Review of Bycatch Mitigation Measures

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Executive summary

This report provides a summary of past and present mitigation measures applicable to the CIBBRiNA case studies, tested in different fishing gears and regions, and promising future directions for research and optimization. As the aim of this report is to provide a source of information for the case studies within the case studies of the project, the presented mitigation measures were assessed based on their effectiveness for different species of interest within the range of each respective CIBBRiNA case study and socioeconomic feasibility. It is evident that different case studies, i.e., fishing gears used in marine regions of the Northeastern Atlantic, require distinct solutions to address bycatch. In addition, the same measure may be effective in mitigating bycatch for one species but not for others within the same case study. Therefore, the most promising approach to bycatch mitigation may be the combination of different measures to protect a broader spectrum of Endangered, Threatened and Protected (ETP) species. While we hope to provide an extensive overview of available mitigation measures, we are not endorsing or recommending the use of one over another and recommend thorough involvement of the fishing sector in question and other stakeholders along with testing of the methods before applying them on a larger scale.

Additionally, mitigation measures should not significantly decrease target catch efficiency or if they do, fishers need to be compensated for their loss in revenue to ensure continued job security and stakeholder active participation. Overall, stakeholder buy-in is a major factor affecting the efficacy of bycatch mitigation measures, and likely responsible for the observed difference in mitigation measure efficacy between scientific studies and implementations in commercial fishery. There is evidence that the involvement of stakeholders in the process of determining, developing and implementing potential mitigation measures can help with post-implementation involvement and increase efficacy. Collaboration requires continuous effort, which is why CIBBRiNA pursues a "Safe Working Environment" characterised by mutual trust and respect for different perspectives. CIBBRiNA developed cooperation principles and best practice guidelines supporting collaboration within case studies and beyond. It should be acknowledged that testing and optimizing mitigation tools depends on collaboration with the fishers at sea, which involves time and effort.

Gillnets pose a high bycatch risk to marine mammals, turtles, seabirds and some elasmobranch species. Different case studies (Northern, Southern and UK gillnets) focus on different ETP species. Regardless of the case study, switching from gillnets to alternative fishing gear with lower bycatch risk has been proposed, especially using pots or traps could reduce bycatch. However, a major point for critique has been the reduction in target catches. Furthermore, stakeholders may be reluctant to learn new fishing techniques and may have to modify vessels and apply for additional/alternative licences.

Currently, the most used bycatch mitigation measure for small cetaceans in gillnets are acoustic deterrent devices (ADD), commonly referred to as “pingers”. Pingers have been shown effective in minimizing bycatch of harbour porpoises and partially successful deterrence of other species such as bottlenose dolphins, short-beaked common dolphins, Franciscana dolphins and striped dolphins. However, potential negative impacts such as habituation, habitat exclusion and reduced fitness have been hypothesized or observed and can render pinger-use ineffective in the long-term. ADDs have not been tested sufficiently for other ETP species or groups apart from marine mammals but preliminary studies suggest a

potential for acoustic deterrence for turtles and some species of sharks. Alternative approaches are increased net visibility, either acoustically or visually. For echolocating cetaceans, adding acrylic beads to the gillnet (PearlNet) shows promising first results in reducing harbour porpoise bycatch while maintaining target catch rates. Coloured or thickened twine of either top or bottom parts of the net have shown to reduce bird and some cetacean bycatch, however, research in other areas or regions is needed to test wider applicability. Similarly, LED lights attached to the net have shown to reduce turtle, seabird, as well as cetacean bycatch in Peru, Ghana and Cyprus. However, studies from the Baltic Sea and Iceland showed the opposite trend for some species of seabirds suggesting species or group-specific effects.

Pelagic trawl fisheries occasionally have bycatch of marine mammals, turtles, and sharks. The most studied bycatch mitigation measure for trawl fisheries is excluder devices (EDs) which consist of a grid structure just prior to the codend of the net and an escape opening at either the top or bottom of the net. The grid functions as a semi-permeable barrier keeping large megafauna and debris from entering the codend and instead being expelled through the escape opening (either actively or passively). Many different configurations of EDs have been tested and the most efficient configuration depends on the target species of the fishery, the main ETP species-of-interest and fishing vessel characteristics. EDs have been successfully implemented in some commercial fisheries in Australia, New Zealand, the USA and EU. Successful exclusion of dolphins and porpoises, seals and sea lions, large sharks and turtles has been shown, both, in scientific trials and commercial settings. Potential issues with EDs are loss of target species catch via escapement through the escape opening or clogging of the grid and studies show mixed results regarding this issue. Depending on the target species of the trawl, EDs can provide affordable and effective bycatch mitigation for several ETP species and taxa if the configuration is optimized for the specific vessel/métier.

Several other mitigation options have been tested, such as entrance barriers, pingers, post-capture release, operational adaptations and lights. However, most of these are either still in the testing phase, have proven ineffective, shown inconclusive results or require severe changes for the stakeholders, which will likely cause slow uptake or resistance to its use. Technological advancements in AI might further help with developments of bycatch mitigation tools via real-time monitoring of the codend or net entry.

Demersal trawl fisheries can have bycatch of demersal sharks and rays. Similarly to pelagic trawls, EDs have been tested and implemented in demersal trawls allowing the escape of non-target species from the trawl net. However, the loss of target species may be greater in demersal trawl fisheries than in pelagic trawl fisheries with reported values between 5 – 37%. Additionally, in mixed fisheries, the separation of ETP species and similar sized commercially valuable species poses a major challenge. Other potential mitigation measures tests are the use of a modular harvesting system, the use of magnetic or electric deterrents, removing the “tickler chain” and conscious post-capture handling of bycaught ETP species, however, none of these individually will eliminate bycatch.

Pelagic longlines attract ETP species such as sharks, dolphins and turtles who can get bycaught while depredating. Potential alternative gear includes so-called “trap-lines”, a new fishing gear that can be operated with the same technology and infrastructure as normal longlines but with reduced bycatch, and Deep-Set Buoy Gear (DSBG).

Alternative hook shapes have been assessed to reduce bycatch of turtles and elasmobranchs and reduce mortality in longline fisheries. Use of circle hooks does not necessarily result in decreased bycatch *per se* but it is thought to reduce the mortality of bycaught animals after release/escape. Nevertheless, some conflicting results have been obtained, indicating that circle hooks may reduce turtle bycatch and mortality but for elasmobranchs, results are highly variable and species-specific. Other trials have assessed hook depth, indicating that if lines are set in a region- and species-specific depth can help reduce bycatch if paired with circle hooks. Alternative leader materials could further aid shark escapement potentially reducing mortality. Changes of bait types could reduce some bycatch but seem species-specific, i.e., fish bait instead of squid bait has been shown to reduce turtle bycatch but increases shark bycatch. Some ongoing efforts are directed at sensory deterrents for elasmobranchs, aiming to deter them by using magnetic or electropositive materials or electric currents. To date, no solution has been found that reduces both turtle and elasmobranch bycatch, nor one that reduces general depredation.

Demersal longlines are in many ways similar to surface longlines regarding their bycatch issue. Elasmobranchs, turtles and some cetaceans depredate on the bait used in longline fishing and often get caught in the process.
As for circle hooks, results are similar to surface longlines with species-specific outcomes and potentially reduced mortality but not necessarily reduced bycatch. Magnetic hooks have been deemed economically unviable due to their short lifespan but the replacement of wire leaders for nylon leaders shows promising first results. As for all case studies, changes in fishing practices such as different fishing depths or reduced soaking time could help reduce bycatch as well with only limited effects on target catch. Few studies have assessed the use of pingers as cetacean deterrent in longline fisheries to no avail.

In addition to the case study specific examples mentioned above, there are few measures that could be applied to most case studies as they are very general in nature: i) Time-area closures, ii) Bycatch quota, iii) Economic compensation.

Time-area closures can be either temporal or full time depending on the importance and usage of the area by the ETP species of interest. Generally, however, it is assumed that these “static closures” are only successful for species with high site fidelity while highly mobile species would be better protected using dynamic closures. These, however, require real-time monitoring of environmental parameters, substantial knowledge of the ETP species’ behaviour and biology, excellent real-time communication with stakeholders and good enforcement capabilities.

Bycatch quotas could help reduce bycatch in all fishing *métiers* by allowing stakeholders to decide themselves how to reduce bycatch in their specific situation to avoid fishing closures. Potential mitigation measures could be switching to alternative gears, avoiding known areas with high bycatch risk or adapting operational factors such as fishing depth, soaking time *et cetera*. Leaving a certain flexibility in the choice of mitigation measures to the stakeholders may help with future active participation. Given that under-reporting of bycatch is a known issue in logbook records, regular and high observer coverage and/or remote electronic monitoring (REM) would be needed to monitor bycatch.

Economic compensations are not a bycatch management tool *per se* but could help with the motivation and willingness of stakeholders to adhere to implemented bycatch mitigation measures by compensating for potential economic losses due to reduced target catch. Compensations could pose a considerable financial burden to the country’s economy and depends on the country’s wealth status. Clear rules would have to be established about the mechanism by which compensation payments are triggered, and the amounts involved.

Despite bycatch being a global problem with critical impact on the ecosystem and extensive research efforts in bycatch mitigation, the issue persists in global fisheries. Nevertheless, different fishing gears, regions and ETP species require different mitigation tools and a “one-fits-all" approach for bycatch mitigation seems highly unlikely. Therefore, international collaboration and stakeholder involvement along with technological advancements are crucial in solving this global problem successfully.

Background to the CIBBRiNA project

The Coordinated Development and Implementation of Best Practice in Bycatch Reduction in the North Atlantic, Baltic and Mediterranean Regions (CIBBRiNA) project aims to minimise the bycatch of Endangered, Threatened and Protected (ETP) species in the North-East Atlantic, Baltic, and Mediterranean seas, working collaboratively as fishers, authorities, scientists, and other relevant stakeholders to achieve this. The species that we focus on include a variety of marine mammals, sea birds, sea turtles, and elasmobranchs (sharks, skates, and rays).

Through cross-border and cross-sectoral collaboration involving stakeholders from 13 European countries, CIBBRiNA is establishing mitigation, monitoring, and assessment programmes in a selection of fisheries with a higher risk of bycatch. Within a proactively fostered “Safe Working Environment”, characterised by mutual trust and respect, safety and cooperation, we aim to build on current approaches and learning from our Case Study fisheries to deliver an innovative toolbox designed to be integrated into policy and best practice in European fisheries management.

CIBBRiNA is funded by the EU’s LIFE programme and runs from 2023 to 2029.

Contents

List of Abbreviations

ACAP	Agreement on the Conservation of Albatrosses and Petrels
ActSel	Active Selection
ADD	Acoustic Deterrent Device
AHD	Acoustic Harassment Device
AI	Artificial Intelligence
ASUR	L'Agora Sciences Université Recherche
BFT	Bluefin tuna catch
BPUE	Bycatch per unit effort
BRD	Bycatch Reduction Device
BSL	Bird Streamer Line(s)
CCTV	Close-circuit Television
cm	Centimetre
CMS	Convention on Migratory Species
CPUE	Catch per unit effort
dB	Decibel
DDD	Dolphin Dissuasive Device
DSBG	Deep-set buoy gear
ED	Excluder Device
EEZ	Economic Exclusive Zone
EFCA	European Fisheries Control Agency
ESA	Endangered Species Act (USA)
ETP	Endangered, threatened and protected species, i.e., marine megafauna such as marine mammals, turtles, elasmobranchs
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GPS	Global Positioning System
ICES	International Council for the Exploration of the Seas
ILVO	Flanders Research Institute for Agriculture, Fisheries and Food (Belgium)
IMAR	Instituto do Mar (Portugal)
ITQ	Individual Transferable Quota(s)
kHz	Kilohertz
LED	Light-emitting Diode
LSF	Large-scale fishery
m	Metre
MSC	Marine Stewardship Council
NGO	Non-governmental organization
NOAA	National Oceanic and Atmospheric Association
NSAC	National Sustainable Agriculture Coalition (USA)
PAL	Porpoise Alert

PCH	Post-capture handling
PCR	Post-capture release
PIER	Pfleger Institute of Environmental Research
PMMA	Polymethyl methacrylate
PRS	Post-release survival
REM	Remote electronic monitoring
RFMO	Regional Fisheries Management Organization
SED	Seal Excluder Device
SepNep	Separation panel for Nephrops
SLED	Sea lion Excluder Device
sPAT	Satellite Pop-up Archival Transmitting (tag)
SSF	Small-scale fishery
TED	Turtle Excluder Device
TMR	Technical Measures Regulation
UK	United Kingdom
USA	United States of America
UUV	Underwater Unmanned Vehicle
VMS	Vessel Monitoring System
WGBYC	Working Group on Bycatch of Protected Species (within ICES)
WP	Work package

1. Introduction

1.1. Purpose and objectives

The present report is a summary of the available knowledge on past and current mitigation measures relevant for the specific case studies addressed within the LIFE CIBBRiNA project. The CIBBRiNA case studies focus on four main fisheries in the North-East Atlantic (gillnet, longline, pelagic trawl and bottom trawl) targeting specific fish stocks with associated endangered, threatened, and protected (ETP) species or groups of concern with the aim to test mitigation measure(s) appropriate for the fishery and ETP species/group.

There are eight specific case studies addressed in the CIBBRiNA project:

1. Northern small-to-large scale gillnet fishery (Icelandic and Norwegian waters, and Baltic Sea)
    - Target species: demersal species (e.g., cod, turbot, flatfish, lumpsucker), perch, pikeperch and white fish.
    - ETP species of concern: grey seal, harbour porpoise, common dolphin, eider duck, greater scaup, velvet scoter, razorbill, and red-necked grebe.
    - Mitigation measure(s) tested: alternative gears, pingers, acrylic pearls, spatial and temporal analysis of seabird bycatch.
2. Southern medium-to-small scale gillnet fishery (Spanish waters incl. Galicia and the Western Mediterranean.)
    - Target species: hake, sea bass, sole, crustaceans, anglerfish and rays.
    - ETP species of concern: Iberian harbour porpoise, common dolphin, spiny dogfish, blue or common skate and basking shark.
    - Mitigation measure(s) tested (incl. depredation): pingers, acrylic pearls, LED lights, other potential gear alternatives, and potential spatial/temporal measures.
3. Deepwater, medium-to-small scale gillnet fishery (UK waters)
    - Target species: hake, monkfish, pollack and other demersal species.
    - ETP species of concern: common dolphin, harbour porpoise, blue or common skate, porbeagle and razorbill.
    - Mitigation measure(s) tested: pingers, electromagnetic fields, net modifications, hydrophones and 3D tracking systems to study cetacean behaviour.
4. Deepwater bottom, drifting or set longline fishery (Portuguese waters incl. Madeira and Azores)
    - Target species: black scabbardfish and demersal fish.
    - ETP species of concern: green turtle, loggerhead turtle, Portuguese dogfish, leafscale gulper shark, and gulper shark.
    - Mitigation measure(s) tested (incl. depredation): magnetic hooks; pingers.
5. Seasonal, small-scale surface longline fishery (Madeira waters)
    - Target species: swordfish, bluefin tuna and bigeye tuna.
    - ETP species/group of concern: manta rays, porbeagle, spiny dogfish, sand tiger shark, devil fish, blue shark, shortfin mako and tope shark, bottlenose dolphin, common dolphin and loggerhead turtle.
    - Mitigation measure(s) tested: magnetic hook, pingers, tags to be placed on bycaught ETP species to analyse survival rates after release.
6. Small scale, longline fishery (waters surrounding the east and west of Shetland in the UK and southwest of Ireland)
    - Target species: hake and to lesser extend ling.
    - ETP species of concern: Balearic shearwater, Portuguese dogfish, leafscale gulper shark and tope shark.

- Mitigation measure(s) tested: focus on improving existing bird scaring lines and optimizing different mitigation approaches through the collaboration with fishing industry.

7. Large scale, pelagic trawl fishery (Celtic Seas and Greater North Sea ecoregions)
    - Target species: herring, mackerel, horse mackerel, sandeel and blue whiting.
    - ETP species of concern: grey seal, harbour seal, harbour porpoise, common thresher shark, basking shark and porbeagle shark.
    - Mitigation measure(s) tested: escape panels, excluder devices, pingers.
8. Large scale, demersal trawl fishery (incl. twin rig, beam trawl and seine in the Greater North Sea ecoregion)
    - Target species: demersal mixed fisheries
    - ETP species of concern: starry ray, cuckoo ray, common blue skate, flapper skate, white skate, angelshark, spiny dogfish and tope shark.
    - Mitigation measure(s) tested: electronic monitoring (EM), handling and release.

This report was created with the aim to inform the LIFE CIBBRiNA case study partners (WP7) on all successful and unsuccessful attempts in developing and testing of the existing mitigation measures for a range of ETP marine species. In addition, the information provided here is the first step towards a database collating information and experience in applying different mitigation measures across global commercial fisheries. The database will ultimately feed into an online support tool or mitigation toolkit (to be delivered in M72) informing the fishers, fishing industry, management, relevant non-governmental institutions (NGOs), and decision-makers about potential mitigation measures suitable for specific fishing gear types, target species and ETP species of concern.

The report contains a detailed analysis of trialled and/or implemented bycatch mitigation measures with an overview of their respective advantages and disadvantages. Each mitigation method is addressed within the context of a relevant fishery and, whenever possible, presented considering its effectiveness, practicality, and socio-economic implications with special consideration to wide acceptability by fishers and consistency with current legislation.

The research and the collection of information performed for the current report were conducted through:

a) systematic literature search using Google Scholar, Web of Science and Scopus search engines;
b) literature collected for projects and tools such as UK Clean Catch;
c) the knowledge and experience of project partners as well as other research collaborators.

It is important to note while this report aims to present an extensive overview, it does not endorse any specific measure. Instead, while aiming to fully evaluate the advantages and disadvantages of each measure, it emphasizes the importance of the active participation of stakeholders and the need for thorough testing before large-scale implementation.

The following two chapters are dedicated to addressing each CIBBRiNA case study separately (Chapter 2) as well as presenting an overview of widely applied mitigation measures (Chapter 3). In Chapter 2, each case study is described and relevant mitigation measures are presented from those most frequently tested or used in commercial fishery towards measures less tested/used up to alternative strategies as well as novel mitigation measures that are in early development stages. In Chapter 3, a comprehensive overview is given of the mitigation measures that can be widely applied across different fisheries (incl. métier) and ETP species of group(s) of concern. Each mitigation measure is presented from a broad view as well as from the aspect of European fisheries. Additionally, certain legal aspects and stakeholder involvement are discussed with respect to co-development and active participation of stakeholders as an inclusive approach to bycatch mitigation.

2. Case studies

2.1. Northern, Southern, and UK Gillnets (CIBBRiNA case studies 1-3)

Case study 1 (Northern gillnets) composes of small-scale gillnet fisheries - like those in the **North Sea, Skagerrak and Kattegat** – that are often operated single-handed with vessels smaller than 10 m in length, targeting multiple demersal fish species such as cod, turbot, flatfish, and lumpsucker; **Baltic** gillnet fisheries also target perch, pike perch, and white fish. The case study also includes **Icelandic** and **Norwegian** gillnetters that range from small vessels (< 10 m) doing day trips to larger vessels (≥ 25 m) that fish for multiple days. In this case study, the main bycatch species is harbour porpoise, but also seals, dolphins, ducks, and alcid seabirds.

Case study 2, the southern gillnet case study, focuses on small-scale gillnet fisheries in **Spanish** waters including Galicia (Atlantic coast) and the Western Mediterranean. Bycatch species of interest in the southern gillnet case study are harbour porpoise (*Phocoena phocoena*), short-beaked common dolphin *(Delphinus delphis)*, common bottlenose dolphin (*Tursiops truncatus*), basking shark, demersal sharks, and deep-water rays.

Case study 3 (**UK** net fisheries) use a variety of gill, entangling and trammel net types to target a diverse range of species in inshore and offshore waters, including anglerfish, hake, flatfish, gadoids, ray and crustaceans. Vessels range from 5m to 40m in length and undertake trips ranging from a few hours to several weeks. Bycatch species of interest are cetaceans (e.g., harbour porpoise, common dolphin), seabirds (mainly Alcidae and Phalacrocoracidae) and elasmobranchs (e.g., common skate, deepwater sharks etc.).

The text here below provides an overview of possible mitigation measures for these three case studies.

Mitigation measures

Pingers

General

In scientific literature, pingers are often classified depending on their output signal and/or target species. Mostly, they are referred to “acoustic deterrent devices” (ADD) if the signal is of low intensity (less than 150 dB; Dawson et al. 2013; IAMMWG et al. 2015). If the device emits a higher intensity signal (i.e., more than 185 dB), it can cause pain or discomfort in the animals’ hearing system and is referred to as an “acoustic harassment device” (AHD) (Dawson et al. 2013; IAMMWG et al. 2015). Some type of pingers, such as the “Porpoise ALert (PAL)” device, emit an artificial or recorded communication signal (usually a distress sound) from a conspecific. For the scope of this report, we refer to all types of (acoustic) signal emitting devices aiming to reduce interactions between marine megafauna and fisheries equipment as “pingers”. For a detailed overview of successfully tested pingers and their respective signal properties, see Table 1.

Traditional pingers aim to modify the behaviour of porpoises by emitting loud acoustic signals, which are believed to be generally aversive stimuli and act to displace animals from the vicinity of the gillnets. Pingers have been shown to be successful in reducing bycatch of porpoises in numerous studies (Dawson et al. 2013 and references therein) and are now implemented in several fisheries in both European countries and in the U.S. There are different types of pingers emitting sounds at various frequencies, some audible to seals, i.e., pingers with frequencies lower than 60 kHz. This can cause increased depredation by seals, especially in the Baltic and other regions with large and increasing seal populations where there are increased severe interactions between seals and small-scale fisheries. Increased presence of seals around gillnets can also increase their bycatch.

Pingers were tested early on as depredation mitigation tools in aquaculture, to protect the fish and net structures from pinnipeds (Mate & Harvey 1986). Yet, decades later, scientists and the fishing industry are still trying to address concerns and existing issues about the use of pingers and its efficacy in reducing bycatch of ETP species. Pingers have been hypothesized to act as "dinner bells" for pinnipeds and potentially bottlenose dolphins in some cases (Richardson et al. 1995 as cited in Cox et al. 2003; Mate & Harvey 1986). Some studies have found a significant increase in pinniped depredation rates when using pingers in gillnets (Bordino et al. 2002; Carretta & Barlow 2011). However, Carretta and Barlow (2011) attributed the increase rather to confounding environmental factors and not to the pingers themselves. Thus, more research is needed to definitively rule out the potential for attracting pinnipeds or even other dolphin species while deterring odontocetes with the use of pingers. Additionally, the use of high frequency pingers could prevent any potential of attracting pinnipeds as their proposed hearing capabilities peak in the lower frequency spectrum (<40 kHz for phocids; Kastelein et al. 2009; Ridgway & Joyce 1975). However, high frequency pingers may still be audible to pinnipeds at higher sound pressure levels (> 100 dB), although it is unlikely that pinnipeds would be able to perceive these signals over long distances to act as a dinner bell, especially given ambient noise levels underwater (Königson et al. 2021). The range between 60 and 80 kHz has been proposed as a potential cut-off point between pinnipeds and odontocetes due to poor hearing below this threshold for phocids and good hearing for odontocetes like harbour porpoises (Richardson et al. 1995 as cited in Königson et al. 2021). When considering the use of pingers in a given fishery and region, the presence of pinnipeds and previous history of depredation events should be considered and accounted for in studies.

Another potential way of avoiding the "dinner bell" effect of pingers is by using interactive pingers, which activate only when the device detects odontocete echolocation clicks (Ceciarini et al. 2023; Marçalo et al. 2025). This type of pinger would also generally reduce the noise pollution of pingers, which could be considerable given a fleet-wide implementation of pingers. More trials with interactive pingers are needed to test for their effectiveness in reducing bycatch of dolphins and porpoises. Especially in trawl fishing, the ambient noise levels of the vessel and the trawling activity might mask the dolphin echolocation signals received by the device and hence, fail to activate the pinger. In addition, results obtained by Marçalo et al. (2025) indicate that bottlenose dolphins could still habituate to the pinger despite the interactive sound propagation, which was initially designed to avoid exactly that.

