colour on catch efficiency of target species.

4.6 Depth Restrictions

One approach, which would eliminate risk of bycatch in the portion of the water column where birds typically dive and forage, is to introduce a depth restriction above which gillnets are not set. This would avoid nets being set in the layers used by seabirds and thus reduce bycatch (Bærum *et al.* 2019). In Monterey Bay in the 1980s a law was introduced restricting set nets in the top 10 m of the water column (later extended to 15 m). While seabird bycatch levels reduced, so did target catch (Wild 1990), which is an important caveat to the outcome of this trial. Similarly, dropping the headline of Japanese squid vessels in the North Pacific reduced shearwater and albatross bycatch, but also significantly reduced target catch (Hayase & Yatsu 1993).

Key evidence gaps for possible UK application are:

a) what depth restriction would be effective for what species (noting that RSPB are currently analysing time-depth recorder data from UK-breeding guillemots, razorbills and shags to help inform this (Cleasby *et al.* in prep.)); and

b) is there a knock-on effect on target catch and other non-target species.

5 UK Pelagic Trawl Fishery

Mid-water trawling in UK waters is associated with bycatch of three species; guillemot, razorbill and cormorant, although the relative numbers of birds caught is thought to be small and not considered of conservation concern (Northridge *et al.* 2020). Due to the size of the species it is unlikely that mortality is associated with warp strikes[8], and therefore bycatch is most likely due to net entanglement, primarily during trawling, where the trawl headline is in close proximity to the surface. Birds are likely flushed and those that escape-dive have the potential to be caught in the net as it is towed (Northridge *et al.* 2020). There could be benefit from targeted monitoring (i.e. with cameras) to assess the mechanism of bycatch events for this gear type. It is possible that some bycatch occurs during net hauling and, in instances such as these, an important mitigation measure is safe retrieval of live individuals (see safe handling section). Given the form that seabird bycatch takes in this fishery (i.e. mid-trawl through flushing of birds ahead of the deployed net), it seems unlikely that a suitable mitigation measure will be found, and in any case the numbers of birds involved is probably small (meaning that other fisheries should be prioritised over mitigation in this fleet). Safe handling of birds caught during hauling would seem the primary mitigation measure for this fishery.

6 UK Purse-seine Fishery

There is little direct information on seabird bycatch in the UK-registered purse-seine fleet, which is relatively limited in extent and effort. Evidence from Spain indicates occasional mortality of shearwaters targeting small pelagic fish during hauling of purse-seiners (SEO/Birdlife unpub. data). In Portugal, a similar fishery found that bycatch incidents occurred on an irregular basis but could affect large numbers of birds during one event (although how representative this may be of the UK fleet is unknown) (Oliveira *et al.* 2015). This may potentially be a problem for Balearic shearwaters, which occur in south-western UK waters in variable numbers, and which is Critically Endangered under the IUCN Red List.

Birds are believed to be caught as the net begins to be hauled in and the fish aggregate in a smaller area. Plunge diving birds like gannets are also at risk. The primary mechanism for mortality is thought to be birds foraging in and around the net getting water-logged and then drowning (A. Kingston, pers. obs.).

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[8] Wings being trapped/hit by the warp cables, which attach the net to the back of the boat during trawling.

Some seabird bycatch mitigation research for purse-seiners has been done in the Chilean fleet, where they have a problem with pink-footed shearwater bycatch (Suazo *et al.* 2019). One element they identified as being important was to minimise the amount of netting material to reduce the 'ceiling effect' created by excess netting floating on the water's surface as the 'purse' is drawn together. It is in this 'ceiling' that large numbers of birds are caught in the Chilean fleet (Suazo *et al.* 2019). They also implemented an internal mounting system for the buoy line. They determined that the internal mounting of buoys in relation to the main rope, along with the direct attachment of zippers to the rope without secondary ropes for buoys, reduced the risk of entanglement for plunge diving seabirds (Suazo *et al.* 2019). It is possible that some of these mitigation measures could be adapted to the UK purse-seine fleet, but further investigation would be necessary to determine what mitigation measures are appropriate and feasible. Before any such work is undertaken however, it is important to establish the extent to which any bycatch does occur in the first place.