Another potential adverse effect of pingers is habituation. Several studies testing pingers in gillnet fisheries have found potential indicators for habituation in odontocetes, meaning that the aversive effect of the pinger decreases over time and animals return to their old behaviours after repeated exposure to the stimulus. Interestingly, not only neophilic species such as bottlenose dolphins have been found to habituate (Marçalo et al. 2025) but also porpoises (Amano et al. 2017; Cox et al. 2001; Carlström et al. 2009; Kyhn et al. 2015) and harbour seals (Bowles & Anderson 2012). Efforts to reduce the potential for habituation have resulted in pingers that emit different signals at random intervals instead of a single signal at fixed intervals. The "Porpoise Alerting Device (PAL)" emits a recording of a porpoise signal obtained from captive porpoises which so far have not been tested for habituation and their effectiveness to reduce bycatch appears variable (see Culik et al. 2015; Chladek et al. 2020; Sigurðsson & Jusufovski [*submitted*]). A prototype pinger designed by the Loughborough University in England ("LU-1) emitted eight different signals at different frequencies and random signal intervals. The LU-1 prototype pinger led to the development of the AQUAmark

100 device by Aquatec Group Ltd. after the initial trials reported by Larsen & Eigaard (2014) which resulted in the successful mitigation of harbour porpoise bycatch in gillnets. Kindt-Larsen et al. (2019) tested this version of the AQUAmark series against the AQUAmark 300 model, which emits only one type of signal at fixed intervals, and found that the former seemed to prevent habituation while the latter did not.

It is difficult to address habituation in the wild. Ideally, long-term studies would have to track individuals' encounters with pingers to test whether the same individuals were repeatedly exposed to pingers and show reduced reactions to the signals over time (Kindt-Larsen et al. 2019). Indirectly, habituation would be assumed if bycatch or depredation levels within the same area and fishery increased again after an initial drop just after the implementation of pingers. However, in long-term studies it is difficult to distinguish between seasonal or between-year variations in species abundance (and thus seasonal increases in bycatch and/or depredation) and habituation unless passive acoustic monitoring (or other methods) can exclude the possibility of increased abundance.

In addition to reducing bycatch of harbour porpoises, studies have demonstrated significant reductions in bycatch for other cetacean species such as common dolphins (*Delphinus delphis*), striped dolphins (*Stenella coeruleoalba*) and franciscana dolphins (*Pontoporia blainvillei*) (Dawson et al. 2013). For example, Bordino et al. (2002) showed that pingers reduced franciscana dolphin bycatch in coastal gillnet fisheries off Brazil. However, effectiveness varies by species; bottlenose dolphins (*Tursiops truncatus*) have shown limited behavioural response to pingers and, in some cases, individuals were observed depredating nets equipped with pingers, suggesting a “dinner bell” effect. Trials with finless porpoises (*Neophocaena asiaeorientalis*) in Japan revealed initial avoidance behaviour, but effectiveness declined over time due to habituation (Amano et al. 2017). Habituation has also been reported or suspected in various other pinger trials.

Table 1. Examples of trials testing the effectiveness of pingers to reduce porpoise bycatch with regards to area, brand, sound specifications, spacing, reduction effect, and trial location. Sources for the information are included.

Brand	Source level (dB, 1 µPa @1m)	Pinger spacing (m)	Bycatch reduction (%)	Location	Reference
Netmark1000	105-139	92	89	Gulf of Maine	Kraus et al. 1997
Netmark1000	105-139	92	100	Massachusetts	Kraus & Brault 1999
Lien	122-125	17	88	Washington state	Gearin et al. 2000
Lien	122-125	9-12	79	Bay of Fundy	Richter et al. 1999
Netmark1000	139-145	100	77	Bay of Fundy	Trippel et al. 1999
Netmark1000	132	200	98	Black Sea	Gönener & Bilgin 2009
AQUAmark100	136-145	455	100	North Sea	Larsen et al. 2013
AQUAmark100	136-145	585	78	North Sea	Larsen et al. 2013
Lu-1-prototype	145	140	90	North Sea	Larsen & Eigaard 2014
Banana	145	200	60-90	North Sea	Kindt-Larsen et al. submitted

Brand	Source level (dB, 1 µPa @1m)	Pinger spacing (m)	Bycatch reduction (%)	Location	Reference
Banana	145	500	20-51	North Sea	Kindt-Larsen et al. submitted
Banana	145	500	72	North Sea	Kindt-Larsen et al. submitted
Banana	145	200	0	N-Iceland	Sigurdsson & Jusufovski *submitted*, ICES (2020)
Wideband PAL	20-160	200	100	N-Iceland	Sigurdsson & Jusufovski *submitted*, ICES (2022)
PAL	147?	200	0	N-Iceland	Sigurdsson & Jusufovski *submitted*, ICES (2021)
DDD03	165	variable	63	UK	Northridge et al. 2011
NetGuard Dolphin Pinger & Banana	145	200	94	Norwegian Sea	Moan & Bjørge 2023

Pingers used in European waters

Under EU Regulation 2019/1241 and the subsequent Delegated Regulation 2022/303, EU member states are obligated to implement measures to reduce cetacean bycatch in various fisheries. Notably, this includes measures to protect the critically endangered Baltic Proper harbour porpoise. These measures include the mandatory use of pingers on static net fisheries, particularly bottom-set gillnets, in specified areas and during certain periods. Vessels with a length of 12 metres or more using bottom-set gillnets are required to deploy pingers in designated zones to reduce incidental catches of harbour porpoises.

In addition to the focus on reducing the bycatch of harbour porpoises in the Baltic, efforts have been made to establish areas where pinger use is obligatory. In Sweden, these areas are in the south of the country where there has been bycatch of porpoises or in areas identified as key habitat for porpoises. In Germany and Poland there are also designated Natura 2000 areas where harbour porpoises are protected and where there is obligatory pinger use to protect the harbour porpoise.

In Norway, pingers are now mandatory in the gillnet fishery for cod in Vestfjorden. In some Baltic countries, defence authorities have expressed concerns that the acoustic signals emitted by pingers could interfere with naval sonar systems or other military acoustic equipment. As a result, restrictions on pinger use have been implemented in certain areas to prevent potential conflicts with defence operations.

Figure 1 shows areas of protection for harbour porpoises in the Baltic Sea and the mitigation measures that have been implemented.

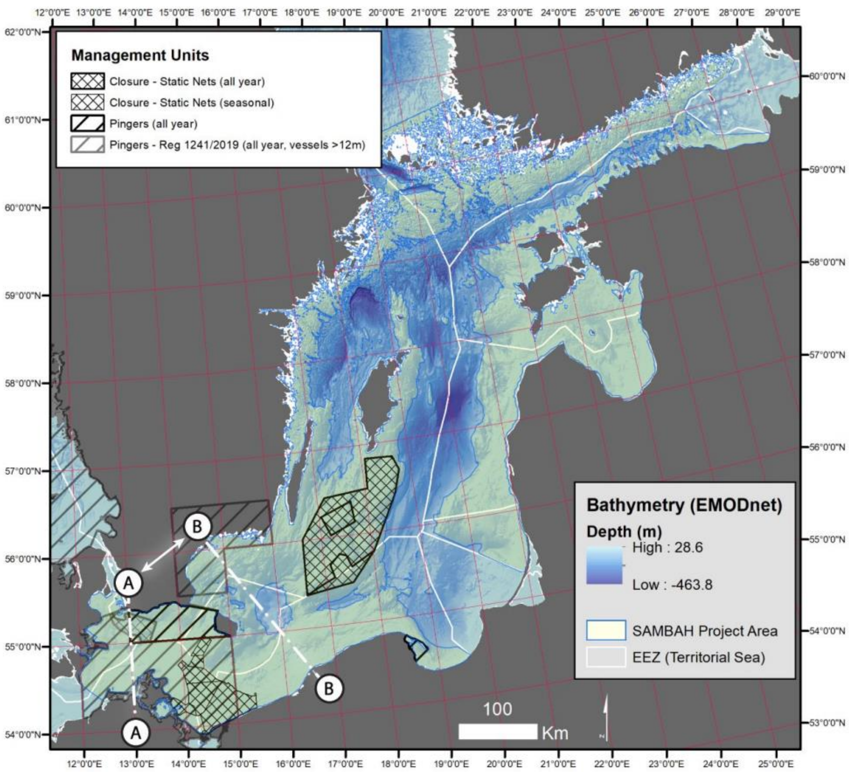

Figure 1. Figure as published in the 2024 report of ICES WKSUP (ICES 2024a. Natura 2000 sites with implemented fisheries management measures to protect harbour porpoise (closures, pingers), the Baltic harbour porpoise subpopulation shifting seasonal boundary (A = winter, B = summer), and management units in effect as of December 2024 identified to protect harbour porpoise bycatch rates under Regulation (EU) 2019/1241.

Increased net visibility (in development)

General

One of the suggestions about how to mitigate bycatch of porpoises and other echolocating cetaceans is to make the gillnets more detectable in their surroundings. Plastic pearls made of acrylic glass (Polymethylmethacrylate, PMMA) have been found to be ideal for this purpose as they are highly reflective to sound underwater, particularly in the frequencies used by porpoises for echolocating (Kratzer et al. 2020, 2022). In theory, this makes the fishing gear highly “visible” to echolocating animals such as porpoises as gillnets equipped with such pearls have substantially higher acoustic backscattering strength. Gillnets with pearl-to-pearl distances of 20 cm perform best, while the acoustic backscatters of gillnets with 40 cm and 60 cm pearl-to-pearl distances are similar (Kratzer et al., 2022). Based on this research, a new type of gillnet, “PearlNet”, was created with the potential to reduce bycatch rates by making cetaceans aware of the presence of gillnets in their surroundings. Besides reducing porpoise bycatch, for fishers to accept this mitigation tool, PearlNets must be at least as effective at catching target fish species as traditional nets (used as a control in the trials). To demonstrate the potential of PearlNets, comparison of catch rates of target and non-target commercial species in control and PearlNets in a set net fishery for cod in the Western Baltic Sea showed that the catch rates were quite similar (Kindt-Larsen et al. 2024).

Despite the positive results on target species catch rates and ability to increase echo backscatter strength, the ability of these nets to reduce bycatch of porpoises still needs to be demonstrated. A trial conducted in the Black Sea in a commercial gillnet fishery targeting turbot (*Scophthalmus maeoticus*) focused on the handling of the gear and identification of requirements for a full-scale trial. The trial proved the viability (from this perspective) of using gillnets equipped with pearls. In addition, the study showed no reduction in catches of target species and a reduction in the number of porpoises caught. However, sample size was too low to demonstrate statistically that the pearls reduced porpoise bycatch (Kratzer et al. 2021).

In April in 2024 PearlNets were tested onboard a large commercial gillnetter targeting cod (*Gadus morhua*) in northern Iceland as part of the EU LIFE CIBBRiNA project. The trial was operationally successful, as there were no issues with handling the long and high net strings used with the pearls attached, and preliminary analysis suggests no significant difference in fish catches. However, there were not enough porpoises caught to determine (based on frequentist statistics) if the pearls significantly reduced porpoise bycatch, and trials continued in 2025.

Net characteristics

General

Changing net characteristics such as the colour of the monofilament, the twine thickness or the colour of the ropes or the float lines might affect and reduce bycatch. Making gillnet panels more visible by either changing the colour of the twine or ropes to red or orange has been suggested as a potential method for mitigation of bycatch for cetaceans, birds, and sea turtles. Few publications have shown an effect, but a study in New England showed that right whales seemed to notice red or orange ropes earlier than normal green ropes (Coulter 2019). Similarly, adding white phosphorus to ropes and toplines of nets to make them glow has been suggested as a mitigation method for both cetaceans and sea turtles, but this method is yet to be tested.

In a recent study in Greenland, researchers observed reduction in bird bycatch by adding a small (45 cm high) small-meshed panel made of thick knotless nylon twine to the bottom part of the net, the area where most of the birds were caught (Post et al., 2023). It is possible that such modifications could reduce bycatch for other species as well.

Another method related to net characteristics is reducing net height, also sometimes referred to as “tie-downs”. This has shown to be successful in reducing bycatch rate of both cetaceans and turtles (Northridge et al. 2016). Tie-downs will change the fishing characteristics of the net, which might reduce catch of groundfish, but might be useful, and potentially better for catching species such as flatfish (Kim et al., 2023) or monkfish species.
Denmark is currently testing both reduced net height and thinner twine and the preliminary results are promising in relation to reducing bycatch. This mitigation method is at an experimental stage and further research is ongoing. While they might reduce bycatch rates, they are unlikely to eliminate bycatch - which might be needed in some regions such as the Baltic and the Iberian Peninsula, given the serious threat status of the porpoise populations in these areas.

Net characteristics in European waters

The mitigation methods relevant to making gillnets more visible/detectable by porpoises are all at a very early experimental stage and further research is clearly needed. Denmark has planned to test both reduced net height and thinner twine size in 2024 and 2025.

Lights

General

Lights have been suggested as a practical, cost-effective solution to reduce bycatch in gillnet fisheries. In most cases, light-emitting diodes (LED) lights that are designed to be used in longline fisheries to attract catch have been used in bycatch reduction trials. In theory, illuminating the net makes it more visible to cetaceans, seabirds, or turtles, reducing the probability of them getting entangled. So far, studies have mainly focused on reducing bird or sea turtle bycatch and the potential effect on cetaceans is less clear but with a few exceptions. A study from Peru reported that nets equipped with LEDs reduced bycatch of seabirds by 84%, sea turtles by 74% and small cetaceans by 70% (Bielli et al. 2020) and studies from Ghana and Cyprus have reported considerable reduction in bycatch of turtles when using LED-equipped nets (Allman et al. 2020, Snape et al. 2024).

Lights in European waters

Despite the successes listed above, two studies have reported an increase in bycatch of birds while using lights, one in the Baltic Sea, where an increase in bycatch of long-tailed ducks (*Clangula hyemalis*) was observed (Field et al. 2019), and one in Iceland, where an increase in bycatch of surface feeding birds such as fulmars (*Fulmarus glacialis)* and northern gannets (*Morus bassanus*) was observed (Sigurðsson 2024). The use of lights as a mitigation measure in nets is still at an early stage and further research is required as the results might be species/group dependent.

Alternative fishing gear

One of the most efficient ways of reducing bycatch is to switch from gillnets to gears that have lower bycatch risk. Three gear types - traps and pots, longlines and seines - have all been shown not to catch certain marine mammals or to be associated with a lower risk of bycatch, and are thus described in detail below. Although longlines are associated with bycatch of birds, seals, turtles, and sharks, switching to longlines could be an option in places like the Baltic where there are no turtles or sharks.

Fishing Pots

General

Pot fisheries account for only a small part of worldwide commercial fishing. In some countries, however, there has been a long tradition of pot fishing, particularly for catching crustaceans. With pot fishing, desired species and sizes can be targeted through gear designs and the choice of bait. Catch size is affected by pot size, bait quantity and quality, time between setting and hauling and preventing escape through the entrance. Furthermore, pots have the advantages that they are species and length selective, have a low impact on the seabed, and are fuel-efficient (Suuronen et al. 2012). They also have low bycatch of sea birds and are mentioned in the guidelines on bycatch by the FAO as an alternative to minimize seabird bycatch when no strategies appear viable (FAO 2021).

Pot fisheries are mainly associated with capture of crustaceans or molluscs but can also be used for capture of demersal finfish as well. The main challenge for widespread use of pots is attaining commercially viable catch rates and numerous fishing trials have been conducted to investigate pot catch efficiency (Furevik & Løkkeborg 1994; Furevik et al. 2008; Bagdonas et al. 2012; Anders et al. 2016; Ljungberg et al. 2016; Jørgensen et al. 2017; Folkins et al. 2021).

Pots in European waters

Due to the absence of seabird and lower marine mammal bycatch in the pot fishery, it could serve as an alternative fishing method in certain areas. However, some issues must be considered before implementation. Pot trials have been conducted in the Baltic Sea mainly by Sweden and Denmark. The focus has been both on the development of the pots, to find the most suitable materials, entrances, bait, and dimensions (Kindt-Larsen et al. 2023; Hedgärde et al. 2021; Ljungberg et al. 2021) and to test their economic value. A Swedish trial has evaluated cod pots versus gillnets and longlines in two areas in the south-central Baltic Sea. The comparison showed that during the first half of the year the pot fishery generated lower daily catches than the gillnet and hook fisheries, while in the second half of the year pot catches exceeded or equalled gillnet and hook catches. In addition to the time of year, the pot catches varied according to soak-time, water depth, and current speed and direction (Königson et al. 2015).

The pot fishery is very limited in terms of target species, and most trials conducted have been in the cod fishery, which is no longer viable in the Baltic. Thus, new efforts are needed to explore if pots for flatfish or other species would be valuable. A recent study in Canada has explored the possibility to use pots to catch Greenland halibut, instead of longlines or gillnets due to high bycatch of Greenland sharks, which suggests that pots might be a viable way to catch larger flatfish (Folkins et al. 2021).

Trap-nets

General

Trap-net fisheries are widely used around the world and include gears such as fyke nets, trap nets, and pound nets. These passive fishing gears typically consist of a leader net that guides fish into one or more chambers where the fish are eventually caught. Trap-net fisheries are commonly used to target migratory species such as salmon and eel, but they are also effective for various resident or semi-migratory species like perch, pike, and whitefish.

One of the main advantages of trap-net fisheries is their low bycatch rate, particularly for marine mammals such as cetaceans. Although seals may occasionally become bycaught (ICES WGBYC 2019), trap gears generally present a much lower risk compared to other fishing methods such as gillnets. Seabirds are rarely caught in these gears. Due to their stationary nature and open design, traps can be highly selective, in terms of both species and size, especially when using appropriate mesh sizes or escape openings.

Trap-net fisheries also have a low environmental footprint. Since the gears are not towed along the seabed, they cause minimal habitat disturbance. In addition, they are fuel-efficient, making them a more environmentally sustainable option compared to many other gear types (Suuronen et al. 2012). Another important benefit is that, because the fish are captured alive in enclosed compartments, trap nets can be designed to be seal-safe, preventing depredation and damage by seals. This not only reduces economic losses but also minimizes harmful interactions between seals and fishing gear. Overall, trap-net fisheries hold significant potential for contributing to more sustainable, selective, and low-impact coastal fisheries, particularly in areas where coexistence with marine mammals, seabirds, and sensitive marine habitats is a key management concern.

Trap-nets in European waters

The development of seal-safe trap-net fisheries has been a key focus in the Baltic Sea region, driven largely by the growing seal populations that have created serious conflicts with small-scale coastal fisheries. Increased depredation and gear damage caused by seals have significantly impacted the economic viability of traditional fishing practices. To reduce seal depredation and damage, a seal-safe trap-net known as the pontoon trap has been developed and widely implemented. These traps target a range of species, including salmon, whitefish, herring, vendace, and cod (Lunneryd and Königson 2017; Ljungberg et al. 2022). The trap nets are seal-safe and most often include a seal exclusion device, which not only reduces seal depredation but also minimizes the risk of bycatch of seals and other marine mammals. In the northern Baltic, particularly along the Swedish coast, pontoon traps have been implemented, and almost all fishers use them (Lunneryd and Königson 2017). Their effectiveness and selectivity have made them a preferred option in areas subjected to seal depredation and damage.

Seal-safe fyke nets have also been under development in recent years. In addition, building on the design principles of pontoon traps, efforts are underway to adapt fyke-nets for the seal-safe capture of demersal and coastal species such as turbot, perch, and pikeperch. This development aims to expand the use of seal-safe fishing methods to a broader range of species and fishing environments along the Baltic coast.

Longlines

General

Demersal longlines are used worldwide and in many countries represent a substantial part of the fishing industry. Although longlines are simple devices, set-up and rigging procedures vary widely between regions and target species. In general, longline gear is tried and tested and can be bought off the shelf from gear manufacturers for most types of target species.
Longline catch rates for target species are largely dependent on the type of hooks, lines, bait, fishing depth, fishing practices and a variety of biotic and abiotic factors. All of these factors will affect the success of fishing and whether it can be viable commercially.

Several studies have compared catch rates from longlines with other gear types (Huse et al. 2000, Santos et al. 2002) discovering that longlines had higher catch rates compared to gillnets. However, comparison of fish sizes in several studies has shown that gillnets catch larger fish than longlines (Huse et al. 1999, 2000; Santos et al. 2002). As the fish caught in longlines are usually alive when hauled, it tends to fetch higher prices at fish markets than gillnet-caught fish. Longlines catches are in general area, current, and season dependent. Fish are particularly hard to catch with longlines during the spawning season, when they are not feeding. Due to the great variety in catch rates, vessels that can switch between gillnets and longlines have shown to be the most profitable due to the possibility of switching between gear systems during periods when one seemed more profitable than the other. Bycatch of cetaceans in longlines is rare, although there are some known cases of larger whales getting entangled in buoy and anchor lines, and dolphins getting hooked after depredating on fish (López et al. 2012; Frisch-Jordán & López-Arzate 2024). Seabird bycatch in longlines can be considerable and needs to be considered if implementing longlines to mitigate porpoise bycatch, despite various mitigation methods have been developed (Melvin et al. 2014). Shark bycatch in longlines can be significant, with some pelagic longline targeting swordfish (Walls et al. 2024).

Longlines in European waters

Longlines are widely used in European waters to catch a variety of fish species. Despite the very good quality of catch and no risk of porpoise bycatch, depredation from seals is likely to be a problem in some regions. Entanglements of large whales in anchor lines can occur. Bycatch of seabirds is likely to be a problem in most regions (ICES 2023). Mitigation methods to reduce seabird bycatch are therefore likely to be needed. Shark bycatch is likely to be an issue in some regions. Longliners operating in the Atlantic Ocean catch 88% of the pelagic sharks captured by the EU fleet, 68% of which as bycatch (EC Sharks fisheries 2020; https://ec.europa.eu/fisheries/marine_species/wild_species/sharks/sharks_fisheries_en).

Mini seine

General

Demersal or anchored seines in two main configurations ("Danish” or anchored, and “Scottish” or fly dragging) are used to some extent in demersal round- and flatfish fisheries in the North Atlantic. These vessels are usually quite large, due to the size of the gear, and the need to haul in long wings of net to get to the bag where the fish are collected. It has been proposed and theorized both in the Baltic and in other regions, such as Iceland and Norway, that a smaller version of such gear, the so-called “mini-seines”, could be used on small vessels that would normally be equipped for gillnets. The idea of the mini-seine is to scale down the entire demersal seining system to a size that can be operated by one fisher on a small gillnetting vessel, such that seine fisheries could be replacing gillnet fisheries subject to high bycatches.

Based on knowledge from larger commercial vessels, demersal seining efficiently catches various target species including species of potential interest for gillnetters like cod and plaice (Noack et al. 2016). We also know that bycatch of cetaceans and other marine mammals is very rare, and demersal seines are, treated as one of the "exempt" fisheries in the US Marine Mammal Protection Act Import Provisions, due to the low probability of bycatch (NOAA 2024). Additionally, the quality of fish caught in demersal seines is high (Dreyer et al. 2008), which can have positive effects on the profit per unit of sold fish. The reason is that catches spend little time in the gear (Noack et al. 2019), thus interactions with other biological and non-biological parts of the catch or net parts are limited.

Seines in the European waters

Gear development is a very time- and resource-demanding process. Denmark and Germany have made some efforts to test mini seines (Noack et al. in review; Thünen 2024). These trials should, however, be regarded as the initial phase of the development of small-scale seine netting, as the data foundation at present is too sparse to determine whether mini-seines can be a solution for the vessels that otherwise engage in gillnetting. Despite challenges, the fishing trials have come a long way, and a system has been developed that can be operated on smaller vessels and which has the potential to be used for species such as flounder, plaice, and turbot on soft bottoms in the Baltic.

To our knowledge, bycatch of marine mammals in the newly developed mini-seine fisheries is low. However, bycatch of demersal (bottom-dwelling) fish species can be substantial. Broadhurst et al. (2006) reviewed over 80 published studies that quantified the mortality of more than 120 species of escaping or discarded taxa in towed fishing gear types that can be considered broadly comparable to seine fisheries. Notably, no marine mammals or seabirds were reported as bycatch in those studies, although purse seines for pelagic fish - which are very different in operation - sometimes catch both marine mammals and seabirds.
Demersal seines require relatively soft and featureless sea bottoms, meaning the suitable fishing area might be more limited than that for gillnets.

2.2. Demersal longlines in Portuguese waters (CIBBRiNA case study 4)

In Portuguese waters deep-water longlines, comprise around 200 vessels with different gear configurations (bottom, drifting or set longlines). Bycatch species of interest are leafscale gulper shark; Portuguese dogfish; birdbeak dogfish; gulper shark; loggerhead turtle. Depredation by bottlenose dolphins in the black scabbardfish fishery.

Alternative fishing gear

Switching from longlining to handlining may reduce deep-water shark bycatch although some fisheries such as for scabbard fish might operate too deep for handlines. Das et al. (2022) found that elasmobranchs in the Azores were less likely to be caught on local vertical handlines (gorazeira) compared to bottom longlines. Fishing using handlines involved shorter soak durations, fewer hooks, shallower depths, and lighter tackle that sharks can readily bite off (Fauconnet et al. 2019). According to Ellis et al. (2017), elasmobranchs caught on handlines have a higher chance of surviving after being released. Local fishers agreed that not only is deep-water shark bycatch higher on longlines, but deep-water elasmobranchs suffer higher at-vessel mortality than on handlines (Fauconnet et al. 2023).

Mitigation measures

Circle hooks

General

Circle hooks have been tested on longlines as a bycatch reduction strategy for sharks and sea turtles, with promising but species-specific outcomes (Read 2007, Afonso et al. 2011, Godin et al. 2012, Reinhardt et al. 2018). Hannan et al. (2013) found that circle hooks catch more Atlantic sharpnose (*Rhizoprionodon terraenovae*) and blacknose sharks (*Carcharhinus acronotus*) when fishing with demersal longline gear. Sharks caught on circle hooks were approximately 5 cm shorter on average than those caught with regular J-hooks, possibly due to the smaller circle hooks compared to the J-hooks (Hannan et al. 2013). A study done in the Azores, found that circle hooks had a higher catch of roughskin dogfish (*Centroscymnus owstonii*), leafscale gulper shark (*C. squamosus*), Portuguese dogfish (*C. coelolepis*), and longnose velvet dogfish (*C. crepidater*) than J-hooks (Fauconnet et al. 2023). Additionally, circle hooks can lower gut hooking, improving shark post-release survival (Howard 2015).

Magnetic hooks

General

The deployment of magnets and rare earth metals in conjunction with longline gear has been trialled both with direct incorporation of these materials into the hooks and through the attachment of discs, weights, or plates at varying positions proximal to the hook with species- and location-specific results (Clarke et al. 2014). Lanthanide metals, including neodymium (Nd) and praseodymium (Pr), generate strong electric fields in water. Four experiments were conducted in various parts of the Pacific Ocean, two deepwater longline experiments were carried out in and offshore fisheries of Kaneohe Bay, targeting juvenile scalloped hammerhead sharks (*Sphyrna lewini*), while the other targeted sandbar (*Carcharhinus plumbeus*) and tiger sharks (*Galeocerdo cuvier*). A third experiment was carried out in pelagic longlines in the Southern California Bight targeting mako (*Isurus oxyrinchus*) and blue sharks (*Prionace glauca*), while longlines targeting pelagic sharks were set off Ecuador's coast as the fourth experiment (Hutchinson et al. 2012). When compared to the controls, the number of juvenile hammerhead sharks caught in hooks with lanthanide metal was significantly lower. In contrast, there was no difference in catch rates between experiments targeting sandbar sharks in Hawaii, the SCB, and Ecuador (Hutchinson et al. 2012). Potential explanations for these intraspecific differences include variances in hunger levels, shark density, size, or plasticity in feeding strategies under different environmental conditions (e.g., visibility, salinity) (Hutchinson et al. 2012).

Additional variables to consider are target capture rates and cost. There are suggestions that the physical structure of the magnets may influence the behaviour of the branch line, reducing the catch of target species (Godin et al. 2013). Furthermore, because rare earth metals generate magnetic fields by chemically reacting with seawater, the need to place these materials in, on, or near every hook, combined with dissolution timeframes as short as two days and a cost of US$ 20 per kg of material is likely to be a significant barrier to widespread implementation (Stoner & Kaimmer 2008).

Magnetic hooks in European waters

No studies assessing the use of electropositive or magnetic materials in European demersal longline fisheries were found.

Sensory Deterrents

See section on this mitigation measure in the pelagic longline case study.

Pingers

General

For a general introduction to pingers, please see chapter 2.1 (Gillnets case study).

Pingers in European waters

In the Azores region, cetacean bycatch in longline fisheries was not observed and <1% of the 384 sets monitored showed evidence of cetacean depredation, namely by killer whales (Silva et al. 2011; Parra et al. 2023). Pingers were tested in the Azores in the hand-jig squid fishery to reduce depredation from Risso's dolphin (*Grampus griseus*) (Cruz et al. 2014). The study found that the use of pingers had no significant effect on the catch per unit effort of squids. Depredation rates were similar for the control (0.20), inactive (0.19), and active (0.19) pinger conditions. Models indicated no significant effect of pinger brand and condition on cetacean depredation (Cruz et al. 2014).

In mainland Portugal black scabbard fishery, pingers were used for deterring bottlenose dolphins that attack the catch when the longline is being hauled and fishers reported that after, some trips using the pingers, they no longer had any effect because the dolphins would return and feed on the catch.

Gear characteristics

General

Fishers can reduce shark interactions with longlines by shifting fishing grounds, changing depth, or soaking gear for a different duration (Clarke et al. 2014; Sainsbury, et al.). Coelho et al. (2003) found that positioning hooks farther from the seafloor had strong potential to reduce the catch of deep-water sharks on demersal stone-buoy longlines, with limited effect on the catch of target species. This is corroborated by the success in using floats to suspend demersal longlines in the water column where they are less likely to be encountered by demersal sharks (Afonso et al. 2011).

In a study carried out on the Patagonian toothfish (*Dissostichus eleginoides*), demersal longline fisheries operating in the Crozet and Kerguelen Economic Exclusive Zones (EEZs) (South Indian Ocean), the probability of sperm whale depredation increased from 0.30 for sets hauled from a depth of 506 m to 0.48 for sets hauled from 2140 m depth (Janc et al. 2018). Similar results were found with killer whales interacting with the same fishery, where the probability of interactions between vessels and killer whales was decreased when longlines were set at shallower depths (Tixier et al. 2015).

Fish Bait

General

Using fish bait instead of squid has been associated with the reduced bycatch of certain species, including sharks and sea turtles. A controlled study in 2002 in pelagic waters in the northwestern Atlantic Ocean found that using mackerel (*Scomber scombrus*)-baited instead of squid (*Illex* spp.)-baited J-hooks reduced unwanted catch of sea turtles, and bycatch on circle hooks tended to be lower in a tuna *Thunnus* spp. and swordfish *Xiphias gladius* longline fishery (Watson et al. 2005). When mackerel *Scomber* spp. -baited J-hooks were used instead of squid-baited J-hooks, the number of unwanted sea turtles caught was reduced (0.13-0.15 turtles per 1,000 hooks) (Watson et al. 2005).

Another study done in the northeast Atlantic Ocean monitored pelagic longline swordfish (*Xiphias gladius*) fishery trips in 2008–2011 (Coelho et al. 2015). They found that changing from squid (*Illex* spp.) bait to mackerel bait reduced unwanted catch of hard-shell sea turtles (Cheloniidae), from 0.14–0.35 to 0.07–0.16 turtles/1,000 hooks. However, unwanted catch of leatherback turtles was similar when mackerel (0.39–0.95 turtles/1,000 hooks) or squid (0.50–0.10 turtles/1,000 hooks) bait was used (Coelho et al. 2015).

Fish bait in European waters

Squid is not used the Portuguese mainland black scabbard fishery as small fish such as *Sardina pilchardus* or *Scomber colias* is most common and this method is therefore not applicable to that fishery._In Madeira, the use of squid as bait in the scabbardfish fishery is very common and the method might warrant further investigation although fishers have stated that based on their experience small pelagic fish (like *S. colias* and *T. picturatus*) are not as effective as bait for this fishery.

Leader material

General

The effectiveness of nylon leaders in reducing shark bycatch, in comparison to wire leaders, is still being researched, and more data is needed to confirm their use as a bycatch reduction method (Clarke et al. 2014; Favaro & Côté 2015; Fauconnet et al. 2023)**.** However, studies have shown that shark catch rates are higher when using steel wires on longlines, instead of monofilament nylon line. Ward et al. (2008) found that longline vessels off northeastern Australia using wire leaders had 13% higher target catch rates of all species combined than on nylon. The catch rate of all bycatch species combined on nylon was close to half that on wire (Ward et al. 2008).

Leader material in European waters

In the Azores deep-water bottom longline fishery experiments revealed that using nylon leaders resulted in significantly higher rates of bite-offs compared to steel leaders. This suggests that nylon leaders may reduce shark retention on the line, potentially lowering shark bycatch rates (Fauconnet et al. 2023).

2.3. Pelagic longlines in Madeira waters (CIBBRiNA case study 5)

Pelagic surface longline fisheries are considered the biggest contributor to global shark bycatch. It is estimated that especially tuna longline fisheries may have a discard ratio of around 28.5% with a large proportion of this consisting of sharks (Oliver et al. 2015). Oliver et al. (2015) even found that the bycatch of sharks may exceed the target catch in some instances. Pelagic longline fisheries in the Atlantic Ocean show a particularly high bycatch rate of blue sharks (50 – 90% of shark bycatch). Pelagic sharks, including blue shark, are becoming a target of these fisheries, especially in certain areas or seasons and depending on the quota. Data from onboard observers in the Azores pelagic longliners targeting swordfish between 2015 and 2018 indicate that this is a very selective fishery, in which 96% of the individuals are blue shark and swordfish (73.5% and 22.4%, respectively) and where the shortfin mako represents 1.4% of the catches. However, 91% of blue shark catches are of immature individuals, who have not yet produced offspring (Vandeperre et al. 2020). A high number of sea turtle bycatch in pelagic longline fisheries is also of concern as well as interactions with marine mammals, which may cause entanglement and/or economic losses for the fishers.

In Madeira waters, seasonal small-scale pelagic longliners target mainly bluefin tuna, bigeye tuna and swordfish, fishing mainly between January and March. The fleet comprises 29 small-scale vessels (mainly under 10 m in length). Bycatch species of interest are pelagic sharks including blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*) and tope shark (*Galeocerdo galeus*); bottlenose dolphin (*Tursiops truncatus*); short-beaked common dolphin (*Delphinus delphis*); and loggerhead turtle *(Caretta caretta)*.Although targeting large migrating pelagic species such as swordfish (*Xiphias gladius*) and tunas (*Thunnus* sp.), this is a multispecies fishery.

Alternative fishing gear

Trapline

Recently, a new fishing gear called “trapline” (synonymous with “trap-line” and “trappolina” in Italian) has been used in the Mediterranean Sea (Garibaldi et al. 2024). The following gear description and assessment is based on the report by Garibaldi et al. (2024). This gear does not fit into any previously known category and should be treated as a separate fishing gear. According to interviews with local fishers in Italy, the gear had been used by Spanish fishers since at least 2021 in the swordfish fishery. This gear poses a number of new challenges to researchers, including how to define the CPUE of the last three years as the values have been incorporated into the longline fishery statistics rather than their own category. The data collection, management, and regulation of this new gear should also pose new challenges.

Traplines can be operated without the use of hooks, instead, artificial lures in the shape of a mackerel or squid with sardine inside can be used (Figure 2). Some fishers may even place LED lights inside the lures, however, after initial trials with hooks and lights, the fishers found both to be unnecessary and the baited lures alone worked well enough. Around the lure, concentric loops made of monofilament nylon of different thicknesses are attached (Figure 2). The number of nylon loops may vary between six and eight and vary in size from 30 – 70 cm. These loops act like meshes on gillnets, i.e., entangle the swordfish by its pectoral fins or even dorsal fin.

These individual traps are placed at the end of the branch line where usually hooks and baits are placed in conventional longline fisheries. Hence, traplines operate with the normal longline infrastructure on board the fishing vessels and can be operated by the same fishers without learning new skills or gears. Additionally, some fishers have learned to construct these traps themselves, and they are comparably cheap at approximately € 6-7 per trap (plus lure). Albeit only limited observations and data is available for this new gear, the estimate CPUE is at least 50% higher for traplines traps than for longline hooks. Direct information from fishers even suggests and increase of more than 400% for traplines.

Again, only limited data is available to date regarding the bycatch of traplines and hence, the results presented by Garibaldi et al. (2024) should be regarded with care. Nevertheless, bycatch of traplines seems to be considerably lower than for conventional longline fisheries targeting swordfish. In the Ligurian Sea, bycatch was mainly comprised of bluefin tuna (*Thunnus thynnus*) and sunfish (*Mola mola*). In Sicily, however, recorded bycatch species included additionally blue sharks (*Prionace glauca*), other pelagic sharks, and striped dolphins (*Stenella coeruleoalba*). Thus, more data is required to assess whether traplines could really be a bycatch-reduced alternative fishing gear for pelagic longlines.

Figure 2. Trapline with mackerel lure, adapted from Garibaldi et al. 2024. The new fishing gear consists of concentric loops made up of nylon thread in different thickness and a central lure which can either be a mackerel or squid shape. Initially, fishers supplemented the lure with sardine bait and/or lights but later found the gear also works well without either.

Deep-Set Buoy Gear (DSBG) and Linked Buoy Gear (LBG)

The following paragraph is a summary of the information provided by Sepulveda et al. (2024). Another alternative fishing gear for pelagic longlines could be the use of Deep-Set Buoy Gear (DSBG; Figure 3) or Linked Buoy Gear (LBG; Figure 4). LBG is a modified version of DSBG that connects the buoys to a single mainline. This type of method is used to target swordfish in deep waters, utilizing a system of buoys and hooks that operate at depths of up to 400 metres, below the thermocline where swordfish are concentrated during the day. This technique allows a quick response to release unwanted catch when a catch occurs, enabling the live release of non-target species.

Tested extensively over the past five years by scientists and cooperating fishers, DSBG has proven to be effective for selectively catching swordfish with minimal bycatch of non-target species. Between 2015 and early 2017, the Pfleger Institute of Environmental Research (PIER) conducted experimental and commercial trials, using DSBG off the coast of California. The objective was to test the viability of using DSBG as a sustainable alternative for swordfish (*Xiphias gladius*) fishing off the southern California coast. During the first two years (2015-2017) of the PIER Deep-Set Buoy Gear Exempted Fishing Permit (DSBG-EFP), the catch was composed of seven species, with swordfish accounting for more than 80% of the total catch and an overall marketable catch rate of more than 98%. Other marketable species included opah (*Lampris guttatus*), bigeye thresher shark (*Alopias superciliosus*), mako shark (*Isurus* *oxyrinchus*), and escolar (family Gempylidae). Swordfish catch rates further increased during the study period and was calculated at 93.9% for the study period from 2017-2021. Additional marketable catch comprised of bigeye thresher sharks, escolar, and mako shark collectively accounted for 5.1% leaving non-marketable bycatch at only 1%. Non-marketable bycatch was made up by blue sharks, salmon sharks, ocean sunfish, and one northern elephant seal that was released alive. Catch and bycatch was monitored via logbook entries and onboard observers with a consistent observer coverage above 20%.

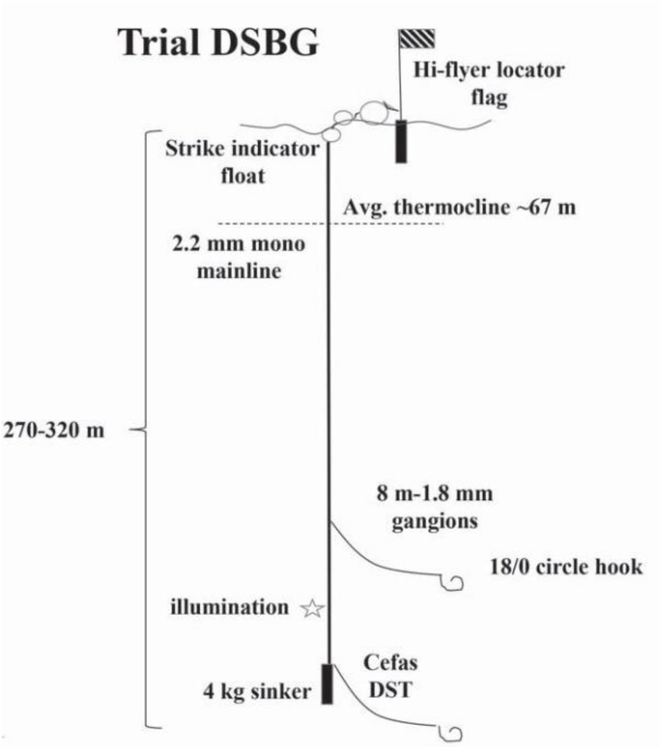

Figure 3. Deep-set buoy gear (DSBG) setup. Figure from Sepulveda et al. (2015).

For LBG during the same study period, the swordfish catch rate was calculated at 92% with the remaining 8% consisting of bigeye thresher sharks, escolar and mako sharks. No non-marketable catch was recorded for LBG, although the fishing effort was lower than for DSBG. Due to potential for higher entanglement risk for LBG compared to DSBG, an observer coverage of 69% was achieved during the study period.

Overall, the swordfish selectivity of the gear increased continuously from the early period of the study period until the end which Sepulveda et al. (2024) attributed to the learned avoidance of areas with high bigeye thresher shark catches by the fishers.

Although bigeye thresher sharks are marketable, fishers preferred to release this species due to comparably low market-value.

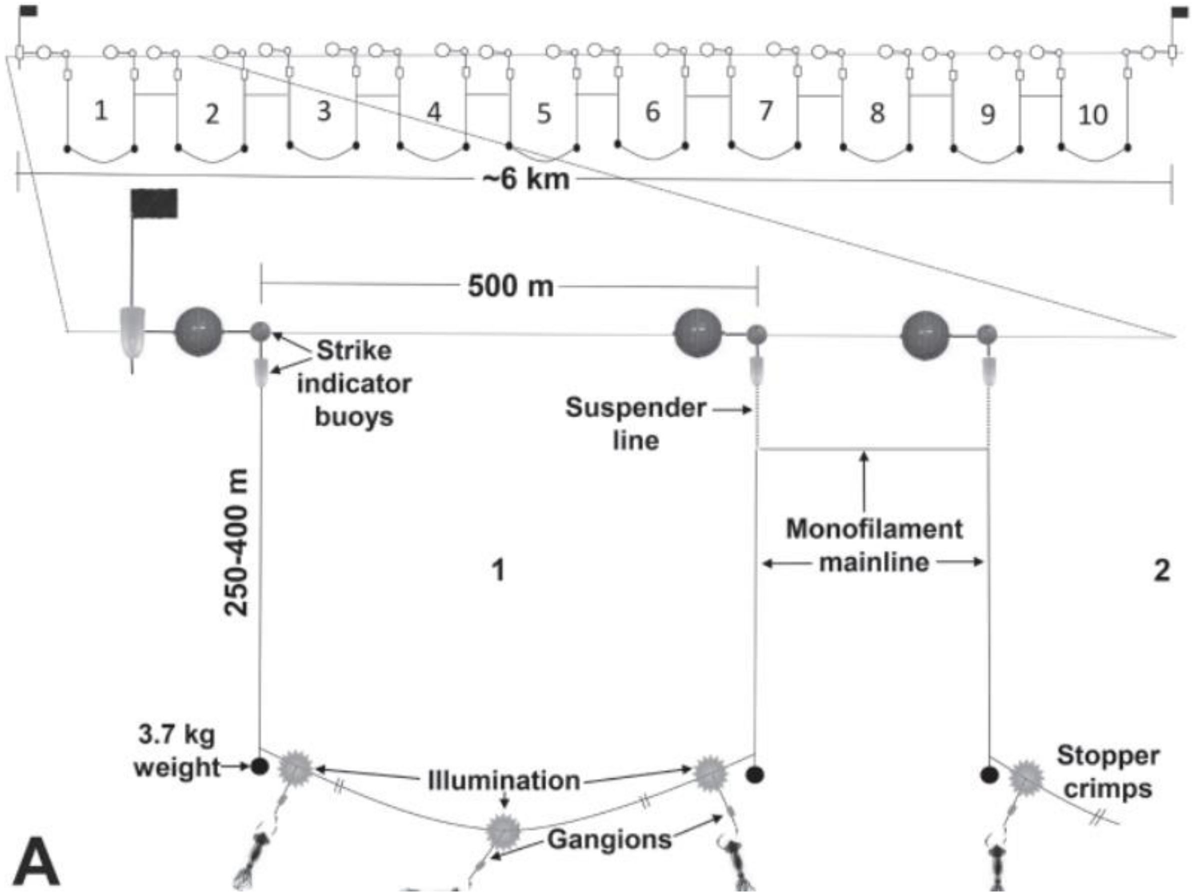

Figure 4. Linked-buoy gear (LBG) setup. Figure from Sepulveda et al. 2015.

Bycatch of ETP species for this fishing gear seems very low based on these results and consisted mainly of blue sharks and a single incident of a northern elephant seal. Blue shark bycatch in the North Pacific is very common and DSBG and LBG bycatch of this species are below average for surface longlines in the same area making it a promising potential alternative for longline fishing for swordfish.

Mitigation measures

The sustainability of longline fisheries would greatly benefit from optimizing gear configurations to enhance selectivity for target species and improve the post-release survival of bycatch. Mandated bycatch mitigation measures include gear configuration (e.g., float line length, branch line requirements, weights, bait restrictions, use of circle hooks). Simple modifications to fishing gear such as changes in leader material type (wire or monofilament), hook size, diameter, shape and metal type have been shown to have significant impacts on bycatch mitigation.

Hook shape

General

Circle hooks, as opposed to traditional J-hooks, have been widely recommended for reducing bycatch and post-release mortality of turtles and non-target shark species (Domingo et al. 2012; Sales et al. 2010). This is because circle hooks are more likely to lodge in the jaw or cause external perforations, whereas J-hooks often result in deep-hooking and generally more internal perforations, which significantly increases mortality due to internal injuries to the oesophagus and stomach lining (Pacheco et al. 2011; Santos et al. 2012). However, results are often statistically inconclusive and seem highly species-specific (Pacheco et al. 2011; Santos et al. 2012) and may even vary with seasons (Kerstetter & Graves 2006).

Several studies have found a significant reduction in bycatch of turtles with the use of circle hooks. Sales et al. (2010) compared two circle hook types (18/0 Korean circle hook and 18/0 Brazilian circle hook) with J-hooks (9/0 Mustad type) in the Brazilian pelagic longline fishery targeting tuna, swordfish and sharks. A total of 148,828 hooks was assessed, half of which were J-hooks and half were circular hooks. A total of 170 loggerhead turtles was bycaught. The BPUE (number of turtles caught per 1000 hooks) was reduced by 64.7% when using circle hooks compared to J-hooks (BPUE of 1.605 for J-hooks and 0.727 for circle hooks). CPUE for the four target species of the observed fishery was significantly increased when using circle hooks, however, CPUE for swordfish was significantly decreased for unknown reasons. The authors of the study suggested that the use of circle hooks could benefit turtles in three ways: i) decreased bycatch rates, ii) decreased rate of deep-hooking events, and iii) decreased proportion of turtle releases with gear still attached.

Similarly, Domingo et al. (2012) found a decrease in loggerhead turtle bycatch of 25 - 45% when circle hooks were used in the Uruguayan pelagic longline fishery for swordfish and elasmobranchs. Albeit this difference was statistically non-significant. The authors observed a marked difference in turtle bycatch between two different types of longlines used (American-style *versus* Spanish-style) which used different baits (squid *versus* mackerel) with mackerel bait seeming to complement the bycatch reduction of circle hooks. However, both circle hooks and mackerel bait seem to decrease swordfish catches which are a target species of this fishery and hence, any reduction will likely result in reduced acceptance of this mitigation measures by fishers. Although some tuna species showed increased CPUE for circle hooks (Curran & Bigelow 2011; Sales et al. 2010).