Figure 6. Details of mounting system of the buoy line for an unmodified purse seine gear (left) and the modified purse seine (right) with the main rope passing through the buoys and direct mounting of zippers (figure taken from Suazo *et al.* 2019).

The UK purse-seine fishery already has a voluntary 'code of conduct' that includes rescuing water-logged birds, drying them on deck and releasing them once they are recovered. Anecdotal observer data indicates this is happening (A. Kingston, pers. obs.). There is also a technique employed of 'banging metal on metal' to scare birds out of the danger zone (A. Kingston, pers. obs.). It would seem prudent for targeted monitoring to occur in this fishery to seek to observe how frequent bycatch of Balearic shearwater may be. As this appears to occur sporadically, observing such events may prove difficult with existing levels of observer coverage. Moreover, numbers of Balearic shearwaters in the area vary from year to year and at finer temporal scales.

Table 1. Summary of mitigation device characteristics and relevant fisheries.

Transferability scores: 1=No mitigation solution currently available or highly experimental to-date, 5=mitigation fully demonstrated to be effective, and easily transferred to UK fleets.

Fishery	Mitigation Device	Worldwide Trials to-date	Transferability to UK	Transfer-ability Score	Further Research Required in UK
All	Time/area closures	Area closures trialled in California; effective in reducing bycatch but markedly lowered fishing effort (Wild 1990). Limited closures used in UK (e.g. St. Ives Bay byelaw), but difficult to implement due to unpredictability of birds, prey, and fishery (E. Dunn, pers. obs., In ICES WKBYCS 2013)[9].	Would need better data on bycatch levels at a fine spatial and temporal scale to justify specific fishery closures. Technically simple measure to apply, but politically and socially difficult. Potential to significantly impact target catch. May displace effort to other grounds and have unintended consequences. May be costly to enforce.	3	More data to predict where most effective/practical. Seasonal/spatial component needs significant monitoring to establish pattern.
All	Night Setting	Highly effective in reducing bycatch (non-UK)[1, 2] particularly in calm conditions, when bird-scaring lines may not work as well (Cortés & González-Solís 2018). Evidence that night-setting increases fulmar bycatch in Alaska (Melvin *et al*. 2019).	Easily transferrable, but extent to which this would impact target catch/safety in UK fleets unknown. Not currently recommended for fulmars (until further research has been done) as there is evidence from Alaska that night-setting increases bycatch (Melvin *et al*. 2019). Period of darkness is reduced in northern waters in summer. May not be feasible for static net fisheries.	4	Fisher engagement to assess applicability/ acceptability. Investigation whether fulmars might suffer increased bycatch with night-setting.

[9] http://www.ices.dk/sites/pub/Publication%20Reports/Expert%20Group%20Report/acom/2013/WKBYCS/wkbycs_final_2013.pdf (04/12/19)

Fishery	Mitigation Device	Worldwide Trials to-date	Transferability to UK	Transfer-ability Score	Further Research Required in UK
All	Reducing Deck Lighting	Simple to implement but potential safety issues. Red and green filters used in UK to try to reduce bycatch (M. Hermida, pers. comm.). Unknown how effective this mitigation is.	Easily transferrable but effectiveness is unknown.	5	UK trials in different fisheries to assess efficacy for reducing UK seabird bycatch.
All	Offal Management	Used to some degree already in the offshore demersal longline fleet (M. Hermida, pers. comm.).	Could be transferred to rest of demersal longline fleet very easily (assuming vessel has enough space).	5	Ascertain how widespread this practice is already. Assess efficacy relative to other measures.
All	Safe handling of caught birds	Several guides available on safe handling of caught birds (Zollett & Swimmer 2019), and hook removal if from a longline vessel[10].	Easily transferrable mitigation and proven to reduce mortality (although hard to quantify its relative impact on bycatch reduction as a whole).	5	No trials necessary on implementation but monitoring of frequency of live retrieval – and of survival rates of released birds – would be useful.