Santos et al. (2012) compared hook type and bait type in the mid-Atlantic pelagic longline fishery and found that BPUE was higher overall with J-hooks than with circle hooks but also generally higher when using squid bait instead of fish bait. In their study, the most bycaught turtle species was olive ridley, followed by leatherbacks and loggerheads. Loggerhead bycatch numbers were not sufficient for a reliable statistical analysis. However, mortality seemed to be species-specific and correlated with the species-specific hooking locations. Animals hooked at flippers or entangled rather than hooked showed a higher survival rate upon haulback (100.0% and 90.5%, respectively) than animals hooked in their oesophagus or mouth (70.0% and 68.1%, respectively). Post-release survival rates were not assessed.

Marine mammals such as pilot whales and bottlenose dolphins may become entangled in the mainlines of the gear (Kerstetter & Graves 2006) or hooked while trying to depredate on the catch or the bait (Papageorgiou et al. 2022). Stakeholder interviews and knowledge suggests that within the Mediterranean Sea, bottlenose dolphins and striped dolphins have learned to depredate the bait after initially feeding on the caught fish (Papageorgiou et al. 2022). Bottlenose dolphins have been reported to depredate more frequently than striped dolphins while the latter cause more damage to catch and gear (Papageorgiou et al. 2022). Furthermore, the majority of bycatch seems to be juveniles that asphyxiated while attempting depredation (Papageorgiou et al. 2022). However, lack of empirical data and controlled studies means the role of hook shape on cetacean bycatch is currently unknown.

For elasmobranch bycatch, circle hooks may increase post-capture survival rates due to reduced deep-hooking (Curran & Bigelow 2011; Pacheco et al. 2011). However, circle hooks have been shown to remain in the animals' mouth longer after release if the hook is not manually removed by fishers (Landreau et al. 2024) and the survivability may additionally depend on species and season (Curran & Bigelow 2011; Kerstetter & Graves 2006).

Nevertheless, several studies have shown reduced capture of elasmobranchs using circle hooks. Curran and Bigelow (2011) found that bycatch rates of sharks declined by 17.1 - 27.5% when circle hooks were used instead of J-hooks or tuna hooks in the Hawai'ian tuna longline fishery. A decrease in blue shark (*Prionace glauca*) catch rates of 36% was observed also in the Hawai'i pelagic longline fishery after regulations requiring the use of circle hooks and bait restrictions were implemented (Gilman et al. 2007).

Ward et al. (2009) reported mostly increased catchability of circle hooks in the Australian pelagic longline fishery but with species-specific differences. While catchability of dusky sharks (*Carcharhinus acronotus)* and ocean sunfish (*Mola mola*) was reduced with circle hooks, relative catchability of blue shark, oceanic whitetip shark, tiger shark and crocodile shark increased which stands in contrast to the results from the Hawai'ian longline fishery.

Similarly, results from Sales et al. (2010) also show an increase in blue shark, shortfin mako, and *Carcharhinus* shark catches with the use of circle hooks in the Brazilian pelagic fishery. Blue shark, *Carcharhinus* shark, and shortfin mako shark catches increased by 17.1%, 51.2%, and 42.7%, respectively, when using circle hooks. It should be noted here however, that these elasmobranch species were targeted in this fishery.

Santos et al. (2019) conducted a meta-analysis assessing the effects of hook, bait, and leader type on the retention rates of target and bycatch species. For hook type, the authors found higher retention rates on circle hooks for tuna species (target) and some elasmobranch species such as porbeagle, shortfin mako, tiger, and crocodile shark (bycatch species). Lower retention rates of circle hooks were found for all turtle species analysed and the pelagic stingray, suggesting that circle hook may be used to reduce turtle bycatch but may come at the cost of increased elasmobranch bycatch. Furthermore, depending on the target species of the fishery, target catches may be reduced due to the use of circle hooks. Circle hooks decreased at-haulback mortality of 11 out of 19 analysed species between 6 – 27% including blue sharks, silky sharks, oceanic whitetip sharks, shortfin mako and scalloped hammerhead sharks. In contrast, bigeye thresher, longfin mako, crocodile sharks, smooth hammerhead and tiger sharks showed increased mortality rates with circle hooks albeit only the effect for bigeye thresher sharks was statistically significant. No information on turtle mortality was provided.

Hook shape in European waters

Similar to the studies by Sales et al. (2010) and Domingo et al. (2012) in South American waters, Coelho et al. (2012) compared the performance of J-hooks and circle hooks as well as bait type (mackerel *versus* squid) in mid-Atlantic Portuguese longline fisheries. Again, swordfish catches were significantly reduced for circle hooks (10 - 40% reduction) and for mackerel baited hooks (8 - 34% reduction). For tuna catches, circle hooks increased catch rates (statistically non-significant) but mackerel bait significantly reduced CPUE. Bycatch of bigeye thresher sharks and pelagic stingrays seemed more affected by bait type than by hook shape. Additionally, no effect of hook shape on elasmobranch mortality could be identified in this study.

In the years 2022 and 2023 two projects were carried out in the Mediterranean Sea aiming to improve the fishing selectivity of longline fisheries - the POBLEU and SEPAL project (Landreau et al. 2024). In the POBLEU project tested the selectivity of circular and J-hooks in 31 fishing trips (20 with J-hooks, 11 with circular hooks), to analyse which type caused more bycatch. The characterization of the fishery and the quantification of bycatch appear to show that the marine species most affected by longline fisheries in the Gulf of Lion are the pelagic ray (*Pteroplatytrygon violacea*), the blue shark, and the ocean sunfish with 64% of bycatch by J-hooks.

During Afonso et al. (2012) trials in the Azores a total of 603 individuals (53%) were classified as bycatch, with sharks accounting for approximately 45% of this bycatch. The study concluded that hook type showed no significant effect on fishing mortality for well-represented species or groups, although circle hooks were often associated with lower mortalities compared to J-hooks.

Santos et al. (2012) presented results on turtle bycatch from the same data collection as Coelho et al. (2012). They also found that BPUE was overall higher with J-hooks than with circle hooks but also was generally higher when using squid bait instead of fish bait. In their study, the most bycaught turtle species was olive ridley, followed by leatherbacks and loggerheads. Loggerhead bycatch was not enough for a reliable statistical analysis. However, mortality seemed to be species-specific and correlated with the species-specific hooking location. Animals hooked at flippers or entangled rather than hooked showed a higher survival rate upon haulback (100.0% and 90.5%, respectively) than animals hooked in their oesophagus or mouth (70.0% and 68.1%, respectively). Post-release survival rate was not assessed.

Hook position in the water column

General

The combination of hook type and position in the water column has a strong impact on fishing selectivity and reducing bycatch mortality. Using circle hooks at strategic depths can be an essential tool to mitigate impacts on vulnerable elasmobranchs.

Several interviews with longline fishers reveal that most believe that the depth of baited hooks and the length of time the gear soaks influence shark catch rates (Gilman et al. 2007). Setting baited hooks below a threshold depth has been shown to reduce catches of several species of sharks. For example, in the western and central Pacific pelagic longline tuna fisheries, Williams (1999) found that blue shark, silky shark, and oceanic whitetip shark catches were higher in shallow-set gear (one to nine hooks between floats) versus deep-set gear (at least 10 hooks between floats). Ward & Myers (2005) had similar results with oceanic whitetip sharks and dusky sharks in the Pacific Ocean. Using ecosystem modelling in the north Pacific and eastern tropical Pacific Ocean, Hinke et al. (2004) evaluated the ecological outcomes of longlining and found that restrictions on both shallow-set longline gear and on shark finning together may do more to recover top predators than simple reductions in fishing effort.
One technique for reducing shallow-set hooks in longline fishing involves lowering the mainline by using weighted sections (Beverly et al. 2009, Beverly & Robinson 2004). This configuration requires additional gear, and more time allocated to set and haul back the gear and has not yet been found to significantly reduce the interactions and impacts on sharks. Additional trials and better understanding of the main shark bycatch species' vertical habitat preferences are needed.
For cetaceans and turtles, depth restrictions on pelagic longline fisheries could potentially help reduce bycatch. For cetaceans, it has been suggested that fishing in depths shallower than 400 m could reduce bycatch; however, realistically this could only be achieved for fisheries targeting specific fish species occurring at a wide range of depths (Gilman et al. 2006). Additionally, cetaceans have been reported to engage in depredation also during hauling of the fishing gear, which would not change with changing of fishing depth (Gilman et al. 2006).
Swimmer et al. (2017) also suggested an effect of hook depth for sea turtles indicating that the top 30 m show the highest probability of turtle bycatch with probabilities dropping noticeably at depths higher than 50 m.

Hook position in European waters

Afonso et al. 2011 studied modifications in fishing gear related to hook type and hook position in the water column to assess their effects on catch rates and mortality of elasmobranchs in pelagic and coastal environments in the Azores. Hook position in the water column had a strong influence on the species caught in coastal fisheries. Suspending hooks in the middle of the water column reduced catches of common demersal species such as dusky shark, nursing shark (*Ginglymostoma cirratum)* and American skate/southern stingray (*Hypanus americanus)*, while increasing CPUE of species such as tiger shark *(Galeocerdo cuvier)* and bullish shark (*Carcharhinus leucas)*.

Leader Material

General

A recent study (Scott et al. 2023) aimed to examine options for optimal longline gear configuration to minimize injuries and/or mortality of non-target species while maintaining catch rates of target species. In this study, comparative equipment tests were carried out, evaluating the impact of the type of leader (wire or monofilament) on the capture rates and condition of the target and non-target species. In the Western Pacific Ocean, oceanic whitetip shark (*C. longimanus*) and silky shark (*Carcharhinus falciformis*) populations have been assessed as overfished, with overfishing still ongoing for oceanic whitetip shark. Both species are listed on Appendix II of CITES and the Convention on Migratory Species (CMS). In 2018, oceanic whitetip shark was listed as endangered under the US Endangered Species Act (ESA). Due to conservation concerns, several regional fisheries management organizations (RFMOs) have initiated measures to reduce bycatch mortality of oceanic whitetip shark and silky shark.

During the tests approximately 97 thousand hooks of each type were used, totalling 2984 individuals of 34 species captured. Results showed that for the main marketable species (bigeye tuna, yellowfin tuna, skipjack tuna and swordfish), there was no significant difference in catch rate (CPUE) between leader types, but for the sharks there were 41% more captures with wire leaders than with monofilament (CPUE = 0.76). However, when considering "bite-offs" (lines broken by bites), of which 94% occurred with monofilament, the difference between the types of leaders was no longer significant, suggesting that wire prevents the loss of captured sharks. Specifically, the blue shark was the most captured, representing 75.9% of sharks, with 35.3% more captures with wire. The shortfin mako also had 64.5% more captures with wire, reinforcing that this type of leader increases shark retention. This study concluded that monofilament leaders resulted in lower shark catches and mortality rates compared to wire leaders, without reducing catch rates of target species. About 41% more sharks were brought to the boat with wire leaders, while 94% of bite-offs occurred with monofilament, suggesting that it allows sharks to escape and reduces mortality (Scott et al. 2023).

In a meta-analysis, wire leaders were found to have lower retention rates for billfish and tuna species (target species) as well as for bigeye thresher sharks, pelagic stingrays and crocodile sharks (bycatch species) (Santos et al. 2019). Other elasmobranch species (blue shark, silky shark and shortfin mako shark), however, showed higher retention rates with wire leaders than nylon leaders (Santos et al. 2019). Despite higher retention rates, wire leaders showed decreased mortality rates for blue sharks, bigeye thresher and silky sharks compared to nylon leaders.

No studies were found that assessed the effect of leader material on cetacean depredation and entanglement in longline fisheries.

Leader material in European waters

Afonso et al. (2012) evaluated the effect of leader material and hook type on shark catch and mortality in pelagic longline fisheries in the Azores. Almost all bite-offs occurred on nylon leaders, indicating that sharks frequently escape when this material is used. The bite-off rate relative to the number of sharks caught was approximately 33%, suggesting that actual shark catches may be underestimated with nylon. Shark CPUE was higher with stainless steel leaders, which also caught twice as many live sharks (compared to 40 dead sharks with steel and 37 with nylon). Sharks such as *Carcharhinus falciformis*, *C. longimanus*, and *Alopias* spp. were captured alive only with steel leaders. The study concludes that the use of nylon leaders and J-hooks may lead to underestimation of both shark catch and mortality in longline fisheries.

Bait Type

General

The type of bait used in longline fisheries plays a key role in determining catch selectivity, influencing both target and non-target species. Switching from squid to fish bait has been shown to reduce sea turtle bycatch (Yokota et al. 2009), but it often results in higher shark catch rates (Coelho et al. 2012).

Squid is commonly used as bait in pelagic longline fisheries targeting swordfish (SPC 2009). Empirical studies and interviews with fishers suggest that large reductions in blue shark catch rate can be achieved when squid is replaced with fish baits (Galeana-Villasenor et al. 2009; Gilman et al. 2007; Petersen et al. 2009; Watson et al. 2005). For example, in the Hawai'ian swordfish longline fishery, shark catch rates (all species combined) dropped considerably (36% for blue sharks) when the fishery was required to switch from using J-hooks with squid bait to wider circle hooks with fish bait in order to reduce marine turtle interactions (Gilman et al. 2007). Historically, blue sharks made up more than 90% of total shark catches in this fishery, and the apparent drop in shark catches was primarily attributed to the change of bait.

Coelho et al. (2012) found squid bait yielded higher catch rates than mackerel bait for all target species combined (and regardless of hook type) in the pelagic longline fishery for swordfish, albacore and bluefin tuna. Pooled elasmobranch bycatch was also significantly affected by bait type but here, mackerel bait increased catch rates by 27.5% compared to squid bait regardless of hook type tested. Bycaught elasmobranch species included bigeye thresher shark, manta ray, pelagic stingray and crocodile shark but different species showed different bait preferences: Bigeye thresher sharks were significantly more bycaught with mackerel-baited hooks while manta rays, pelagic stingrays and crocodile shark were more bycaught in squid-baited hooks.

This means there might be a trade-off in conservation of turtles and elasmobranchs and even within elasmobranch species when it comes to mitigating bycatch with bait types in longline fisheries since turtles have been found to be bycaught less if mackerel bait is used (Yokota et al. 2009) and due to the species-specific bait preferences (Coelho et al. 2012; Gilman et al. 2007).

In their meta-analysis, Santos et al. (2019) found supporting results for this conflict between reducing bycatch of elasmobranchs and turtles using fish bait. Loggerhead and leatherback sea turtles showed significantly lower retention rates with fish bait than with squid bait. But six out of eight elasmobranch species showed higher retention rates using fish albeit this result was statistically non-significant. Additionally, blue sharks showed a significant mortality increase of 71% for fish baited-hooks compared to squid-baited hooks.

No studies were found assessing the effect of fish or squid bait on cetacean depredation and bycatch in pelagic longline fisheries. However, species-specific bait preferences can be assumed depending on the species' prey preference or the target species' prey preference. Common dolphins in the Mediterranean Sea and adjacent European waters show an overall preference for fish prey over cephalopods with the latter consisting usually less than 1% of the analysed stomach content of animals in the Aegean Sea (Vella et al. 2021). Given that bottlenose and striped dolphins have been observed to depredate on both, bait and hooked catch (Papageorgiou et al. 2022), and the usually very variable diet of odontocetes, it is unlikely that the type of bait will influence fisheries-cetacean interactions significantly.

Apart from squid *versus* fish bait, another bait modification tested for bycatch mitigation is dyed bait. Yokota et al. (2009) showed that blue-dyed bait may not be useful in reducing loggerhead turtle bycatches but potentially seabird bycatch, results that align with previous findings by Swimmer et al. (2005).

The effects of dyed bait on elasmobranch bycatch or marine mammal depredation are unknown but can be expected to vary across species depending on their visual acuity and/or the degree to which a species utilizes visual cues for predation.

Bait types in European waters

No studies directly assessing the impact of bait type in Portuguese or other European waters was found, however, studies conducted by Santos et al. (2012) and Coelho et al. (2012) were carried out within the Portuguese fishing fleet in equatorial mid-Atlantic waters.

Sensory Deterrents

General

Sensory deterrents can target different sensory systems for different species or taxa. Recently, Lucas and Berggren (2023) provided a comprehensive assessment of different deterrents tested for elasmobranchs, marine mammals and turtles. Deterrents can act on the auditory, olfactory or visual system of the ETP species.

An electric pulse device was developed in collaboration with the company FISHTEK to deter sharks and rays. This device, named “SharkGuard” is installed just above each hook and emits a strong electric pulse (Doherty et al. 2022). Experimental tests were conducted on 22 longline sets to study the effectiveness of the SharkGuard. Half of the set hooks were circle hooks without the device installed and half were circle hooks with the device installed. Hooks equipped with the SharkGuard significantly reduced bycatch of blue sharks (91.3%) and pelagic rays (71.3%). However, data also suggested a reduction in bluefin tuna catch (41.9%) on hooks equipped with the devices, but this difference was not statistically significant and requires further assessment (Doherty et al. 2022).

Other sensory deterrents could be used such as necromones or lights (Lucas & Berggren 2023), however, their efficacy and practicality in longline fisheries would have to be tested.

The use of pingers as bycatch or depredation mitigation tool for cetaceans has mainly been assessed in gillnet fisheries (see Chapter 2.1 Northern, Southern, and UK gillnets) but not much information is available on their applicability in longline fisheries.

Sensory deterrents for turtles have been tested in gillnet fisheries (i.e., LED lights) but no evidence for longline fisheries was found.

Sensory deterrents in European waters

The preliminary study assessing the effectiveness of the SharkGuard in pelagic longline fisheries presented by Doherty et al. (2022) took place in the Mediterranean Sea (Southern France). However, further testing is required to assess the effect of the device on target catches as well as the economic feasibility of a broad scale use within the pelagic longline fishery.

Cruz et al. (2014) tested pingers in a small-scale hand-jig fishery in the Azores with the aim of reducing depredation by Risso’s dolphins. Risso’s dolphin depredation has become an increasing problem in the area together with the previously known depredation by common dolphins and spotted dolphins (Cruz et al. 2014). The authors tested the efficacy of two different pinger types in the small artisan fishery but found no significant difference in depredation between sets with pingers and sets without pingers. In gillnet fisheries, the efficacy of pingers for depredation and bycatch mitigation of species such as bottlenose dolphins and common dolphins is still inconclusive and adverse effects such as habituation and habitat displacement are still debated.

Electropositive and magnetic materials

General

Permanent magnets and electropositive metals or rare earths (a mixture of the lanthanide elements: lanthanum, cerium, neodymium and praseodymium) create an electric field that disrupts the sharks' electrosensory system, causing the animals to exhibit aversion behaviours (Swimmer et al. 2008; Brill et al. 2009).

Field experiments have shown that rare earth metals attached near hooks reduced *Squalus acanthias* catches on bottom longlines by 19% (Kaimmer & Stoner 2008), and in laboratory studies, they reduced the frequency with which capuchin sharks attached to hooks and consumed bait (Stoner & Kaimmer 2008). However, other studies have shown that these metals had no effect on reducing capuchin shark catches when incorporated into longlines (Tallack & Mandelman 2009).

In another study using underwater video, seven configurations of rare earth magnets, two configurations of ferrite magnets, and two electropositive rare earth metals were tested as a way to reduce predation rates on bait by Galapagos sharks (*Carcharhinus galapagensis*). The configurations with three 50 mm diameter magnetic disks showed the greatest potential, with a vertical configuration of the magnets next to the bait reducing predation by 50%. A stacked configuration of the same magnets above the bait also resulted in significantly more sharks aborting investigations before consuming the bait.

This study concluded that magnetic devices and electropositive metals have limited effectiveness as repellents of Galapagos sharks, especially in environments with high shark densities and where social interaction between sharks (competition for bait) appears to be more decisive than magnetic stimuli.

Electropositive and magnetic materials in European waters

No studies assessing the use of electropositive or magnetic materials in European longline fisheries was found.

Other

Due to the well-documented decline in many elasmobranch populations, there is increasing pressure to implement new management and recovery strategies at national and international scales, such as shark sanctuaries and spatial and temporal fishing restrictions, and to improve handling and release techniques to increase post-release survival mortality.

Since 2009, fifteen coastal countries in the Atlantic, Indian and Pacific Oceans have opted to implement Shark sanctuaries that comprises the ban of commercial shark fishing, with laws prohibiting the possession, trade or sale of sharks and shark products (Ward-Paige 2017). In total, existing sanctuaries cover 15.6 million km², which represents about 3% of the world's oceans. Most of this area (88%) is in the tropical Pacific, followed by the Caribbean and the Indian Ocean (Maldives) (Paige & Worm 2017). The findings from Ward-Paige (2017) study indicated that shark sanctuaries generally had a higher relative abundance of sharks, although not greater species diversity. Additionally, there were fewer reports of declining shark populations and fewer instances of shark products being sold in local markets. However, there were no significant differences between sanctuary and non-sanctuary areas in terms of shark fishing or shark tourism activity. The study concluded that shark sanctuaries can serve as a valuable conservation tool, but they are not sufficient on their own. There is an urgent need for more detailed data on shark abundance, bycatch, and trade in shark products in order to better prioritize conservation efforts and enhance the effectiveness of both current and future shark sanctuaries.

The ecological and economic benefits of these spatial protection measures are recognised for many reef and demersal species. However, for highly migratory fish, such as pelagic sharks, it is still necessary to know the species' migration routes and aggregation behaviours and include these areas in spatial protection measures. Knowing these features for each species provides an important opportunity, although often overlooked, to safeguard and even recover stocks of pelagic species. The existence of new remote monitoring tools, both for species and for fishing fleets, offers a way to improve spatial management, especially in areas that are difficult to monitor (Boerder et al. 2019).

Faure et al. (2025) present a detailed study on handling practices and condition assessment of skates (e.g. *Amblyraja taaf*) caught as bycatch in longline fisheries targeting Patagonian icefish in the Southern Indian Ocean. The study found that skates released in good physical condition had an estimated annual apparent survival rate exceeding 92%. Skates handled quickly and with care, especially those protected from wind desiccation and temperature extremes (e.g., using "moonpool" vessel setups), had better survival outcomes. The authors recommended modifying fishing practices, such as reducing hauling speed and soak time, to further limit the impact on skates. They also noted the need to investigate the effects of air exposure duration and to consider the use of electronic tagging for more precise survival estimates in future studies.

ASUR project examined best handling techniques for shark release. Cutting branch lines as close to the hook as possible greatly improves shark survival after accidental capture. Projects have developed automatic branch line cutters to further minimize risks for both sharks and fishers, and these practices are being promoted among fishers to advance shark conservation (Directorate-General for Maritime Affairs and Fisheries, 2024).

Another study related to the project SOS Tubaprof tested several handling practices such as keeping the animal in the water during release, using appropriate tools (gloves, hook pullers, long line cutters) to remove or cut the hook, and avoiding prolonged exposure to air or sunlight were promoted. Whenever it was not possible to remove the hook safely, the line was cut as close to the hook as possible, reducing the negative impact. To reduce stress and increase survival of bycaught sharks it was recommended to place a wet cloth over its eyes and, if necessary, to ensure that salt water passed through its gills with a hose, preventing asphyxiation during handling (IMAR, 2023).

2.4. UK longlines (CIBBRiNA case study 6)

A fleet of around 15 vessels (25-40 m in length), targeting hake and to a lesser extent ling, is based in Spain, with mainly Spanish crew. Bycatch species of interest are variety of surface and plunge-feeding seabirds, including northern fulmar, northern gannet, and shearwaters. The following text here below is mainly based on a report by Kingston et al. (2023), as that review was done before some of the trials that are part of the CIBBRiNA case study.

Mitigation measures

Streamer lines

General

Streamer lines have been used successfully in several longline fisheries to reduce seabird bycatch. They were first developed on Japanese longliners working in the Southern Ocean (Brothers 1999) and are single or multiple lines that are connected to a high point on the vessel and are typically deployed over the stern during line setting operations and are retrieved back onto the vessel after the lines are fully deployed. BSLs have a main rope/s that contain multiple streamers which form a protective barrier over the longline that is designed to deter foraging birds from the vicinity of the baited hooks as the gear is set. The streamers are typically of decreasing length further from the vessel to reduce handling problems that can occur if they entangle the longline. The BSL should be sufficiently long that it extends well beyond the point where the longlines enter the water because baited hooks often remain in foraging range of birds until they have sunk several metres below the surface (ACAP 2016). Numerous studies have shown that the use of single or multiple BSLs significantly reduced seabird bycatch rates in various demersal longline fisheries (Melvin et al. 2001; Lokkeburg & Robertson 2002; Lokkeborg 2003; Paterson et al. 2017) while in another study no clear effect on bycatch rates was found when using a BSL (Fangel et al. 2017). Goad & Debski (2017) also report problems associated with BSLs entangling the longline during setting. BSLs can be tensioned by the deployment of a rope or buoy at the outer end (Goad & Debski 2017; Parker 2017) and this may help maintain the BSL vertically or near vertically above the longline in side-winds, extend its effective range and reduce the likelihood of the bird scaring lines becoming entangled with the gear.

Streamer lines in European waters

Streamer lines have been tested off the coast of Norway, and were shown to significantly reduce seabird bycatch, especially of northern fulmars (*Fulmarus glacialis*) (Løkkeborg 1998). Trials are underway in the UK to both design and test streamer lines.

Water cannons

General

Kiyota et al. (2001) investigated the use of water cannons to deter birds from longline vessels during line setting operations. They used a 30-Kilowatt electric centrifugal pump and reported that the range of the cannon was not sufficient to be particularly effective and that changes in wind direction would further limit its efficacy.

Water cannons in European waters

To our knowledge, water cannons have not been tested in European waters.

Lasers

General

Laser systems have been used to deter birds from fish farms, airports, dairy and other agricultural settings and properties since at least the turn of the millennium (Blackwell et al. 2002; Glahn & Dorr 2000). A marinized version aimed at minimising seabird longline interactions was developed by the Dutch Company SaveWave and marketed by Mustad in 2014. The device aims a green laser over the water around the longline as it is being set, and this circle of light (and beam in some conditions) can have a deterrent effect on scavenging seabirds. This device also comes with an optional acoustic deterrent package so that simultaneous acoustic and visual deterrents can be broadcast. A trial by Melvin et al. (2016) concluded that seabirds showed little detectable response to the laser during daylight hours but at night fulmars showed a transient and localized response. No more recent trials appear to have been undertaken (ACAP 2019b). Concerns have also been raised that it may damage seabird eyesight (ACAP 2016), but the evidence for this is not conclusive (Melvin et al. 2016).

Lasers in European waters

Trials have been conducted in European waters as stated above. Furthermore, there are vessels in Norway and Iceland that have used or continue to use similar devices, although the efficiency has not been examined scientifically.

Night setting

General

In addition to more technical approaches to bycatch reduction as described above, several studies have assessed how vessel operational changes might affect bycatch rates. Most seabird species forage primarily by sight (though olfaction is known to be used by at least some bird taxa) so in general bycatch rates tend to be lower when lines are set in darkness (Weimerskirch et al. 2000), and night setting is recommended as best practise by ACAP and some national authorities including New Zealand. However, night setting at high latitudes during summer months is almost impossible when there is little darkness. Furthermore, some seabirds are able to forage effectively in bright moonlight, while others may use the light from deck lights to aid foraging. Conclusive evidence that night setting is a useful measure to prevent fulmar bycatch is lacking and Melvin et al. (2019) concluded that for most seabird species bycatch rates in Alaskan demersal longline fisheries were lower at night, but northern fulmars were the exception and were caught at higher rates (+
40.4%) at night.

Night setting in European waters

Night setting is used in the winter months in northern Europe due to the short days at northern latitudes, although the efficiency has not been examined scientifically.

Underwater setting/Moonwells

General

An underwater line setter was developed and marketed by Mustad, and efficacy tests have been reported by Løkkeborg (1998) and Ryan & Watkins (2002). Although the device showed promise, several problems were encountered. The line setting tube was attached to the transom of the vessel, which can rise, and fall significantly as the vessel pitches in large waves or swells and the seaward end of the device was frequently lifted out of the water making the baited hooks more visible and available to birds near the boat. Other potential problems included the fact that some of the bird species where the trials were conducted can dive up to 10m below the surface and a line setter extending that deep is impracticable and could cause structural damage in heavy weather. Parker (2017) highlights an example of a longliner in New Zealand that experienced stress on the vessel's transom due to the presence of a setting tube. In a similar vein, another type of underwater line setter, the Kellian line setter, was conceived by a New Zealand fishers and has undergone several incremental developments over the last decade (Baker et al. 2016). The basic design involves towing a device just off the stern of the vessel at a depth of 4 to 7m, which the line and hooks pass under increasing the line deployment angle - meaning the hooks are more quickly out of foraging range of most surface feeding seabird species. Trials of the latest version (KLS4.4) also showed promise but some issues with gear deployment and damage and loss of baits was reported. According to Baker et al. (2016), further work is required to address these issues.

Moon pools involve a vertical tunnel built through the vessels hull that opens into a small pool inside the vessel and they are often found in drilling ships and scientific research vessels. In the context of seabird bycatch, the use of a moon pool would shield the hooks from foraging birds during hauling but would not reduce bycatch that occurs during line setting as lines are usually hauled through the moon pool but are typically set over the stern of the vessel in the traditional manner. Some fisheries also shoot lines through the moon pool. There do not appear to be any direct studies on the effects of moon pools on seabird bycatch rates (Parker 2017).

Underwater setting/Moonwells in European waters

Despite being conceptually appealing and showing some potential as a mitigation approach, underwater line setters have not proven practicable and are therefore not yet used widely in commercial longline operations. The moonwell design has been used in auto-longline vessels in Iceland, Norway, Denmark and the USA (Parker 2017) primarily to provide a safer working environment for the crew compared to open deck vessels, but as stated above there are no direct studies on the effects of moon pools on seabird bycatch rates yet.

Line shooter

General

Hydraulic line shooters reduce or remove tension on the mainline by deploying it more quickly than the vessel is moving (Parker 2017). Studies of the efficacy of line shooting devices on seabird bycatch rates are limited, and results are equivocal. Lokkeborg & Robertson (2002) found that lines set with a line shooter had higher seabird bycatch rates than the same lines set with a bird scaring lines, and Robertson (2008) found that sink rates of weighted mainlines were the same whether a line shooter was used or not. As with underwater line setting approaches, line shooters seem to be a reasonable idea but there is little conclusive evidence that they provide a suitable approach for reducing bycatch in demersal longline fisheries.

Most seabird mortality in demersal longline fisheries appears to occur during line setting operations as birds get caught on baited hooks and are dragged below the surface by the weight of the gear. However, some bycatch also occurs during line hauling and may lead to mortality and injury and some attempts have been made to reduce this interaction.

Line shooter in European waters

See the study mentioned above.

Line weighting

General

Robertson (2000, in Bull 2006) assessed sink rates under different external line weighting regimes by placing 6.5kg weights at various spacings (30m, 50m, 70m, 100m, 140m and 200m) in the demersal longline fishery for Patagonian toothfish near the Falkland Islands. As might be expected, overall sink rates decreased as spacing between weights increased. The sink rate in the top part of the water column was highest with weight spacings of 30m and 50m. Sink rates through the water column did not vary much when weights were spaced 70m or above. A study investigating different weighting regimes (4.25kg, 8.50kg and 12.75kg at 40m spacings) in the Patagonian toothfish fishery around South Georgia found a significant reduction in seabird bycatch rates when 8.50kg rates were used compared to 4.25kg weights, but no additional reduction was achieved by using 12.75kg weights (Agnew et al. 2000, Bull 2006).

Melvin et al. (2001) assessed the effects of adding weights to demersal longlines in fisheries targeting Pacific cod (*Gadus macrocephalus*) in the Bering Sea and sablefish (*Anoplopoma fimbria*) in the Gulf of Alaska where northern fulmar are the most frequently bycaught seabird species. In the first year of the study, the addition of 10lb (4.5kg) weights every 90m in the cod fishery and 0.5lb (0.25kg) weights every 11m in the sablefish fishery reduced overall seabird bycatch rates by 76% and 37% respectively. However, in trials the following year, when the same weighting regimes were compared against bycatch reduction rates associated with the use of paired bird scaring lines, no significant reduction was seen. Marked differences in seabird abundance, bait attack rates and bycatch rates were seen between the two years and the authors concluded that extreme inter-annual variation in rare event phenomena such as seabird bycatch has important implications for fisheries management, and that adequate evaluation of seabird bycatch deterrents via observer programmes will require multi-year data sets.

The use of integrated weighting in mainlines was tested in a demersal longline fishery in New Zealand (Robertson et al. 2004; Robertson et al. 2006). A comparison between lines with integral weighting of 50g/m and standard unweighted lines produced significant reductions of 95%-98% in bycatch rates of white-chinned petrels (*Procellaria aequinoctialis*) and 60%-100% reductions for sooty shearwaters (*Ardenna grisea*). Commercial catch rates were not affected.

In trials in the Alaskan demersal longline fishery targeting cod in the Bering Sea, three experimental mitigation treatments (integral line weighting, integral weighting with bird scaring lines and unweighted lines with bird scaring lines) were compared with a control of no mitigation (Dietrich et al. 2008). Integrated weighting reduced bycatch rates of surface feeding species (northern fulmar and Larus spp.) by 91% to 98% and a diving seabird, the short-tailed shearwater (*Puffinus tenuirostri*s) by 80% to 87%. It was also estimated that integral weighted lines reduced the distance behind the vessel that birds had access to baits by almost 50% when compared to non-weighted lines.

Robertson et al. (2004) recorded link sink rates of unweighted lines and weighted lines made from two materials – silver line and polyester. Tests were carried out from two chartered vessels and no differences in sink rates were found between vessels, but statistically significant differences were observed between line types. The weighted polyester line sank fastest (mean 0.272 m/s), followed by the weighted silver line (0.239 m/s) and the unweighted line (0.109 m/s). However, similar sink rates to those for the weighted lines were achieved by attaching external weights to unweighted lines. In contrast to the findings of Roberson et al. (2004), Pierre et al. (2013, in Parker 2017) found that line weighting configurations and corresponding sink rates varied greatly between vessels operating under normal commercial conditions, which suggests that there could be significant inter-vessel variation in bycatch rates in some fisheries.

Line weighting in European waters

As seen above, to our knowledge, line weighting has not been trialled in European waters before. There are pros and cons of line weighting approaches, as seen in Table 2 below, but this method might work in some cases in European fisheries with seabird bycatch issues.

Table 2. Pros and cons of line weighting approaches

Advantages	Disadvantages
There is evidence that optimal line weighting configurations do reduce seabird bycatch.	There are concerns for crew health and safety associated with the use of extra or heavier external weights.
Reduced bycatch and attack rates associated with optimal weighting configurations will lead to less bait loss and may therefore translate into improved target catch rates.	Use of lead weights (integral or external) increases the risk of this potentially harmful compound accumulating in the marine environment.
Integral weighted lines are safe for crew to use.	Adding extra weights increases crew workload.
Integral weight lines have a uniform sink profile that eliminates lofting associated with external weighted lines (ACAP, 2016).	Integral weight lines are typically used with auto-lining systems so may not be suitable for all vessel configurations.
Appropriate weighting can maintain hooks at the correct depths so may improve target catch rates	The use of appropriate external weighting regimes can only be checked through at-sea inspections.
Catch rates of target species were not reduced using integral weighted lines.	Integral weight lines may lead to higher catches of unwanted fish and elasmobranchs because the main line sits on the seabed.
The use of integral weighted lines can be checked in port inspections.	Increased gear costs.

Frozen bait

General

Investigations into the potential bycatch reduction effect of using thawed rather than frozen baits have largely focused on pelagic fisheries but may have relevance to demersal fisheries. Parker (2017) provided a short summary of work that has been conducted in this area. Two studies (Brothers et al. 1999; Klaer & Polacheck 1998) indicated that thawed baits sink faster, one tested actual sink rates (they also found that swim bladder state affected sink rates) and the other compared seabird bycatch rates from thawed and frozen baits and assumed because rates were lower with thawed baits that sink rates must therefore be higher. However, when Robertson et al. (2010) tested thawed versus frozen bait sink rates they found only negligible effect and concluded that there would be no significant reduction of seabird bycatch rates with thawed baits. Some issues associated with the use of thawed baits highlighted in Parker (2017) are that: baits may not be fully thawed before deployment, there is a lack of evidence of efficacy of this approach across bait types; thawed baits may detach from hooks more easily and bait thawing requires a specific part of the vessel to be set aside for this task

Frozen bait in European waters

As seen above, to our knowledge, the effect of using frozen bait has not been trialled in European waters before.

Offal/discard management

General

Management of offal or discards onboard longline vessels, particularly when setting or hauling the catch can reduce the number of birds around the vessels and therefore the chance of interactions with the gear (Weimerskirch et al. 2000). This can include keeping all offal on board the vessel or avoiding releasing offal into the water when hauling or setting the gear.

Several national authorities (e.g., New Zealand) have developed standards making offal management a key part of any mitigation strategy by ensuring offal is not discharged at the same time as lines are being set or that offal disposal during hauling operations is carried out on the opposite side of the vessel. Offal retention (for subsequent disposal when not setting or hauling is occurring) is recommended by ACAP (2019), but it has been highlighted that there may be logistical, or safety constraints associated with the temporary storage of all offal onboard (Bull 2006).

Offal and discard management in European waters

Discard bans, such as in Norway and Iceland, are thought to have reduced seabird bycatch, and reduced interactions of fulmars to the vessels.

Magnetic or Electric Deterrents

Elasmobranchs exhibit species-specific responses to various deterrent and selectivity devices, including magnetic and electric deterrents. These technologies aim to reduce
Sensory deterrents for turtles have been tested in gillnet fisheries (i.e., LED lights) but no evidence for longline fisheries was found.

Sensory deterrents in European waters

The preliminary study assessing the effectiveness of the SharkGuard in pelagic longline fisheries presented by Doherty et al. (2022) took place in the Mediterranean Sea (Southern France). However, further testing is required to assess the effect of the device on target catches as well as the economic feasibility of a broad scale use within the pelagic longline fishery.

Cruz et al. (2014) tested pingers in a small-scale hand-jig fishery in the Azores with the aim of reducing depredation by Risso's dolphins. Risso's dolphin depredation has become an increasing problem in the area together with the previously known depredation by common dolphins and spotted dolphins (Cruz et al. 2014). The authors tested the efficacy of two different pinger types in the small artisan fishery but found no significant difference in depredation between sets with pingers and sets without pingers. In gillnet fisheries, the efficacy of pingers for depredation and bycatch mitigation of species such as bottlenose dolphins and common dolphins is still inconclusive and adverse effects such as habituation and habitat displacement are still debated.

Electropositive and magnetic materials

General

Permanent magnets and electropositive metals or rare earths (a mixture of the lanthanide elements: lanthanum, cerium, neodymium and praseodymium) create an electric field that disrupts the sharks' electrosensory system, causing the animals to exhibit aversion behaviours (Swimmer et al. 2008; Brill et al. 2009).

Field experiments have shown that rare earth metals attached near hooks reduced *Squalus acanthias* catches on bottom longlines by 19% (Kaimmer & Stoner 2008), and in laboratory studies, they reduced the frequency with which capuchin sharks attached to hooks and consumed bait (Stoner & Kaimmer 2008). However, other studies have shown that these metals had no effect on reducing capuchin shark catches when incorporated into longlines (Tallack & Mandelman 2009).

In another study using underwater video, seven configurations of rare earth magnets, two configurations of ferrite magnets, and two electropositive rare earth metals were tested as a way to reduce predation rates on bait by Galapagos sharks (*Carcharhinus galapagensis*). The configurations with three 50 mm diameter magnetic disks showed the greatest potential, with a vertical configuration of the magnets next to the bait reducing predation by 50%. A stacked configuration of the same magnets above the bait also resulted in significantly more sharks aborting investigations before consuming the bait.

This study concluded that magnetic devices and electropositive metals have limited effectiveness as repellents of Galapagos sharks, especially in environments with high shark densities and where social interaction between sharks (competition for bait) appears to be more decisive than magnetic stimuli.

Electropositive and magnetic materials in European waters

No studies assessing the use of electropositive or magnetic materials in European longline fisheries was found.

Other

Due to the well-documented decline in many elasmobranch populations, there is increasing pressure to implement new management and recovery strategies at national and international scales such as shark sanctuaries, spatial and temporal fishing restrictions and improve handling and release techniques to improve post-release survival mortality.

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2.5. Pelagic trawl fisheries (CIBBRiNA case study 7)

The CIBBRiNA case study addressing large-scale pelagic trawlers includes vessels ranging from 40 to140m with fishing operations targeting herring, mackerel, horse mackerel, sandeel and blue whiting. The fisheries of current case study have already initiated trials of different mitigation measures for relevant ETP species. The bycatch groups of possible interest area seals, dolphins and porpoises, and pelagic sharks.

Mitigation measures

Bycatch reduction devices & excluder devices

General

The terms “bycatch reduction devices (BRDs)” and “excluder devices (EDs)” are often used interchangeably, causing some confusion. Both are umbrella terms for structures within trawling nets that aim primarily at reducing bycatch of non-target species with a secondary aim of reducing debris accumulating in the net. The term BRD generally refers to an opening in the top or bottom of the trawl net that allows non-target species such as marine mammals, turtles or sharks to exit the net without getting caught and hauled (Figure 5). EDs often have group-specific names according to the animal group being bycaught, such as turtle excluder device (TED), seal excluder device (SED), sea lion excluder device (SLED), etc. EDs are grid-like structures within the trawl net, usually situated just prior to the codend, that act as a semi-permeable barrier filtering out large megafauna, usually not targeted by the fishery, while simultaneously allowing smaller target species to pass through into the codend. Another term for an ED is “Nordmøre grid**”** – a term mostly used in the context of shrimp bottom trawls in higher-latitude fisheries. These barriers are usually applied together with a BRD to allow the exit of non-target megafauna from the net.

For the scope of this report, we are using the term ED as an umbrella term for all configurations of a selection grid in combination with escape openings (BRDs) for any trawl fishery and any ETP species.

The detailed configuration of the device varies depending on the species to be excluded and the target species. The adjustable features are the angle, material and rigidity of the grid, the position of the device within the net, the location of the escape opening (top or bottom of net), covering of the escape opening (to avoid loss of target species), and grid bar intervals (according to target and non-target species' sizes). Hence, there is no one-size-fits-all ED configuration and achievement of the most efficient designs requires careful planning and testing for each fishing *métier* (Baker et al. 2014).

There is a considerable body of literature assessing the efficacy of EDs in numerous different fisheries, regions and for different bycaught species. It is apparent that EDs in their basic form, i.e., an opening in the net without any grid, are ineffective in reducing bycatch (Brewer et al. 2006). Furthermore, the different configurations of the device seem to be vary widely in terms of their efficacy and should be assessed individually for each ETP species and target fishery. Generally, it has been suggested that EDs that allow upward escape might be more suitable for air-breathing megafauna such as marine mammals due to their natural tendency to swim towards the surface (Allen et al. 2014; Jaiteh et al. 2013; Lyle & Willcox 2008; Tilzey et al. 2006). However, other studies have shown no difference in results for upward or downward escape (Brewer et al. 2006). An additional benefit of upward excluding EDs would be the avoidance of deceased, bycaught animals falling out of the net during hauling causing an underestimation of the bycatch rate (cryptic mortality; Allen & Loneragan 2010).

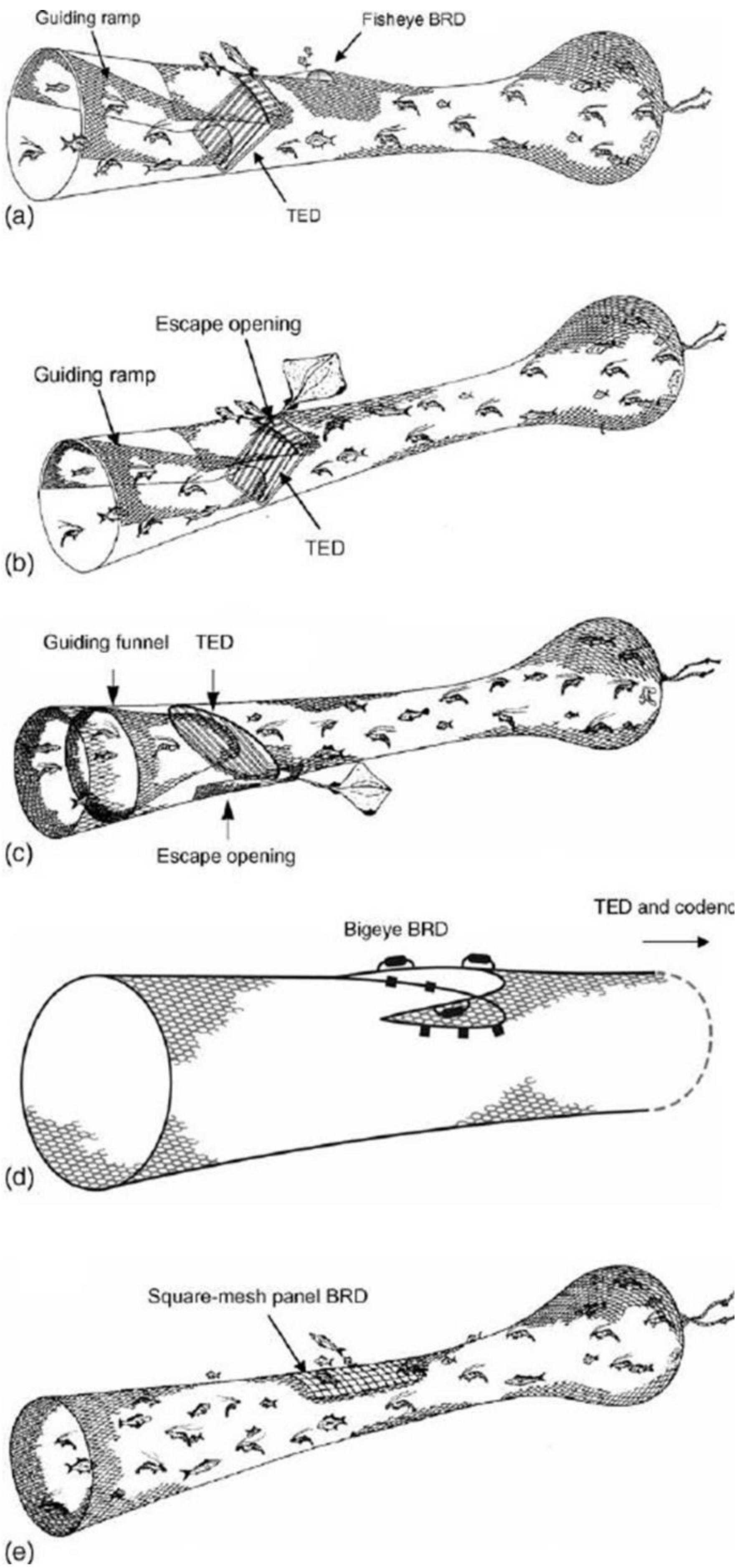

Figure 5.

Example designs and configurations of bycatch reduction devices (BRD) and turtle excluder devices (TED) by Brewer et al. (2006).

(a) A combination of a BRD and TED with a "guiding ramp" to avoid loss of target species. The TED grid is angled and leading to the top of the net with an escape opening. Additionally, a so-called fisheye BRD is present behind the TED grid to allow further escape of non-target species that may have been too small to be filtered out by the grid.

(b) The same upward excluding TED design with the guiding ramp but without the additional BRD.

(c) A downward excluding TED with a guiding funnel, also often referred to as "accelerator funnel" and no BRD.

(d) Bigeye BRD in the top of the net further upstream from the codend. Either with or without TED closer down the net.

(e) BRD only net. The BRD is covered by a square-mesh panel, but further configurations could include the opening to be uncovered. In their study, Brewer et al. (2006) found BRD only nets to be ineffective in excluding bycatch, while TED+BRD and TED only nets performed best. Downward excluding TEDs seemed to perform better and over a wider range of bycatch taxa than upward excluding TEDs

Furthermore, grids require a certain rigidity and angle to be effective in guiding the animals towards the escape opening (Allen & Loneragan 2010; Lyle & Willcox 2008, Wakefield et al. 2014). Flexible grids would eliminate the issues associated with the hauling process of rigid EDs (Lucchetti et al. 2016) and the storage problem for smaller vessels. However, some flexible grid configurations might be ineffective due to either additional entanglement risks or reduced target catches (Stephenson & Wells 2006). Most studies, however, report no significant difference between flexible or semi-flexible grids and their rigid counterparts (Lucchetti et al. 2019; Sala et al. 2011; Vasapollo et al. 2019; Wakefield et al. 2017).