[10] https://www.acap.aq/en/documents/working-groups/population-and-conservation-status-working-group/population-and-conservation-status-wg-meeting-1/2086-pcswg1-doc-07-acap-guidelines-on-hook-removal-from-seabirds/file (03/12/19)

Fishery	Mitigation Device	Worldwide Trials to-date	Transferability to UK	Transfer-ability Score	Further Research Required in UK
Demersal Longline	Line weighting – external weights	One of the most proven mitigation measures in demersal longline fleets. Anecdotal evidence of trialling in UK hake fleet, with placing weights closer to hooks to reduce bycatch (M. Hermida, pers comm.).	Uncertainties how transferrable to UK ‘semi-pelagic’ hake longline fishery, but some trials have been undertaken.	3	UK trials to identify best practice in ‘semi-pelagic’ hake fishing gear. RSPB/industry research into simulated sink rate profiles completed; follow-on at-sea trials now required (Rouxel *et al.* in prep.), subject to industry approval and to funding availability.
Demersal Longline	Bird scaring lines	Extensive trials of this very effective method in a range of fleets worldwide. Best practice advice is available for standard demersal longline vessels[1]. Have been issues in other fleets (Glacis *et al.* 2017).	Anecdotal evidence that they do work in UK fleet (M. Hermida, pers. obs.). The extent to which they are effective in ‘piedra bola’ demersal longlines (main issue in UK) is yet to be determined but informal UK trials have been done.	4	Further trials in offshore hake longline fleet: a) Is attachment height sufficient? b) Is the length of the bird-scaring lines sufficient? c) Are there entanglement issues? d) What is the optimal line weighting regime to use alongside?

Fishery	Mitigation Device	Worldwide Trials to-date	Transferability to UK	Transfer-ability Score	Further Research Required in UK
Demersal Longline	Bird Exclusion Device (BED)/Brickle Curtain	Demonstrably effective, in Southern Ocean, at reducing bycatch on hauling, when used in conjunction with other mitigation measures (Brothers *et al.* 1999; Sullivan 2004; Otley *et al.* 2007; Reid *et al.* 2010).	Easily transferrable but unknown how effective in reducing bycatch in UK fleet, due to lack of knowledge of bird behaviour on hauling. May not be technically appropriate for UK gear set-up.	3	a) Desk study to scope potential for UK species/setting b) UK trials to assess efficacy.
Gillnet	Acoustic pingers	Variable success, species dependent. Trialled in US (Puget Sound) on salmon drift gillnet fishery (Melvin *et al.* 1999).	Unknown how transferrable to demersal gillnet fishery. Species-specific results.	1	UK trials (in tandem with marine mammal work) to assess suitability for demersal and mid-water static nets. Trials to explore species-specificity.
Gillnet	White gillnet mesh panels (top of net)	White gillnet mesh panels in the upper portion of the net reduced bycatch of US West coast auks. Only reduced in 50-mesh visual alert nets, not in 20-mesh (Melvin *et al.* 1999).	Applicable only to shallow-set fisheries and may be species-specific	1	Possibly UK trials in shallow-set fisheries due to visibility.

Fishery	Mitigation Device	Worldwide Trials to-date	Transferability to UK	Transfer-ability Score	Further Research Required in UK
Gillnet	Net lights	Green LED trialled in demersal static gillnet in Peru, reduced cormorant bycatch by 85%. However, there was also an anecdotal increase in the number of Peruvian boobies caught (Mangel *et al.* 2018), suggesting potential species-specific effects. Green lights trialled but ineffective for seaduck in Baltic gillnet fishery (Field *et al.* 2019). Increased bycatch of long-tailed duck using white-flashing LEDs.	Contradictory and situation-specific results to-date. Not outside of experimental trial stage. No transferability to UK fleets in current form for this reason.	1	Possibly trials targeted at e.g. cormorant (susceptible to popn. impacts) but highly experimental at this stage. Needs consideration of depth-setting of UK fleet.
Gillnet	Black and white mesh panels (mid-net)	Trialled in Baltic gillnet fishery, where long-tailed ducks and velvet scoter commonly caught (Field *et al.* 2019). No bycatch reduction observed. Field *et al.* (2019) concluded ineffective measure, but unknown whether this result is species-specific OR influenced by turbidity.	Would require further trialling in UK context to establish whether or not this technique works in UK fleet set-up and with UK seabird species.	1	Possibly UK trials in shallow-set fisheries due to visibility. Could examine efficacy in relation to depth and species.
Gillnet	Net colour	Orange coloured monofilament lines resulted in lower collision rates (5.5%), while clear and green monofilament lines resulted in higher rates of collision (35.9% and 30.8%, respectively) (Hanamseth *et al.* 2017). Only trialled in caged experimental conditions with good light and no turbidity.	Would need trialling in situ, in a variety of UK fleets to investigate efficacy over a range of metiers.	1	Possibly UK trials in shallow-set fisheries due to visibility. Could examine efficacy in relation to depth and species.