Initial concerns have been raised regarding loss of target species through the escape opening and different approaches have been considered of how to minimize fish escaping. So-called acceleration funnels or curtains can help reduce the loss of target catch (Fennessy & Isaksen 2007). Furthermore, larger escape openings that have been linked to higher exclusion of non-target species (Lyle & Willcox 2008). Another viable modification of the funnel is the attachment of a "kite" over the escape opening preventing fish from swimming through the opening (Tilzey et al. 2006). Seals and sea lions can and have been observed to successfully escape from EDs with such kite structures (Queirolo et al. 2025; Tilzey et al. 2006). However, it remains to be tested whether this also works for turtles and elasmobranchs.

Studies assessing pinniped bycatch show mixed results and are often not reliable due to low sample sizes or generally low occurrence of bycatch events. Lyle and Willcox (2008) showed that 64% of seals that entered the net while trawling exited through the ED and only 22% exited via the net mouth while a much lower proportion were retained in the net. An increase in escape opening size was associated with a threefold reduction in mortality (Lyle & Willcox 2008) while Hamer and Goldsworthy (2006), however, showed that the mortality does not differ significantly between trawls with and without EDs reflects the mixed results in this field.

Allen et al. (2014) showed a reduction of dolphin bycatch in trawls with EDs by 45% in an Australian trawl fisher while another fisheries report in 2008 reported a significant reduction in dolphin, turtle, and some shark bycatch due to use of an ED (Stephenson et al. 2008). Stephenson et al. (2006) reported a 90% reduction in bycatch of large sharks (>152 cm) and large rays (>80.1 cm) in the Pilbara pelagic trawl fishery due to using the ED, while maintaining the same level of target catch.

EDs might not be as effective for dolphins as for other ETP species as they are generally strong swimmers and have mostly been observed to actively swim within the net in the direction of trawling and are able to exit through the mouth of the net rather than the escape opening (Wakefield et al. 2014; Santana-Garcon et al. 2018). In the comparatively rare instances where dolphins interacted with the ED, the animals seemed to be already distressed (Stephenson et al. 2007; Wakefield et al. 2017) or seemed to fail to locate the escape opening (Jaiteh et al. 2014). Most of these animals seem to passively approach the grid tail-first rather than head-first, posing additional entanglement risk by potentially lodging their tail fluke between the grid bars (Wakefield et al. 2017). However, EDs might be helpful in passively excluding dolphins during the hauling process or when the mouth of the net collapses during directional manoeuvres (Wakefield et al. 2014). Alternatively, they could prevent dolphins from venturing too far into the net where the chance of escape becomes increasingly small (Stephenson & Wells 2006).

Literature regarding the loss of target catch due to the ED shows varied results. Some studies found no significant differences between trawls with and without EDs (Fennessy & Isaksen 2007; Lucchetti et al. 2016; Vasapollo et al. 2019) and found that their configuration as a flexible ED helped with the handling on board for the fishers (Lucchetti et al. 2016). Stephenson and Wells (2006) reported reduced target catch due to a flexible ED design, although it is unclear whether this was the subjective opinion of the participating fishers or whether it was empirically assessed by the authors. Different ED configurations seem to affect target loss at different levels, and a balance needs to be found between maximizing the exclusion efficacy of an ED and minimizing its potential for clogging and passive target species loss.

Further concerns have been raised regarding the unintended injuries caused to ETP species that collide with the ED, potentially causing sub-lethal trauma and thus contributing to cryptic mortality (Meyer et al. 2017). However, efforts to assess post-exclusion mortality are scarce and will require considerable research expense an – and development of a viable protocol – to capture animals post-ED-interaction and tag them prior to release without inflicting additional injury and stress.

EDs are currently mandatory in several fisheries and countries around the globe. Australia has required the use of TEDs in the winter fishery for blue grenadier since 2005 (Baker et al. 2014), and there is also mandatory TED-use for shrimp trawls in EU-associated waters within the Indian Ocean and the Western Atlantic (European Union 2025), and for shrimp and summer flounder trawls in the USA (Code of Federal Regulations, Title 50 Part 223 2024). Additionally, Australia and New Zealand mandate the use of SEDs and SLEDs within certain fisheries (Hamer & Goldsworthy 2006; Chilvers 2008).

Additional benefits to the fishers are provided by the filtering capacity of the EDs, to exclude large debris that would otherwise damage the target catch in the codend and reduce catch quality (De Santis et al. 2024; Lucchetti et al. 2019; Sala et al. 2011; Vasapollo et al. 2019).

Bycatch reduction devices in European waters

Stephenson and Wells (2006) reported on efforts within UK waters with flexible and rigid grids as a dolphin bycatch mitigation method. According to the authors, the UK trials resulted in inconclusive results regarding the bycatch reduction, and a flexible grid configuration seemed to reduce target catches after which a rigid grid was implemented. A rigid steel grid seemed most effective in reducing bycatch and it was hypothesized that this may have been the result of the reflective properties of the grid (Stephenson & Wells 2006).

Northridge and colleagues (2011) reported some efforts and promising results from trials in the UK pair trawl fishery for bass (*Dicentrarchus labrax*) between 2003 and 2006 using EDs to mitigate short-beaked common dolphin bycatch, however, due to interference by an animal welfare organization, these trials could not be continued.

Studies in demersal trawling have proven effective for elasmobranchs in the Mediterranean Sea albeit smaller individuals or species can still slip through the grid (Brčić et al. 2015; De Santis et al. 2024; Vasapollo et al. 2019).

Assessment of the loss of target species and handling of the EDs on board the fishing vessels has shown that there are no significant differences between trawling nets with and without EDs regarding target catch and handling can be simplified when using a semi-rigid or flexible ED rather than a solid design (Lucchetti et al. 2016).

Entrance barriers

General

Entrance barriers aim to mitigate the initial entry of ETP species into the trawl net as opposed to EDs that subsequently exclude the animals after they have already entered the net. This would have several benefits as less modification to the trawl net is required and ETP species would theoretically have higher chances of survival because the risk of the animals getting trapped in the net and drowning is reduced. Especially dolphins have been observed to spend a period of time within the net foraging (Jaiteh et al. 2013) and only few actually make contact with EDs further down within the net but when they do, they already seem distressed and in bad condition (Stephenson et al. 2007; Wakefield et al. 2017). The effect that this distress has on the animals' survival chance post-exclusion is unknown. The initial prevention of animals entering the net would hence be preferable and ideally reduce the loss of target species due to depredation by the dolphins.

Entrance barriers have not been tested on a broad scale; hence, only limited information is available. These barriers can be vertical ropes, or a mesh attached at the mouth of the net aiming to prevent the initial entrance of ETP species into the trawling net. Only two references were found for the use of entrance barriers in bycatch mitigation trials. Baker et al. (2014) reported on the use of vertical rope barriers used in Dutch and Irish pelagic trawlers off the Northwest coast of Africa. However, no information on the efficacy in reducing dolphin bycatch was found. Iriarte et al. (2020) reported on the trial of a square mesh barrier to reduce pinniped bycatch in bottom trawls in South America. The barrier did not mitigate bycatch but rather posed an additional entanglement risk to the animals and caused operational difficulties by clogging. The authors deemed this approach overall ineffective. However, both studies mentioned using flexible barrier materials, i.e., rope and mesh.

Flexible EDs have also been found to pose additional entanglement risk, and semi-rigid or rigid configurations are preferred (Stephenson & Wells 2006). Whether semi-rigid or rigid entrance barriers would be feasible is questionable since trawling nets can measure 200 – 300 m in width at the mouth of the net; a rigid or even semi-rigid structure of that size could be impossible to handle or store on board and may increase net drag or cause other issues. A merged approach between an entrance barrier and an ED would be to move the ED forward within the net. Instead of having the excluding structure only just prior to the codend, moving it closer to the net mouth might increase the survival rate of ETP species by minimizing the time animals spend within the net. How far forward an ED could be moved depends on several different factors and would have to be tested métier specific. Due to the tapered nature of trawl nets, i.e., large mesh sizes at the net mouth gradually decreasing to the codend, moving the ED too far forward could increase target catch losses and pose additional entanglement risk for ETP species. Allen et al. (2014) found that the bycatch rate of bottlenose dolphins slightly increased according to independent onboard observers (11% of trawls) after moving the ED forward but according to the skippers' logbooks (89% of trawls) decreased. The forward position of the ED was just at the start of the net extension. More research is needed to assess the efficacy of moving EDs forward in pelagic trawls and whether this further reduces ETP species bycatch while maintaining target catch.

Entrance barriers in European waters

Limited information is available regarding entrance barrier trials in trawl fisheries within European waters. Stephenson and Wells (2006) reported on attempts in the UK conducted by Northridge. Rope barriers were trialled together with reflective floats. Only a few tows were carried out; while the barriers seemed to effectively deter dolphins from entering the net, the target catch was found to be low and efforts were discontinued (Stephenson & Wells 2006). Entrance barriers were also tested as part of the Cetambicion project, and results from those trials will be available in the near future.

Pingers

General

For a general introduction to pingers, please see chapter 2.1 Northern, Southern and UK Gillnets.

Pingers in European waters

Few studies have assessed the efficacy of pingers or other acoustic deterrents in pelagic trawl fisheries in general. Most efforts have taken place within the UK sea bass pelagic pair-trawl fishery. In 2001 and 2002, Northridge deployed up to 12 Dukane NetMark pingers on the foot and head rope of the trawl net but no significant difference in bycaught short-beaked common dolphins was found when compared to trawls without pingers (Northridge 2003 cited in Stephenson & Wells 2006). Additional trials using the AQUAmark 200 pinger did not show any promise either (Northridge 2004 cited in Stephenson & Wells 2006).

Further attempts have been made by Northridge and colleagues (2011) testing the DDD02F and DDD03H pingers in the UK bass pair-trawl fishery to assess their potential for short-beaked common dolphin bycatch reduction. They found a 77% reduction in bycatch and hypothesized that if only the newer DDD model had been used (DDD03H), a 100% reduction could have been achieved. Morizur et al. (2008) tested the CETASAVER#7 device by IFREMER/Ixtrawl in pelagic trawl fisheries in French waters, also targeting reduction of short-beaked common dolphin bycatch. Unfortunately, due to the low number of overall captures of dolphins during the study period, the reduction in bycatch was not statistically significant. However, based on a bootstrapping approach by the authors, a bycatch reduction rate of 50 – 70% was estimated for this device. In the final report for the PIC project ("Analyse de l'utilisation des PIngers à Cétacés pour les activités de pêche des chalutiers pélagiques et des fileyeurs"), Rimaud et al. (2019) estimated a 65% reduction in bycatch of short-beaked common dolphins for the DDD03H device based on data from field trials.

There are no pinger studies for mitigating bycatch of elasmobranchs in trawl fisheries. Behavioural studies on sharks in captivity have yielded variable and species-specific results (Chapuis et al. 2019; Ryan et al. 2018) with some showing a deterring effect of sound. More research is needed to determine whether pingers emitting sounds within the hearing range of elasmobranchs could act as a bycatch mitigation measure in trawl fisheries.

Recent discoveries of turtle vocalizations have opened research efforts in developing acoustic deterrents for turtles as potential bycatch mitigation measure. Chevallier et al. (2024) have laid the groundwork for these efforts by identifying a specific signal termed "rumble" which elicits alertness and escape responses in green turtles. Playback experiments showed that 55.6% of turtles showed vigilance after the sound and 38.9% of turtles showed immediate escape or escape after vigilance. Only 5.6% did not show any reaction to the sound. Animals did not react to any of the synthetic sounds or earthquake signals used in this study. The reaction to the stimulus was distance-dependent and the threshold seems to be at 300 m. However, repeated signal exposure led to a reduction in reaction within short periods, which speaks for rapid habituation. While promising, the use of pingers utilizing natural sound signals for turtles requires more research and may be more suitable for passive fishing gear like gillnets rather than trawlers due to the louder environment and the distance-dependent signal response.

Post-capture release

General

Post-capture release (PCR) refers to active efforts of sorting the catch into target and non-target species and releasing non-target animals as swiftly and gently as possible. While post-capture release does not prevent the bycatch of non-target species in the first place, it may help reduce the mortality of some bycaught species. Safe handling guidelines depending on bycatch taxa and fishing gear are available to increase survival rates and minimize stress of bycaught animals (Zollett & Swimmer 2019). This practice normally does not require any additional equipment or modification, however fishers need to receive adequate training and education on safe handling procedures and staff safety always needs to be the priority. A practical guide has been developed to inform stakeholders on best-practice release procedures to help reduce stress and physical trauma to live-captured dolphins and porpoises for commercial fishing gear (Hamer & Minton 2020). However, these guidelines do not specify safety procedures assuring the safety of the crew apart from a short safety note. Large animals such as cetaceans, pinnipeds and large elasmobranchs can pose a health risk to fishers who have to lift the animals to release them from the fishing gear and back into the water once brought aboard. Depending on the species, animals can weight up to several hundred kilograms. Lifting of such a weight and/or being hit by a distressed, thrashing animal can cause serious injuries. In the case of sharks and rays, fishers are also at risk of more severe injuries due to sharp teeth or venomous barbs (in some species). Rough weather can further complicate the release procedures and endanger fishers especially if large animals are brought alongside and are released while still in water (release of an animal in water is preferred to hauling them on deck due to reduced mortality of the animal). Leaning over the side of the boat to cut free the entangled animal can pose a serious risk to fishers. All necessary precautions need to be taken before any release is attempted. Fishers' safety takes priority over animal welfare. Several different safety guidelines are available regarding different gears and bycaught species (e.g., Clarke 2018; Peverell 2010) but may not be easily accessible for stakeholders.

Furthermore, post-release survival (PRS) rates vary depending on several factors such as severity of injuries and the animal's size and sex. In addition, survival rates are highly taxon- and species-specific (Enever et al. 2010; Saygu & Deval 2014). For trawlers in particular, bycaught animals can experience severe injuries through barotrauma (Ellis et al. 2017; Wilson et al. 2014). For air-breathing megafauna, trawling periods are usually too long (commonly between 4-6 hours but can be up to 12 hours) to survive if the animals enter the nets and become entangled during net shooting or trawling (e.g., Browne et al. 2005). Hence, virtually no studies are available assessing the post-release survival rates of marine mammals. Air-breathing marine megafauna may be hauled in alive if the animal becomes entangled during the hauling process. Even then, the weight of the caught fish in the codend and/or the stress the animal experiences until release can cause significant injuries and impair its PRS (Wilson et al. 2014).

Parga et al. (2020) assessed the post-capture survival of bycaught turtles in the Brazilian bottom-trawl fishery. Of a total of 28 bycaught turtles, 12 arrived onboard in active and alert condition and were released with a sPAT tag. Five turtles arrived weak, two of which died onboard the fishing vessel while the condition of the remaining three animals improved while they were being held onboard. After their apparent recovery, these individuals were also equipped with tags and released. Eleven turtles arrived in very bad condition and out of which ten died on the vessel. A total of 12 animals died on board the fishing vessel (43%) and 16 animals (57%) were tagged and released. Of the released animals, three died within six days of release. These animals were initially hauled on board in weak condition but seemed to have improved before release. This raises the overall mortality to 54%. In 16 animals, ultrasound was used to check for gas embolism due to the hauling of the trawl nets. In all assessed animals, signs of gas embolism were present and were found in kidneys and renal vessels. While it remains unclear whether gas embolism was the primary cause of death for the majority of turtles assessed in this study, it highlights that even seemingly active bycaught animals are likely die after release due to the bycatch-associated injuries and stress. With a mortality rate of 57%, post-capture release seems relatively ineffective as a method to reduce turtle bycatch mortality.

Post-capture release in European waters

Few studies in European waters have assessed the PRS of elasmobranchs caught in pelagic trawls. Saygu and Deval (2014) showed that the survival rate depends on tow duration and animal size for thornback skates, while total catch affected the PRS additionally for brown skates. Overall, the survival rate ranged between 44 and 92% for thornback skates and between 9 and 49% for brown skates (Saygu & Deval 2014). Enever et al. (2010) measured a survival rate between 55 and 67% for small-eyed skates (*Raja microocellata*).

Operational changes

General

Operational changes include a wide array of alternative equipment or fishing practices such as fishing in alternative areas, depths, mesh sizes, reducing trawling/soaking time and so on. Switching to alternative fishing gear that is less likely to result in bycatch has been proposed but is usually challenging due to reduced fishing efficiency or operational difficulties in relation to the fishing vessel (Pinn 2023; Ryan et al. 2022). Alternative gear such as pots and traps have mainly been suggested as alternatives for gillnets and some gears will not be able to catch target species targeted by pelagic trawls (more information on alternative gears in 1.1, p. 16 ff.). Time-area closures have been used in many areas to conserve different species in fisheries management (Murray et al. 2000; Niemi et al. 2012; Pastoors et al. 2000; Ye et al. 2000). In particular, dynamic time-area closures are preferred over full time closures to account for seasonal distribution changes of the species of interest and environmental changes (Smith et al. 2021). Ideally, detailed species distribution models are needed for the ETP species of interest to optimize the closures. However, time-area-closures can be associated with considerable loss in profit for the stakeholders and the local economy (O´Keefe et al. 2014). Furthermore, for highly mobile species with wide distributions as is usually the case for small cetaceans and pinnipeds, this approach may not be effective enough to accept the economic loss (O´Keefe et al. 2014). For a more comprehensive assessment of alternative gears and time-area closures see section 1.2 (p. 6 ff.).

Several studies have identified a correlation between megafauna bycatch and fishing depths in trawlers. Thompson et al. (2013) found a negative correlation between fishing depth and common dolphin bycatch in New Zealand trawl fisheries with decreasing bycatch risk for increased fishing depth. The authors suggested that an average increase of 21 m in fishing depth could have halved the probability of common dolphin bycatch. Most critical seemed to be the upper 40 m of the water column in this study with 70% of the observed captures having occurred in this depth. Additionally, the same study showed a correlation between low light conditions and bycatch with 80% of all captures having occurred at low light.

Operational changes in European waters

Depth

Two studies assessing short-beaked common dolphin bycatch in European waters have shown a significant effect of depth on dolphin bycatch (Fernández-Contreras et al. 2010; Puente et al. 2023). Both publications show an increased risk of bycatch in depths ranging from around 100 to 300 m. Fernández-Contreras et al. (2010) suggested that a ban on trawling in depths shallower than 250 m could have reduced dolphin bycatch events by 68% while a ban on trawling in waters shallower than 300 m could have eliminated all bycatch. However, the average fishing depth for the study was 299 m, meaning that a ban of fishing in depths shallower than 300 m would likely not be accepted as readily as a ban on 250 m and below (Fernández-Contreras et al. 2010). The same two studies also found higher bycatch rates during the night compared to the day. While this effect was statistically significant for the data collected by Fernández-Contreras (2010), Puente et al. (2023) did not find a statistically significant difference. Nevertheless, reducing night trawling could further reduce dolphin bycatch numbers. Depth restrictions could also help reduce turtle bycatch (Guimaraes et al. 2018).

Mesh shape

Some studies have assessed the effects of switching from diamond mesh to square mesh codends and increased mesh size on discards in bottom-trawler fisheries (Enever et al. 2010; Ordines et al. 2006). This could be helpful in reducing dogfish bycatch and skate discards by selecting against small individuals (Enever et al. 2010). By switching from 80 mm to 100 mm meshes, the authors demonstrated a significant reduction in discards by 72% while maintaining the commercial value of the retained catch. The increase in mesh size and changed configuration (from diamond mesh to square) also reduce overall codend weight which resulted in improved health of landed skates which could then be released and are assumed to have a higher survival probability than skates bycaught in the common 80 mm diamond mesh codends (Enever et al. 2010). However, Ordines et al. (2006) did not find a difference between 40 mm diamond and 40 mm square mesh nets regarding skate selectivity albeit for other species. Further research is needed to assess the efficacy of this gear modification in mitigating the bycatch of other species of interest and across different trawling fisheries.

Day versus Night

Some data suggests that common dolphin bycatch in pelagic trawls is higher during nighttime hours than during daytime hours (López et al. 2003; Fernández-Contreras et al. 2010; Morizur et al. 1999). Fernández-Contreras et al. (2010) found that despite the Galician pair trawler fishery operating mainly during the day, in relative numbers more bycatch occurs during the night. The authors found that after depth as the main influencing factor for bycatch, time of the haul (i.e., day versus night) is the second most influential factor. Morizur et al. (1999) compared numerous French, Irish, Dutch, and UK trawl fisheries and their marine mammal bycatch and found that most bycatch of dolphins occurred during the night or the early morning hours. It is possible that limiting nighttime trawling could reduce dolphin bycatch in some trawl fisheries. However, due to the rare nature of bycatch events and most trawls being performed during the day anyway, the feasibility and cost-benefit advantage would need to be carefully considered before implementing any broad scale regulations.

Interestingly, Hamer and Goldsworthy (2006) found an inverse effect for seal bycatch in the Australian winter blue grenadier fishery. Australian fur seals were exclusively bycaught during the day despite 50% of observed trawls having taken place during nighttime. Whether this pattern also applies to European seal species and trawl fisheries has, to our knowledge, not been studied. Therefore, it is not possible to say whether night-trawling restrictions would harm other ETP species populations even though they might reduce common dolphin bycatch.

Lights

General

Lights as a deterrent is often trialled in gillnet fisheries as bycatch mitigation approach. Larsen et al. (2018) tested green LED lights in addition to a BRD to reduce bycatch of non-target fish species, but no significant reduction was found. Hannah et al. (2015) added blue LEDs to escape opening to increase escapement rate of chinook salmon from pelagic trawl nets. The addition of LEDs significantly increased the escapement rate from 52.6% to 75.0%. Allman and colleagues (2020) tested green LED lights at different brightness levels and intervals on the net in the Ghanaian gillnet fishery and found an 81% reduction in turtle bycatch while maintaining target catch levels. Generally, a substantial amount of research has investigated the use of light sources as bycatch mitigation measure in gillnet fisheries for turtles and other marine megafauna (see chapter 2.1 Northern, Southern and UK Gillnets, p. 16 ff.). Whether or how these findings could translate into uses for trawl fisheries remains to be investigated.

We are not aware of studies assessing the effect of light in trawling fisheries on marine mammals, elasmobranchs, or turtles in non-European waters.

Lights in European waters

To our knowledge, no studies have assessed the efficacy of lights as bycatch mitigation in trawling fisheries in European waters.

Real-time catch composition assessment and AI (in development)

Rose & Barbee (2022) developed and tested an automated active-selection BRD ("ActSel BRD"). Using a remote trigger and hydrodynamic devices to open and close the escape opening within the trawl, the authors can switch between capture and release mode within 10 seconds. The authors argue that this might not be fast enough to select on a fish-to-fish basis. However, it is possible that this could aid the release of ETP species, which usually do not pass through the net as quickly as fish and are able to swim into the current at greater speed than the trawl. Additionally, shooting and hauling of the net have been associated with high bycatch risk of marine mammals (Hamer & Goldsworthy 2006) and performing these steps with a net in release mode would exclude at least some bycatch. Rose & Barbee also suggested the combination of their ActSel BRD with automated video analysis, which could potentially exclude larger bycatch species automatically. However, this requires further development and field trials and will likely not help with the mitigation of bycatch in the near future.

The EU HORIZON project "Marine Beacon" also includes a work package (WP5) designated to develop AI-based methods for real-time monitoring of fisheries and ETP species bycatch. While this approach would not directly reduce bycatch, faster and more reliable data on bycatch could be used to make informed conservation decisions and inform, for example, time-area closures more reliably. Bycatch and species distributions are incredibly dynamic and thus, being able to respond to changes as they happen would allow for more effective bycatch mitigation (more information about Marine Beacon and WP5 here: https://marinebeacon.eu/work-packages/ and https://marinebeacon.eu/smarter-tools-for-a-smarter-ocean-wp5-and-the-future-of-bycatch-monitoring/).

Other

Sensory deterrent/SharkGuard

SharkGuard is a device developed by Fishtek Marine to reduce shark and ray bycatch in longline fisheries. The device emits an electric pulse that can be perceived by elasmobranchs and has shown positive effects in field trials (see Chapter 2.4 Surface longlines for more details).

Trials testing this device in trawl fisheries are under way and time will tell if it can help reduce elasmobranch bycatch in pelagic and demersal trawl fisheries.

Predator silhouettes

Some studies have investigated the use of predator silhouettes or dummies as bycatch mitigation tool for turtle bycatch in gillnets. While it has been found to significantly reduce turtle bycatch, it unfortunately also significantly reduced target catch, making it a non-feasible mitigation approach (Barkan 2010). However, this has been proposed as a potential tool for bycatch in trawl fisheries where the dummies could be attached to the trawling gear ahead of the net to scare away turtles in the trawling path or even the use of underwater unmanned vehicles (UUVs; "underwater drones") has been suggested (Lank & Roberts 2022). The efficacy and feasibility of such an attempt and the potential for extrapolation to the complete fleet remain to be determined.

Phosphorescent nets

The idea of creating glowing fishing nets or ropes as an alternative to LED-illuminated nets was proposed in a report by Barkan (2010) as part of a research project. Buoys were painted with phosphorescent paint while the lead and foot line were specifically produced by Genesis Light Line, LLC. However, the materials were too expensive to be incorporated into commercial fisheries at that point. However, the author argued that if this gear modification shows successful in reducing turtle bycatch, efforts would be made for mass production of the rope, thus making it more affordable. Unfortunately, no further results or mention of the trials could be found. If found successful, this glowing material could have been potentially implemented in trawl fisheries either to illuminate the entrance to the net or to make the BRD or TED more visible for marine megafauna to escape through the opening in the net.

Reflective floats/materials

Anecdotal evidence of trials conducted in the UK sea bass pelagic trawl fishery suggests some degree of deterrence of reflective structures for common dolphins. Northridge trialled a net entrance barrier with interspersed reflective floats and a steel exclusion grid which reduced dolphin catches (Stephenson & Wells 2006). However, the sample size was low and the effectiveness of the materials was never assessed separately.

2.6. Demersal trawl fisheries (CIBBRiNA case study 8)

This chapter explores potential mitigation measures to reduce or eliminate bycatch of elasmobranchs in demersal (bottom) trawl fisheries in the North Sea. Even though the focus of the case study in CIBBRINA is the reduction or elimination of bycatch of elasmobranchs in mixed demersal fisheries for flatfish with tickler chains and in flyshoot fisheries, in this chapter, available mitigation measures for other demersal trawl fisheries are also explored to assess their applicability in demersal trawl fisheries.

Central in the assessment of measures relevant in demersal trawl fisheries are the following vulnerable or conservation-sensitive species, including the starry ray (*Amblyraja radiata*), cuckoo ray (*Leucoraja naevus*), common blue skate (*Dipturus batis*), flapper skate (*Dipturus intermedius*), spiny dogfish (*Squalus acanthias*), and tope (*Galeorhinus galeus*).

Mitigation measures

Although various mitigation devices have been developed to reduce or eliminate the bycatch of elasmobranchs in fisheries, only a few devices are specifically suitable for demersal trawl fisheries. This is mainly due to the morphological similarities between target species of such fisheries and elasmobranchs (e.g., flatfish and rays), combined with practical constraints, such as trawling speed and catch methods, which limit the number of feasible mitigation options.

Below is an overview of available measures that can be applied in demersal trawl fisheries, with general descriptions, information about their applicability in which type of demersal trawl fisheries, and information about their use in European waters.

Excluder devices

Excluder devices such as hard/rigid or soft grids placed ahead of the cod-end can effectively direct large-bodied elasmobranchs out of bottom trawl gear, specifically in prawn, Nephrops and brown shrimp fisheries:

- **The Nordmøre grid**
  The Nordmøre grid is an excluder device designed to exclude large non-target species, such as sharks and rays, in bottom trawl fisheries, particularly for prawn (northern shrimp) fisheries, but also for Nephrops trawling. The grid is made of parallel bars spaced to allow small target species (e.g. prawn, Nephrops) through into the codend, while larger animals are deflected upward toward a designated escape opening (Valdemarsen & Suuronen 2003).

The Nordmøre Grid is mandatory in Norway, Russia (Barents Sea cooperation), Iceland (some regions) and used in prawn (northern shrimp) and Nephrops fisheries (Larsen et al. 2019)

- **The SepNep**
  Similar in idea to the Nordmøre grid is the SepNep (SEParation panel for NEPhrops trawls) is a gear innovation developed to improve selectivity in Nephrops (Norwegian lobster) trawl fisheries. Installed inside the trawl net, typically near the codend, the device consists of an inclined separator panel that takes advantage of behavioural differences between species: Nephrops tend to stay low and crawl along the seabed, while fish and other bycatch species—such as sharks, rays, and flatfish—swim upwards. This separation allows the catch to be divided into two compartments, one for Nephrops and the other for bycatch (Steins et al. 2017).

  The SepNep is widely used in the Netherlands, but also in Scotland and Sweden (where it is called 'the Swedish Grid' and mandatory since 2004) (Catchpole et al. 2006).

- **The KingGrid**
  In German brown shrimp beam trawl fisheries, the KingGrid was developed to address challenges such as bycatch and clogging, in particular from suspended materials like seagrass, which are problematic for the commonly used sieve nets. Unlike traditional rigid steel grids, the KingGrid is made from polycarbonate, making it lighter, more flexible, and more robust in handling operations. Its modular design requires minimal skills for assembly and repair, while also allowing for easy adjustment to meet selectivity requirements (NSAC, 2024).

  The KingGrid is used in brown shrimp beam-trawl fisheries in Germany (particularly in Schleswig-Holstein and the North Sea region (NSAC, 2024).

- **The Sieve Net**
  The sieve net (*zeeflap in Dutch*) is a funnel-shaped mesh panel that is mounted inside a shrimp trawl net. It has a mesh size of 50–70 mm. Shrimp pass through the meshes of the funnel-shaped sieve net and enter the codend. The funnel ends with an opening at the bottom of the net. Bycatch that is too large to pass through the mesh (e.g. sharks and rays) is directed out of the net via this escape opening.

  Under EU Council Regulation 850/98, fishers in the brown shrimp fisheries are required to use a sorting grid in order to reduce discarding of juvenile commercial fish species (Council of the European Union, 1998). In practice most shrimp vessels (in the Netherlands, Germany, the UK, Denmark, and Belgium) use a sieve net (Acoura Marine Ltd. 2017, Slijkerman, et al. 2016, Nederlandse Vissersbond, 2025).

Although grids are effective excluder devices in the fisheries addressed above, the applicability of such grids to mixed demersal trawl fisheries targeting flatfish may be less suitable:

- While a grid could be used to separate non-target species such as sharks and rays, doing so would result in the potential loss of commercially valuable fish like turbot.
- While using an additional bycatch compartment could, in theory, be used and opened during fishing to release non-target species such as sharks and rays, doing so would also result in the potential loss of commercially valuable fish like turbot. A more effective, though less optimal approach (in terms of time and effort involved) could be to keep the bycatch compartment closed during towing and carefully release any

bycaught sharks or rays after hauling, helping to reduce mortality (Wageningen Marine Research, internal information).

- However, even with a bycatch separation device in place, it remains extremely difficult to distinguish and separate ETP (Endangered, Threatened, and Protected) ray species from non-ETP species, which are of commercial value. Similarly, separating ETP species from commercially valuable fish with similar body sizes and shapes poses a significant technical limitation (Wageningen Marine Research, internal information).
  Another limitation is that the effectiveness of bycatch reduction measures in demersal trawl gear is predominantly influenced by towing speed; to improve the performance of devices such as escape panels, the towing speed must be reduced. However, doing so will allow sole -being strong swimmers- to swim ahead of the gear or escape through larger mesh openings in the forward sections of the gear. This can lead to reduced catches and negatively impact the fishery's profitability (Wageningen Marine Research, internal information).

Modular Harvesting Systems

A new fishing technique, originating from New Zealand, is currently being tested in the Netherlands: the Modular Harvesting System (also called 'FloMo', or the 'Kiwi-codend' (Moran et al. 2023) (Figure 6). In this method, the final section of the trawl net (the extension and codend) is replaced by three different plastic modules: a cone (tube), retention modules, and a lift bag. The cone is a funnel-shaped module without openings, ensuring that the gear remains open at all times. The retention modules have holes that allow undersized fish to escape and enable water to flow out, preventing the gear from collapsing. The lift bag functions as the codend and has no openings, allowing the catch to be hoisted aboard while still submerged (Van Mens et al. 2025).

This technique offers notable advantages in terms of fish welfare and selectivity. Its rigid structure keeps the codend open, preventing fish and elasmobranchs from being crushed or overly confined, which reduces mechanical damage and stress. Additionally, the lift bag allows fish and elasmobranchs to remain submerged during hauling, minimizing stress from exposure to air. In terms of selectivity, the retention modules include escape holes that enable undersized or non-target fish to exit the gear before reaching the codend (Moran et al. 2023). As such, the FloMo presents a viable alternative for returning relatively undamaged elasmobranchs to the sea, particularly in cases where other technical solutions, such as grids, are not feasible due to unacceptable loss of marketable catch.

This technique has been and is being tested in the Netherlands. However, it cannot currently be used in practice. The EU Technical Measures Regulation (TMR) does not explicitly prohibit the use of the FloMo but does impose mesh size requirements for towed fishing gear. As the FloMo is made of rigid plastic components rather than traditional netting, it does not have a mesh size and therefore falls outside the scope of adherence to the TMR. Consequently, legal amendments to the regulation are necessary for the FloMo to be permitted in commercial fisheries within the EU (Van Mens et al. 2025).

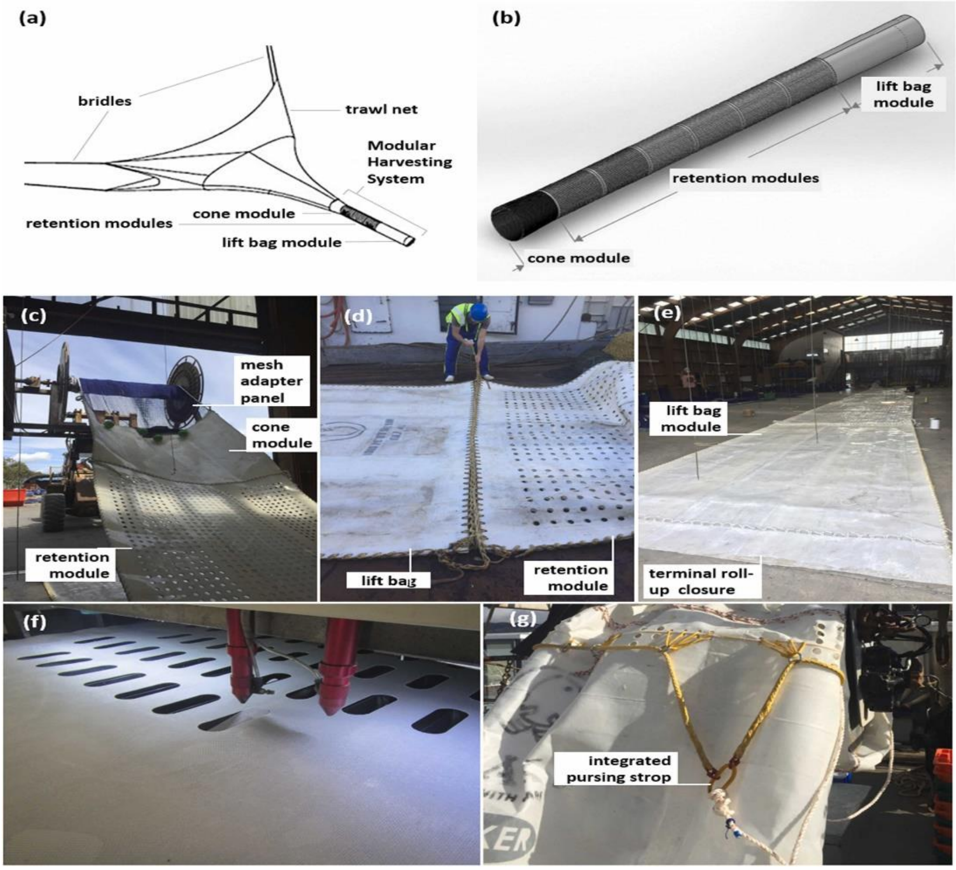

Figure 6. Modular Harvesting System (MHS) as developed by Moran et al. (2023). The system replaces the standard codend in trawl nets and consists of three major parts: i) the cone module, ii) the retention modules, and iii) the lift bag module. The MHS does not mitigate bycatch itself but allows the catch (including bycatch) to be hauled aboard while still submerged in seawater potentially increasing the post-release survivability of bycaught species such as sharks and rays. Figure adapted from Moran et al. (2023).

Magnetic or Electric Deterrents

Elasmobranchs exhibit species-specific responses to various deterrent and selectivity devices, including magnetic and electric deterrents. These technologies aim to reduce bycatch by exploiting the sensitivity of elasmobranchs to electric or magnetic fields, discouraging their approach to fishing gear.

While promising results have been observed in some regions, the use of such deterrent devices in European waters remains limited. Moreover, there is still a significant knowledge gap regarding how elasmobranch species native to the North Sea respond to these mitigation measures, highlighting the need for further region-specific research and testing (ILVO, internal information).

Removing the tickler chain

A trial carried out in Western Scottish waters, showed that removing the tickler chain can significantly reduce the catch rates of skates and sharks. While this modification had minimal impact on the catches of haddock, whiting, and flatfish, it did lead to a notable decline in the catch rate of commercially important anglerfish (Kynoch et al. 2015)

This technique is currently not mandatory and has not been applied in practice outside of the trial (area).

Post-capture handling and release

As discussed in more detail in the section about pelagic trawling, post-capture release (PCR) refers to active efforts of sorting the catch into target and non-target species and releasing non-target animals as swiftly and gently as possible, increasing post-release survival rates. While post-capture release does not prevent the bycatch of non-target species in the first place, it may help reduce the mortality of some bycaught species (Zollett and Swimmer 2019).

In general, post-release survival (PRS) rates for elasmobranchs vary depending on several factors such as air exposure periods, severity of injuries, and are highly taxon- and species-specific. For trawlers in particular, bycaught animals can experience severe injuries through barotrauma (Ellis et al. 2017; Wilson et al. 2014).

In order to increase survival rates, handling procedures could be improved when releasing live bycaught animals into the sea. Optimised handling procedures increase survival rates and minimize stress of bycaught animals and do not usually require any additional equipment or gear modification - depending on bycatch taxa and fishing gear. While published guidelines are available for various bycatch taxa in various types of fishery, fishers need to receive adequate training and education on safe handling procedures and staff safety always needs to be the priority (Zollett & Swimmer 2019). Furthermore, the suitability of generic guidelines for specific situations should always be reviewed.

A specific mitigation measure that could increase survivability post-capture is a water-filled hopper to temporarily store the catch on board of the vessel. The reasoning behind such devices is that for trawlers in particular, bycaught animals can experience severe injuries through barotrauma (Ellis et al. 2017; Wilson et al. 2014). By introducing a water-filled hopper on the vessel to temporarily store the catch, the duration of air exposure, and associated stress, for rays and skates can be significantly reduced (NSAC, 2023).

Air hoppers have been developed and trialled in various fisheries around the world with mixed results. One example of a project where it was trialled was the Raywatch project (a two-year EMFF-funded project), which identified a correlation between air exposure and ray survivability (NSAC, 2023).

Ideally, any modified gears incorporating technical mitigation measures are not compromised in their catch performance for the target species, in particular sole, as well as for other commercially important bycaught species such as turbot or megrim.

However, in the (southern) North Sea, preventing bycatch of sharks and rays in mixed-species demersal trawl presents a significant challenge, as available technical mitigation measures, in particular excluder devices, tend to affect the catch rates of both target species and other commercially important, non-target species, including other ray species.

Due to the continued lack of effective and practical solutions for reducing elasmobranch bycatch in bottom trawl fisheries during fishing, there is a clear need for more fundamental research to better understand the challenges and develop targeted mitigation strategies.

While safe handling procedures and post-capture release do not avoid the initial bycatch, they can lower mortality rates among some bycaught species, making them a partial but valuable mitigation tool. These measures are low-cost, gear-independent, and do not require new equipment, making them broadly applicable across fleets. In addition, water-filled hoppers can significantly reduce air exposure and improve survivability post-capture.

3. Widely applied mitigation measures

The efforts to reduce undesired and incidental bycatch go beyond the scope and time frame of the current project. While CIBBRiNA case studies focus on testing and developing concrete mitigation measures in close collaboration with fishers appropriate for the combination of fishing gear, target species and ETP species in focus, fisheries management across the globe has been tackling bycatch with approaches shown to be applicable across fisheries and species. In this chapter, we present the most common bycatch mitigation measures applied based on currently available peer-reviewed research and expert/stakeholder opinion.

3.1. Overview of broadly applicable mitigation measures

Time-area closures

General

One way of reducing bycatch is by limiting the fishing effort in a specific area and/or over a certain time period, so-called time-area closures. The idea behind time-area closures is to take advantage of naturally occurring variations in the degree of co-occurrence between target and bycatch species (Murawski 1994). Time-area closures have been used in many areas to conserve different species in fisheries management (Murray et al. 2000; Niemi et al. 2012; Pastoors et al. 2000; Ye et al. 2000).

Determining the appropriate closure area, size, and/or season is difficult since many marine species are widely distributed and move over large distances (Nemeth et al. 2006; Wilson et al. 2004). Likewise, fishing effort changes over seasons and years. The right closure is, however, extremely important since incorrect closures may simply displace the bycatch problem either spatially or temporally (Diamond et al. 2010; Murray et al. 2000) and impose unnecessary socio-economic impacts on stakeholders (Harley & Suter 2007; Murray et al. 2000).

Time-area closures can be split into temporal and full-time area closures (Figure 7). The full-time closure is self-explanatory as the area is simply closed full-time (e.g., MPAs). Most full-time area closures are focused on key site selections, although the area that needs protection might change over time. Thus, in order for full-time area closures to succeed, bycatch rates must be consistent over the time and space in question. Temporal closures can be split into dynamic closures and seasonal closures. Unlike full-time area closures, dynamic and seasonal closures adapt to changing environmental conditions, seasons, and/or species distributions (Vigo et al. 2024). These closures thus only close an area for a certain amount of time and then reopen, which can result in less negative impacts for fisheries while potentially improving biodiversity conservation outcomes (Vigo et al. 2024).

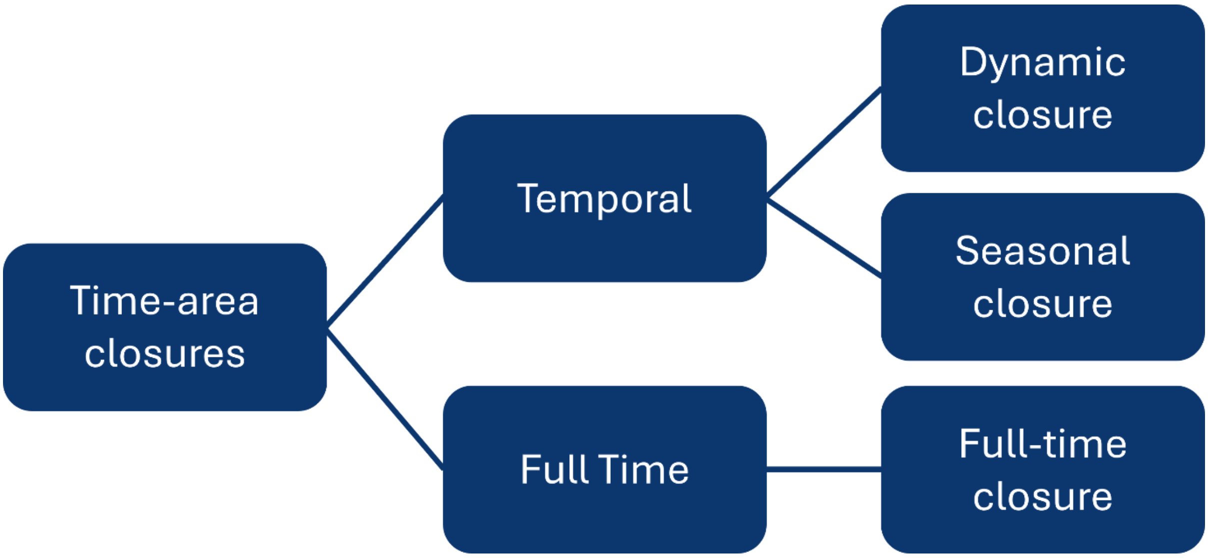

Figure 7. Types of time-area closures, adapted from Zemah-Shamir et al. (2023). Time-area closures can be divided into temporal and full-time measures based on their temporal restrictiveness. Similarly to full-time closures, seasonal closures are static albeit temporally limited to certain time periods – closure is predictable and easy to communicate. Only dynamic closures are spatially and temporally flexible and hence, hypothesized to be more suitable for highly mobile species. However, they can change rapidly in space and time depending on real-time changes in environmental parameters and communication of these changes may be challenging (Zemah-Shamir et al. 2023).

Time-area closures globally

Closures can be challenging to apply in case of highly mobile marine species. This has been especially investigated in shark conservation efforts where it has been proven difficult to monitor shark population recovery due to their known slow population growth and longevity. Even within protected areas, there is very limited evidence on the speed of shark population recovery from, e.g., overexploitation. Dwyer et al. (2020) found that effective protection for mobile shark species is most often achieved in countries that have established large marine reserves. However, similar to other highly mobile megafauna, the full range of shark movements extends beyond the boundaries of most Marine Protected Areas (MPAs), where they often receive little to no protection (Hobday et al. 2014). Despite these limitations, recent studies have shown promising outcomes. Well-enforced MPAs can significantly contribute to the recovery of shark populations. For example, Speed et al. (2018) reported that an eight-year prohibition on targeted shark fishing at Ashmore Reef led to a notable increase in grey reef shark (*Carcharhinus amblyrhynchos*) abundance. Similarly, White et al. (2017) concluded that large MPAs provide substantial, albeit incomplete, protection for reef shark populations.

Full-time closures are commonly implemented in areas identified as bycatch hotspots or critical habitats for marine megafauna such as mating grounds for whales and dolphins, pupping grounds for seals, nursery grounds for sharks and different pelagic migratory corridors (e.g., Lascelles et al., 2014; Grantham et al., 2008). For instance, in Australia, time-area closures have been used to protect gummy sharks during their pupping season, significantly reducing pup mortality (Walker 1998). However, static closures often lack the flexibility to respond to temporal shifts in species distribution—particularly as oceanographic conditions change due to climate variability. This inflexibility can lead to inefficiencies, when the closures no longer align with actual bycatch hotspots, and may even shift fishing effort to areas inhabited by other vulnerable species.

To address these challenges, Pons et al. (2022) evaluated the effectiveness of static, temporal, and dynamic area closures in reducing bycatch of threatened species (incl., fish, marine turtles, seabirds, sharks, marine mammals) across 15 global fisheries with a range of surface to bottom set fishing gear. Dynamic closures—those that adjust spatially and temporally in response to environmental variability and patterns of ocean use—were found to be significantly more effective. On average, dynamic closures reduced bycatch by 57% without compromising the catch of target species. In contrast, static closures achieved only a 16% reduction in bycatch. These findings suggest that adaptive, data-driven closure strategies may offer a more efficient and ecologically responsive approach to bycatch mitigation in shark fisheries.

To reduce high observed bycatch of harbour porpoises (*Phocoena phocoena*) the United States National Marine Fisheries Service implemented time-area closures for gillnet fisheries in the Gulf of Maine (Murray et al. 2000). The results showed that the closure was not effective since the number of bycatches in the Gulf of Maine rose (Bisack 1997). This failure was mainly due to temporal and spatial variations in bycatch patterns and displacement of fishing effort to areas outside the closed area, where porpoise bycatches likewise occurred (Murray et al. 2000). Subsequently, the time-area closures have been expanded spatially and temporally to reflect the inter-annual variability in harbour porpoise migration patterns, and pingers were required on gillnets to prevent porpoises from interacting with the gear (Orphanides & Palka 2013).