Fishery	Mitigation Device	Worldwide Trials to-date	Transferability to UK	Transfer-ability Score	Further Research Required in UK
Gillnet	Net Attendance	Very effective mitigation in J-shaped inshore gillnet fishery at Filey Bay, UK (K. Borrow, pers. comm.), although trialled in conjunction with high visibility leader line, so difficult to distinguish which of the two measures most effective.	Transferable to other J-shaped inshore gillnet fisheries with a similar set-up, but very few of these in UK. Safety issues for night net attendance and poor weather conditions.	4	a) Desk study to scope need for wider implementation b) Monitoring in fisheries where deployed to assess efficacy.
Gillnet (J-shaped)	High visibility section of leader line	Potentially effective mitigation in J-shaped inshore gillnet fishery at Filey Bay, UK (K. Borrow, pers. comm.) although trialled in conjunction with net attendance, so difficult to distinguish which of the two measures most effective.	Potentially only suitable in J-shaped inshore gillnet fisheries, of which there are limited numbers in UK.	4	a) Desk study to scope need for wider implementation b) Trials to assess transferability of method
Gillnet	Coloured floats	No scientific trials to-date – but different colours trialled on the floatline at Filey Bay, UK. Varying levels of success (K. Borrow, pers comm.).	Likely variability in success depending on the gillnet set-up in question. Could be trialled in other surface gillnet fisheries, as well as demersal fisheries, depending on the depth the float-line may be set (too deep and turbidity becomes an issue and birds may not be able to see the coloured floats).	1	Further trials on mid-water and demersal gillnets (more typical of UK fleet). However, likely to be limited benefits in deeper waters.

Fishery	Mitigation Device	Worldwide Trials to-date	Transferability to UK	Transfer-ability Score	Further Research Required in UK
Gillnet	Above Water Deterrents	Pilot-trial of a prototype looming-eyes buoy at Filey Bay, UK. Effectiveness demonstrated for long-tailed ducks in Estonia. Further trials by RSPB/BirdLife scheduled in Estonia (Y. Rouxel, pers comm.). Lithuanian and Portuguese BirdLife partners also planning to test "predator shaped" kites attached on buoys. Aiming for similar "scarecrow" effect.	In technical testing phase. Not known how effective in static UK gillnet fisheries for auks.	2	Await further trials scheduled.
Gillnet	Depth restrictions	Trialled in California halibut fishery restricting fishing in top 10–15m depths or more. Effective in reducing seabird bycatch but also reduced target catch (Wild 1990).	Potentially transferrable but unlikely to be adopted if reduced target catch as a result. Success also linked to depth at which bycaught species feed.	2	a) Assess which fisheries would be feasible to adopt in. b) Trials to assess if reduction in bycatch and target catch.
Pelagic Trawl	Safe handling of caught birds	No mitigation trials to-date and little incidences of bycatch in this fleet. Birds mainly caught during haul (gannets) or through disturbance at the surface (guillemots). Unlikely to find suitable mitigation for this fishery, as incidences rare. Not highest priority for mitigation research and trials. Should implement safe handling of caught birds wherever possible, through outreach.	Easily transferrable and applied to UK fleet. Just requires training and out-reach programme.	5	Low priority: bycatch events are rare, so monitoring unlikely to increase knowledge base much. Voluntary self-reporting from this fleet may be useful.

Fishery	Mitigation Device	Worldwide Trials to-date	Transferability to UK	Transfer-ability Score	Further Research Required in UK
Purse-seine	Safe handling of caught birds	Reportedly most bycatch in UK fleet in these gears takes the form of water-logged birds that have been foraging as the net closes in (A. Kingston, pers. obs.). So safe handling and release important.	Easily transferrable and out-reach should ensure that the measure is taken up fleet-wide.	5	**Priority is potential risk to Balearic shearwater off S Cornwall**. Monitor frequency of live retrieval (but unknown mortality rates of live birds caught and released, following safe handling).
Purse-seine	Banging metal on metal	Anecdotal evidence that banging metal on metal as net is closed reduces bycatch (A. Kingston, pers. obs.). No empirical trials on this to-date.	Easily transferrable and out-reach should ensure that the measure is taken up fleet-wide.	4	**Priority is potential risk to Balearic shearwater off S Cornwall**. Assess the extent to which this is an effective mitigation measure in this fleet.

Fishery	Mitigation Device	Worldwide Trials to-date	Transferability to UK	Transfer-ability Score	Further Research Required in UK
Purse-seine	Reduce 'ceiling effect'	Evidence from Chilean purse-seine fleet found reducing the available amount of net at the surface of the water, as the net was being pulled together, reduced the risk to seabirds (Suazo *et al.* 2019).	May be transferrable but needs investigation to establish if method compatible with UK gear set-up.	3	Does not require new gear. Relatively easy to perform but needs investigation (through fisher interviews) as to whether this would work in practice.
Purse-seine	Internal mounting system for the buoy line	Evidence from Chilean purse-seine fleet found internal mounting of buoys (rather than secondary ropes to attach buoys) reduced the risk to seabirds (Suazo *et al.* 2019).	Needs further research to establish if gear set-up the same on UK vessels, and how likely to work with UK species.	3	Does not require new gear. Relatively easy to perform but needs investigation (through fisher interviews) as to whether this would work in practice.

7 Discussion

In summary, evidence from Northridge *et al.* (2020) suggests that the UK fisheries that would be the highest priority for targeted seabird bycatch mitigation measures, due to current indicative levels of bycatch, are the **northern UK offshore demersal longline fleet** (*c.* 2,500–9,000) individuals per annum across five species) and the **< 10 m set gillnet fleet** (*c.* 2,000–4,000 individuals per annum across nine species). These fisheries have the highest numbers of seabird bycatch, as represented by the observer data currently available.

The species of primary concern are fulmar (longlines, which are estimated to kill sufficient numbers to possibly cause population-level impacts (Miles *et al.* 2020)), but also **guillemot** (static nets, due to the large numbers estimated caught, although unlikely to cause substantial population impacts (Miles *et al.* 2020)) and **cormorant** (static nets, where the number caught is relatively low but nonetheless could cause population-level impacts, though not as large as predicted for fulmar (Miles *et al.* 2020)). Moreover, non-UK vessel effort is not accounted for in these numbers, so bycatch levels are likely to be substantially higher in UK waters, especially in the demersal longline fleet, which has a higher proportion of non-UK vessels (P. Arcos, SEO/Birdlife, pers. comm.).

The UK's most threatened seabird – the Critically Endangered Balearic shearwater – has not to date been recorded as bycatch in UK fleets but is potentially susceptible in purse-seine fisheries around SW England. Existing observer programmes could in future ensure some coverage of relevant metiers, like purse seines, and that observers are primed to record bycatch if they see it. However, it is important to note that sampling, within the fisheries that are monitored, is limited and patchy and while our conclusions are drawn from the best available evidence, this evidence has considerable limitations. Hence these conclusions are only preliminary.

The most applicable and widely researched mitigation advice for demersal **longliners** comes from the Agreement for the Conservation of Albatrosses and Petrels (ACAP) best practice guidelines[1], recognising that in most cases these are derived from studies outside the UK so require verification in this setting. These guidelines are globally recognised and constitute the best examples of fisheries management practices to reduce seabird bycatch. Relatively easy and cheap mitigation measures to adopt (i.e. require little gear modification) are **night-setting** (where practical and noting the evidence from Alaska given by Melvin *et al.* 2019 that this might actually increase bycatch of fulmar, so may not be appropriate in a UK setting – requires further investigation and research) and **offal management**. However, potentially the most effective mitigation measures are adequate **line weighting** and appropriately designed **bird-scaring lines**. These need further work to ensure they are properly designed and implemented for the UK demersal hake longline fleet, which uses the 'piedra bola' lofted line gear type. Some vessels in this fishery already employ certain mitigation measures and, in collaboration with the RSPB, have recently undertaken a pilot study on line weighting (M. Hermida, Hooktone, pers. obs.; Y. Rouxel, in prep.) – see Section 3.1 for details.

The UK static net fisheries are much more difficult to prescribe 'quick fix' mitigation measures for, and while total number of birds killed by UK fisheries are estimated to be around half those from longlines (Northridge *et al.* 2020), cormorants in particular could be at risk of population level impacts from static nets (though to a lesser degree than for fulmar bycatch in longline fisheries), even though the estimated numbers of guillemots bycaught is higher (see Miles *et al.* 2020). So far there are no widely applicable seabird bycatch mitigation measures available for gillnets. Net illumination and acoustic pingers have had variable results and indicate some level of species-specificity in their effectiveness. In fact, some types of net illumination appeared to increase bycatch of some species. Some UK trials have indicated the efficacy of high visibility netting, but this was in a very specific type of fishery, which used J-shape nets (Filey Bay), and so may have limited transferability to larger static net fisheries (although see Hanamseth *et al.* 2017). Also, some of the above options may not be suitable for demersal gillnet fisheries, due to depth/visibility issues. The extent and complexity of the UK gillnet fleet makes mitigating the impacts of seabird bycatch very challenging, as no one mitigation measure is likely to work in all scenarios.

Experimental trials of technical mitigation measures are required as a matter of priority for (and in) UK gillnet fleets. Non-technical mitigation measures, such as time/area closures and net attendance, could be advised in the interim, but these come with caveats and limitations. For example, time/area closures need research to identify where and what might be appropriate to close and come with associated challenges of industry acceptability, enforcement and monitoring. They can lead to displacement of fishing effort to other areas (thereby leading to unintended consequences), so require their own assessments before being applied. Net attendance was thought to be an effective mitigation measure at Filey Bay but may not always be practical in larger offshore gillnet net fisheries. Restricting the depth at which nets can be set (i.e. not in the top tens of metres, or within the effective diving depth of bycaught species) is a further possibility, but may be impractical due to reduced target catch rates (which may be dependent on net setting near the surface).

For the other fisheries, where some level of bycatch has been reported, (e.g. mid-water trawls and – less well documented – purse seiners and demersal trawls), further and perhaps increased monitoring/expansion of geographical scope of bycatch sampling would be appropriate at this stage, rather than mitigation measures. In particular, establishing the bycatch risk to endangered species such as Balearic shearwater, which to-date has not been recorded as bycatch in the UK, is a priority.

There are two principle biological elements to consider when identifying priorities for reducing seabird bycatch in UK fleets; welfare impacts and population impacts. **Fulmars** in the demersal longline fleet and **guillemots** in the static gillnet fleet are examples of species that fall under the ‘welfare’ category, as it becomes a welfare issue when large numbers of birds are potentially being killed[11]. But there are also instances where bycatch levels could impact species at a population level (i.e. where bycatch is potentially removing enough individuals to alter population trajectories). **Fulmars** in the demersal longline fleet and **cormorants** in the static gillnet fleet are examples of species that fall into this category, with bycatch causing a median estimated UK population suppression of *c*. 7% and *c*. 2% over 25 years, respectively (Miles *et al.* 2020). The balance of welfare issues and possible population impacts should also be borne in mind when determining where to target mitigation efforts.

8 Recommendations

Given finite resources to implement any potential mitigation measures in UK fisheries, it would seem sensible to identify, using the best available information, those gear types and areas where mitigation might have the greatest impact in reducing bycatch levels (both in terms of numbers of birds bycaught and in terms of population impacts). However, it is important to acknowledge the data gaps and relatively limited nature of monitoring that these priorities are based upon. We await the results of a study on “UK seabird bycatch hotspots” (Northridge *et al.* in prep.), which analyses the results of Northridge *et al.* 2020 in further detail. Additionally, we anticipate a study in the near future on data gaps and areas for improvements under the UK Bycatch Monitoring Programme (which will hopefully also

[11] See FAO Code of Conduct for Responsible Fisheries, which stipulates that States should take appropriate measures to minimise bycatch (http://www.fao.org/3/v9878e/V9878E.pdf) (11/03/20)

consider other schemes operating in the UK). Notwithstanding the above, based on existing information, the following preliminary priorities are identified.

a) Priority gear types

The UK fishery with the greatest estimated numbers of birds accidentally caught is the northern offshore demersal longline fleet, particularly for fulmar, where bycatch rates are higher than further south (Northridge *et al.* 2020). Furthermore, Miles *et al.* (2020) predict the greatest potential population benefits of future mitigation would be experienced by fulmar. The second largest bycatch component (in terms of individual seabirds) is from the static gillnet fishery (particularly the < 10 m fleet) which, while catching large numbers of auks (particularly guillemot), may actually be more of a problem -at a population level - for cormorants (Miles *et al.* 2020). It is recommended that these two gear types be treated as priorities in any efforts to reduce seabird bycatch.

b) Priority regions

For the demersal longline fleet (in particular to reduce fulmar bycatch): focal areas should be the regions off the north-west of Scotland and off the Shetland Islands, as this is where the majority of fulmar bycatch appears to occur (Northridge *et al.* 2020) and where greatest population benefits of potential mitigation may be realised (Miles *et al.* 2020).

Static gillnets (in particular to reduce cormorant bycatch): the southern coast of Devon and Cornwall and the north-east coast of England would appear to be high priority areas where bycatch is predominant (see Northridge *et al.* 2020). However, Northridge *et al.* (in prep.) notes that winter fishing effort is high off the south-east coast of England as well, and that more focused monitoring there might highlight additional bycatch previously unrecorded.

c) Priorities for further research

Given ACAP best practice guidelines recommend line weighting and BSL as top mitigation measures for demersal longliners, and section A highlights this as a priority fleet, we would advise that optimal configurations for these measures are developed - through experimental trials - specific to the particularities of the UK demersal longline fleet (which use the ‘piedra bola’ system). Additionally, that the efficacy of night-setting and offal management are further investigated - along with the practicalities of these methods being implemented.

Mitigation measures for static net fisheries are less well developed, but given initial indications of existing research, it would seem reasonable to explore acoustic pingers, net illumination and different net meshes/colours and above-water deterrents in an experimental trial setting, and across a range of different metiers within this fishery class. If (as is likely) funding for such trials is limited, opportunities to “piggy-back” off existing experimental trials for other protected marine species (e.g. cetaceans) might be explored.

The above should build upon the work already done by the fishing industry in parts of the UK longline fisheries (M. Hermida, Hooktone, pers. obs.; Rouxel in prep.) and fixed net fisheries (K. Borrow, pers. comm.; Quayle 2015).

d) Mitigation measures that can be applied now

Mitigation measures that can be applied with little further research (i.e. because they are relatively simply implemented and can only positively influence the extent of bycatch) are: safe handling of live-caught birds (see Section 2.6), as this increases the likelihood of birds surviving a bycatch encounter, and offal management (see Section 2.4), as this reduces the likelihood of many birds being present around the danger zone of fishing gear (in trawl, longline or static nets).

e) Industry implications

Of fundamental importance to the success of any future trials or development of existing methods for mitigation is the extent to which they can be introduced in a way that maximises benefits for the fishing industry (and to skippers and crew) or at least minimises negative consequences to an acceptable level. This includes considerations of impact on catches of target species and costs/logistics of introducing gear modifications and alterations to fishing operations (which are all outside the scope of this report). Therefore, we recommend the initiation of a study of these matters be undertaken alongside the above recommendations.

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