Another example of time-area closures is that of the vaquita (*Phocoena sinus*) in the Upper Gulf of California, Mexico, which is critically endangered (Rojas-Bracho et al. 2008), with the population currently thought to consist of fewer than 10 individuals. To protect the vaquita, the Mexican Government created, in 1993, a protected “Biosphere Reserve” wherein gillnet fishing was prohibited in a small part (SEMARNAP 1995) and, in 2005, an additional “Refuge Area” was created. Gillnet and trawl fishing in the Refuge Area was prohibited, although with little enforcement the fishing ban was widely ignored (Gerrodette & Rojas-Bracho 2011). It was not until 2008, with the introduction of a Species Conservation Action Plan for Vaquita (SEMARNAT 2008), that a comprehensive protection and recovery effort was introduced. Although efforts to implement the plan probably slowed the vaquita’s decline, the goal of eliminating bycatch by 2012 was not attained (Rojas-Bracho & Reeves 2013). However, it should be noted that this is an unusual case in that most bycatch of vaquita is caused by illegal fishing for totoaba (*Totoaba macdonaldi*), a situation which has been described as “organised environmental crime” (Boilevin et al. 2023).

Time-area closures in European waters

Time-area closures were used in the Bay of Biscay in 2024-2026 with the goal to reduce bycatch of common dolphins in the region. The French Government imposed a non-continuous one-month spatio-temporal closure during the winter months for three consecutive years, providing several exemptions and derogations for high-risk fisheries in special regulation. The results of that measure were quite successful in reducing the bycatch of dolphins. Computed bycatch from strandings of common dolphins along the Atlantic sea-border of mainland France was approximatively halved during the 2024 one-month closure in the Bay of Biscay southwards from latitude 48°N. No such decline was observed outside the closure period or north of latitude 48°N between 22nd of Jan 2021 and 21st Feb 2024 (incl.). The apparent bycatch rate after the end of the closure bounced back to its before-closure level in the Bay of Biscay (Peltier et al., 2024).

Another one-month closure was implemented in 2025, from 22nd January 2025 until 21st February 2025, but the results are yet to be analysed. Long-term effects, and socio-economic effects of the closures have not been studied or analysed yet.

Effective implementation

While implementing time or area closures may appear to be an effective conservation strategy, such measures are likely to be ineffective without a robust implementation plan or mechanism. If fishers cannot adapt to the closures (for instance, opt to relocate their fishing efforts), the intended benefits of time-area closures will not materialize. Effective and successful implementation often depends on fisher buy-in, as support for the measure can encourage self-regulation and make monitoring more manageable. However, in situations where fisheries operate over large or remote regions, implementation of time-area closures can be logistically challenging and costly. In such cases, satellite-based surveillance may offer a viable solution. Within the European Union (EU), all vessels over 12 metres in length are required to carry a Vessel Monitoring System (VMS), which transmits location data hourly. A tool called "Geofencing" enables remote monitoring of geographic areas surrounded by a virtual fence (geofence) that automatically detects when VMS tracked vessels either enter or exit them (Reclus & Drouard 2009). Another way would be the use of Remote Electronic Monitoring (REM) systems, which can monitor the position of the vessel in relation to closed areas.

Economic costs

Closures are often unpopular within the fishing industry, as they can lead to longer steaming times, higher fuel costs, lost fishing opportunities, and reduced catches (O'Keefe et al. 2014). In the Gulf of Maine, the industry expressed concern that the closure disproportionately impacted fishers operating smaller vessels, which were unable to travel far from shore (Murray et al. 2000). On the other hand, it was argued that the closures were too limited in scope, potentially excluding critical habitats and merely displacing fishing effort rather than reducing bycatch (Read 2013). Understanding the trade-offs between ecological benefits and economic impacts is therefore essential for designing policies and management strategies. However, in some rare cases, compromise between conservation needs and fisheries may not be possible—particularly when the survival of a population could be jeopardized by the loss of even one individual, for instance in case of Maui dolphins or vaquita (Slooten & Dawson, 2020; Arreguin-Sanchez et al., 2025).

Economic compensation

General

There is a limited number of studies addressing economic measures that can be used to reduce bycatch of threatened megafauna. Generally, these measures can be grouped into incentive-based systems (e.g., Payments for Ecosystem Services), tradable bycatch rights (including Individual Transferable Bycatch Quotas or ITQs; see next subsection "*Bycatch Quota*" for examples), and various compensatory mechanisms (bycatch levies, biodiversity offsets, buy-outs, and auctioned bycatch shares).

If the implementation of bycatch measures results in significant industry losses, one way to gain acceptance is through economic compensations or incentives, for example compensating fisheries affected by measures such as time-area closures and encouraging fishers to either stop fishing or switch gears. In case of Indonesian small-scale fishery (coastal gillnet and semi-commercial pelagic longline), the fishers agreed to support bycatch reduction efforts for the hammerhead sharks and wedgefish (family Rhinidae) motivated by incentives (Booth et al. 2021). Their model-based projections indicated that 98% fishers will accept the measures if compensated which could lead to 18,500 hammerheads and 2,140 wedgefish being saved annually.

In the upper Gulf of California, Mexico, economic compensation has been used to protect the vaquita. Alongside area closures, the Mexican government implemented economic incentives to eliminate driftnets and gillnets from the vaquita's habitat. This voluntary programme offered fishers three options: (1) rent-out: an annual payment of US$3,500 to stop fishing, (2) switch-out: a US$25,000 payment and a new fishing permit to use alternative gear with no vaquita bycatch, or (3) buy-outs: turning in boats, nets, and fishing permits for US$25,000 to US$35,000 (SEMARNAT 2008).

In 2008-2010, the programme was modified to make the buy-out option less appealing and the rent-out option more attractive. The switch-out option was also adjusted to include temporary switch-out to increase its appeal (CNANP 2008, 2009, 2010). Analysis of fishers' participation revealed that those with skills in alternative economic activities were more likely to stop fishing, while those with less productive vessels were more inclined to switch to vaquita-safe fishing methods. However, only 15.5% of the total fleet either stopped fishing or permanently switched to vaquita-safe gear as part of the programme (Avila-Forcada et al. 2012).

With regard to seabird and marine turtle populations, compensatory approaches showed cost-effective in studies addressing different fisheries of Hawaii, Australia and New Zealand. Wilcox and Donlan (2007) investigated the potential of seabird (albatrosses, petrels and shearwaters) and marine turtle bycatch reduction using a bio-economic analysis of bycatch levies and additional funds used to motivate fishers to remove invasive marine mammals from breeding grounds which has proven 23 times more effective than an introduction of a closure. In addition, further compensatory approaches such as biodiversity offsets created through a collaboration between fisheries and island conservation have the potential to ensure seabird and marine turtle population recovery from bycatch mortality (Donlan & Wilcox, 2008). In this study, the authors explore and thoroughly discuss the importance of fishers engaging in this bycatch mitigating effort as well as the reasons for conservation NGOs and managers enabling the fishers’ involvement in this strategy where direct bycatch reduction approaches are not possible.

Economic compensation in European waters

Few countries have a tradition of economic compensation in relation to the management of ETP species bycatch. Swedish fishers have, however, been compensated for damages to fish catch or fishing gears caused by seals (Anon. 2014). Economic compensation was one of management options identified by a literature review- and interview-based study in case of gear damage caused by depredation of common bottlenose dolphins in many areas of the Mediterranean Sea (La Manna et al. 2024). Between adaptation, mitigation and alternative strategy, the predominant management option preferred by fishers was economic compensation for the damaged gear (see La Manna et al. 2024 for details). However, this option was less favoured by other stakeholders in the study (i.e., environmentalists, tourist operators, researchers and technicians, and protected area managers).

Bycatch quota

General

Quota system is widely used in fisheries management as a means to control for the fish uptake by commercial fisheries of various scale and gears. A specifically allocated bycatch quota could potentially be used to reduce or keep bycatch levels below a certain threshold. Implementing these quotas would allow a certain level of bycatch while it would be up to the managers and eventually, industry to determine how the level would be kept within the defined limits. Quotas can be applied either individually or fleet-wide where a transfer, purchase and lease of quotas could be possible (Alverson et al. 1994; O'Keefe et al. 2014), which are known as Individual Transferable Quotas or ITQs. While ITQs are still mainly used for management of fish catches, there is a number of studies looking into the application of bycatch ITQs for particular dolphin and seal species.

A bycatch ITQ approach has been tested in case of the Hooker's sea lion (*Phocarctos hookeri*) bycatch reduction in the New Zealand squid fishery. Since Hooker's sea lion is a protected species, a bycatch limit has been set each year since 1992, based on population models and sustainable mortality levels. In a study by Maunder et al. (2000), the Bayesian-based analysis showed a 69% probability that the sea lion's population will recover (exceed 90% of carrying capacity) regardless of the management decisions. There is also a very small difference in sea lion population levels reached between the management decisions including a bycatch quota (F= 0,15) and the one assuming no bycatch mortality. However, a severely depleted population will have less chance of reaching the threshold of 90%. In comparison, the squid fishery is much more sensitive to bycatch limits than the sea lions, as the fishery showed a 24% economic loss with respect to only 6% increase of sea lion population (Maunder et al. 2000).

A positive example was, however, observed in the purse seine fishery for yellowfin tuna in the Eastern Tropical Pacific (ETP). Here, dolphin bycatch of various species was allowed only until a certain level of bycatch was reached, which led to a large reduction in the total dolphin bycatch (Hall 1998; Gosliner 1999). The mitigation of dolphin bycatch by the US fleet in the purse seine fishery for tuna in the ETP in the 1970s is one of the best-known examples of successful reduction – although not elimination - of bycatch mortality. This involved development of the backdown procedure to release encircled dolphins, and the education of skippers (see National Research Council 1992).

So far, quotas have not been used as a management tool to reduce bycatch of harbour porpoises. However, in a comparative, model-based study by Bisack & Sutinen (2006), the authors the economic efficiency of bycatch ITQs, time-area closures and fishing effort (days-at-sea) restrictions for bycatch mitigation of harbour porpoises. To study these management options, these authors developed a numerical bioeconomic model of harbour porpoise bycatch in the New England sink gillnet fishery. The model incorporated spatial and temporal patterns of fish species and marine mammals over several seasons and years and tested seven management programmes (includes combining the known management options with annual or seasonal application). The results showed that the ITQ was the least costly management option to the industry compared to the closures. This refers to the estimated profit loss of only 10-20% reduction in profit with roughly 34% reduction in cod landing in case of ITQ (in comparison to "no management" scenario), while closures reduce profits by 20-30% reduction with 29% reduction in cod landing. However, the highest economic loss was observed in case of annual fishing effort reductions where industry was losing between 50-60% in profits and ≈55% in cod landings (Bisack and Sutinen 2006). While this management option seems extreme in losses, in practise, some managers might still allow it depending on the port´s characteristics (e.g., logistics, capacity, administration).

Bycatch quotas in European waters

Based on our literature review, there is very little research dedicated to investigating the application and effect of bycatch quota in European waters. The most comprehensive review evaluation of different bycatch mitigation measures, which among others include bycatch quotas or caps is the one compiled by O´Keefe et al. (2014). This study provides an overview and evaluation of different bycatch mitigation measures such as time/area closures, bycatch quotas/caps, and fleet communication programme, yet no European case studies were examined. However, the review is very informative in terms of the efficiency of these mitigation measures with regard to the effects on the target and non-target species (e.g. low or no bycatch/discards, low or no negative effect on catch and viability of fishery, low or no negative effect on spatial/temporal displacement of bycatch).

Overall, bycatch quotas might not be a viable solution for certain ETP species or population, such as the Baltic Proper subpopulation and the Iberian harbour porpoise population which need more prompt bycatch mitigation measures. Since zero bycatch has been recommended in both cases - by HELCOM and OSPAR respectively - theoretically a bycatch of only one animal could harm the population and would in any case lead to closure of the fishery. However, if the species recover, a bycatch quota might be a potential option for management in these regions, which would ultimately need efficiency monitoring through onboard observers or real-time camera systems.

3.2. Legal aspects of mitigation measures

Various stages from testing, implementation, optimization and final use of novel mitigation measures can sometimes be hindered by the legality of these measures, which is something managers and regulatory bodies need to consider. Modifications of fishing gears can be restricted by technical measures regulations, and regulations about gear can be outdated as technical developments can move faster than the legal framework around them. As an example, regulations on the specifications of pingers in European legislation are quite outdated. And while mandatory use of pingers for larger vessels (>12m) in UK is driving a successful bycatch reduction for that portion of static net fishery, the legal requirements for the usage of pingers in case of small inshore vessels (<12m) are the main obstacle in furthering bycatch mitigation efforts (particularly harbour porpoise bycatch). Small inshore vessels are responsible for a large proportion of bycatch events and fishing effort in UK fisheries (Pinn, 2023). Whilst small vessels need to acquire a license for the use of pingers, according to Pinn (2023) there has been no successful acquisition of license made due to a requirement for detailed and complicated documentation. One solution to this dilemma is the allocation of the license to the regional fisheries management organisation to handle the pinger usage in its associated management area. While this is only one such example of legal difficulties in the usage of mitigation measures, for the industry as well as other interested parties, it is important that the innovations being tested are in accordance with the appropriate legislation. Close contact with the relevant permitting authorities (and, if necessary and appropriate, the European Commission) is advised in this regard, to ensure that successful solutions are legally permissible.

3.3. Stakeholder involvement and active participation

Many bycatch mitigation measures discussed in this report are established tools in commercial fisheries in specific countries or regions. Acoustic deterrent devices (ADDs) and excluder devices (EDs) have already been implemented in commercial fisheries via legislation in countries such as Australia (Fisheries (Commercial Fisheries) Regulation 2019), USA (Code of Federal Regulations, Title 50 Part 223 2024) and the EU member countries (European Union 2025), albeit not without difficulties.

Initial field studies and scientist-supervised fishery trials have often shown great successes for different mitigation approaches in reducing bycatch rates by > 80% in some cases (e.g., Huang et al. 2024; Allman et al. 2020; Renaud et al. 1997; Stephenson et al. 2008). However, long-term monitoring has often shown a much lower success rate compared to these scientific studies. It became clear that stakeholder involvement was low in many cases and is potentially one of the drivers for the decrease in bycatch mitigation success (see Dawson et al. 2013; Hamilton & Baker, 2019). In the review by Hamilton & Baker (2019), the authors proposed the mandatory use of on-board observations or dockside inspections, for each mitigation measure, that will (potentially) encourage proper use of the mitigation measures and consequently, bycatch reduction.

There are numerous studies of stakeholder willingness and collaboration in following a regulation demanding obligatory use of mitigation measure for specific type of vessels. For instance, Cox et al. (2007) compared the bycatch rates of harbour porpoises and short-beaked common dolphins (*Delphinus delphis*) within the Gulf of Maine and the California gillnet fisheries after the mandatory use of pingers. Initial scientific studies had shown a 70-90% bycatch reduction rate within the same fishery, however, in the Gulf of Maine bycatch reduction dropped to 50-80% for pinger use within commercial fishing activities. Onboard observers estimated a non-participation rate of 78%, i.e., setting gillnets without acoustic alarms (Cox et al. 2007). Fishers´ involvement within the California gillnet fishery increased from 75% in 1997 to 99% in 2001 likely due to better outreach, education and stakeholder engagement programmes in the region (Cox et al. 2007) highlighting the importance of these programmes for bycatch mitigation success.

Cox and colleagues (2007) continued to compare trawl fisheries and the mandatory implementation of turtle excluder devices (TED) between the USA and Australia. Both countries require TEDs to be installed in certain fisheries and with approved specifications (Code of Federal Regulations, Title 50 Part 223 2024; Fisheries (Commercial Fisheries) Regulation 2019). However, while Australia supported the legislation with outreach, educational programmes and economic incentives for fishers, similar support for fisheries in the Gulf of Mexico area was lacking (Cox et al. 2007). Therefore, bycatch reduction rates for Australia’s fishery were similar to those achieved during scientific trials while reduction rates were likely more than halved for the Gulf of Mexico fishery (Cox et al. 2007; Moore et al. 2009). Active stakeholder participation can also be achieved via incentives and high observer coverage (Bellanger et al. 2025). The most feasible approach may depend on the specific fishery and country, i.e., the resources available, or ideally be a combination of several programmes.

In other fisheries, active participation after the introduction of the obligatory use of pinger in 1997 has been consistent in case of the driftnet fishery for swordfish and thresher shark in California (Carretta & Barlow, 2011). Since 1998, the fishers’ participation in the use of pingers remained above 99%, albeit this was recorded on observed vessels only (average of 15.5% pooled across all study periods). While the unobserved vessels (responsible for roughly 48%

of estimated fishing effort, calculated for 2009) can be occasionally inspected by the Coast Guard, this is not frequent enough to confirm high fisher involvement in pinger use.

Incentives as tool for implementing bycatch mitigation

Incentives can be positive or negative by either rewarding favourable behaviours or discouraging unfavourable behaviours, respectively. Consequently, incentives to increase fishers´ participation and involvement could be of either nature.

As a positive incentive, a “bottom-up" approach is mainly favoured over a strict “top-down" (hierarchical) approach. In other words, working directly with fishers through active participation and positive incentives such as financial compensation for the purchase of mitigation tools is likely to lead to higher success rates than negative incentives (Alexandre et al. 2022; Bellanger et al. 2025). This might be especially important for less regulated SSF where data deficiency hinders the understanding of the role of SSF for bycatch mitigation, and a good collaboration and partnership with fishers is needed (Lewison et al. 2014). Other positive incentives to reduce bycatch and/or increase active involvement could come via eco-certification bodies such as the Marine Stewardship Council (MSC) and the competitive advantage by holding such certifications (Jubinville et al. 2022). In Iceland, for example, high seal and seabird bycatch within the gillnet fishery for lumpfish (*Cyclopterus lumpus*) have caused the subsequent withdrawal of the MSC certification for this fishery in 2018 and since sparked, increased efforts by the industry to reduce bycatch as suggested in an action plan submitted to the MSC (ISF 2018). Unfortunately, bycatch numbers continued to be above acceptable limits and even led to a spatial closure before the certification was suspended again in 2025. Yet, the economic benefits resulting from eco-labels could help motivate industry partners to participate in bycatch studies and/or in implementing bycatch mitigation tools.

Alternatively and whenever possible, active participation could be rewarded with additional (fish) quota allocation (Bache 2003). Again, this would require regular monitoring in a representative manner, i.e., via comprehensive onboard observers or electronic monitoring.

A negative incentive which aims to discourage unfavourable behaviours could be, for example, to include the combination of a gear modification such as EDs or pingers with bycatch quota-dependent fishery closures: i.e., if the (improper) use of bycatch mitigation measures still results in incidental catch of ETP species and exceeds a threshold, the fishery will be closed (Bellanger et al. 2025). Bycatch quotas or caps have been applied previously as a bycatch mitigation tool itself (Bellanger et al. 2025). Yet, the early fishery closure can lead to considerable economic losses (O’Keefe et al. 2014). To minimize these economic losses, fishers could then potentially switch to alternative gear with a lower bycatch risk (O’Keefe et al. 2014). Economic losses could act as an incentive for industry stakeholders to participate and collaborate with scientific partners to develop new and better bycatch mitigation strategies (O’Keefe et al. 2014), however, voluntary collaboration and positive incentives should be preferred if possible. Additionally, if the monitoring of bycatch relies mainly on self-reporting by the fishers, quotas will have to be chosen very carefully as in many cases logbook data is a gross underestimation of actual bycatch numbers (e.g., Allen et al. 2014; Basran & Sigurðsson 2021; Christensen-Dalsgaard et al. 2019). Ideally, bycatch could be monitored via independent onboard observers and/or via remote electronic monitoring (REM) as discussed in the next section *“Novel approaches to stakeholder participation: remote electronic monitoring (REM)*”.

Novel approaches to stakeholder participation: remote electronic monitoring (REM)

Remote electronic monitoring (REM) systems usually require several different components: GPS sensors, activity sensors, specific computer hardware and CCTV (Van Helmond et al. 2020). The exact configuration, number and position of cameras depend on the specific vessel, fishing gear used and other constraints (Van Helmond et al. 2020). The initial development was motivated by the fishing industry itself as a security against gear theft within the crab fishery in British Columbia, Canada (Van Helmond et al. 2020).

Recently REM has become a valuable tool for fishing activity monitoring and a cost-efficient alternative or complement to onboard observer programmes (Ewell et al. 2020; Kindt-Larsen et al. 2011, 2012; Van Helmond et al. 2020). REM trials and implementations have steadily increased since the early 2000s with Canada, the USA and European countries at the forefront (Van Helmond et al. 2020).

REM could increase availability of data on bycatch and the efficacy of mitigation, which can inform future studies and legislation (Plet-Hansen et al. 2019; Van Helmond et al. 2020). Several studies have shown a marked discrepancy between bycatch numbers reported by skippers versus numbers reported by independent onboard observers (e.g., Basran & Sigurðsson 2021; Christensen-Dalsgaard et al. 2019). Thus, logbook data are only of limited use for scientific analyses and monitoring of ETP species. REM would allow fishery management agencies to cross-check logbook-reported data with REM footage or, in future, use automated image analysis or AI-tools to analyse bycatch directly off the video material (Rose & Barbee 2022; Van Helmond et al. 2020). REM could thus, in theory remove the necessity to report such information in logbooks. Manual video/photo analysis is time-consuming and would likely exceed time and money available in most countries; however, there are several methods of reducing the resources needed. One option is to analyse only a fraction of the recorded data and validate those data with the corresponding logbook entries (Van Helmond et al. 2020). As the selection of the fraction is random, fishers would be encouraged to comply for all trips and not just for the trips when onboard observers are present (Van Helmond et al. 2020). Furthermore, instead of having technical staff analysing the material, trained student staff could be used to reduce costs for the data collection (Kindt-Larsen et al. 2012). The amount of footage that is analysed would have to be chosen depending on the aim of the monitoring, e.g., monitoring compliance with regulations, monitoring the efficacy of bycatch mitigation or bycatch assessment , and the rarity of the observed event/species.

Additional benefits could include observer and crew safety, with the former being potentially exposed to threatening and dangerous behaviours at sea (Ewell et al. 2020) as well as a better scientific understanding of bycatch numbers and even underwater behaviour of ETP species with bycatch mitigation devices such as pingers and excluder devices (EDs) if underwater cameras are deployed (Jaiteh et al. 2013, 2014; Wakefield et al. 2014).

It is, however, important to regard personal privacy laws and cost-benefit aspects when planning the broad scale implementation of REM systems across the fishing fleet. Small vessels may not be suitable for the installation of REM systems (Van Helmond et al. 2020), and/or it may not be financially viable if costs need to be borne by the fishers alone. The financial aspect needs to be addressed if REM systems become mandatory: Who will carry the costs of the installation and maintenance of the system and who will be responsible for the storage and processing of the video footage and data?

In most cases, initial implementation of REM systems is co-funded between the government and the industry and later moves to industry-only funding (Van Helmond et al. 2020). Plet-Hansen et al. (2019) estimated the costs for the Danish fleet of vessels sized 12 m or larger at € 4.9 million for the first implementation and maintenance and at € 1.7 million annually thereafter for recurring maintenance. That equals to € 8,300 and € 4,200 per vessel for initial implementation and annual maintenance, respectively (Plet-Hansen et al. 2019). This estimation is approximately 1/5 cheaper for the initial implementation costs than the costs reported by Kindt-Larsen and colleagues in 2012 who reported costs of € 10,200 per vessel based on the expenses for the trial using six vessels (Kindt-Larsen et al. 2012). This is likely due to a reduction in installation costs between 2012 and 2019 (Ewell et al. 2020). Regardless, REM systems are likely more cost-efficient than other methods to monitor bycatch, the efficacy of mitigation and compliance with regulations that are used at the moment, like at-sea patrol vessel controls and onboard observer programmes with high coverage (Ewell et al. 2020; Plet-Hansen et al. 2019).

REM would also reduce the observer limitation and expand the coverage of monitoring in the fleet, which would be particularly helpful for the SSF. However, due to the small vessel sizes and often outdated technology within the SSF fleet, as well as the low income for the fishers, REM systems need to be adapted to fit the needs within the SSF (Barreiro et al. 2025; Bartholomew et al. 2018).

It is also important to note here that REM systems are not failure-proof and the correct installation, use and maintenance of the system, and the resulting data need to be carefully planned and communicated to stakeholders. In several studies, errors have occurred due to system failure, camera obstruction and/or data loss (Van Helmond et al. 2020). This means that onboard observer programmes are still needed at least in the early stages of REM implementation to verify the catch analyses obtained using REM and to potentially adjust camera positions or settings (Van Helmond et al. 2020). Data storage on physical media such as hard discs is tedious, error-prone and a high risk for data loss while data transmission via 4G has proven more efficient and reliable (Van Helmond et al. 2020).

According to EU regulation 2023/2842 (Art. 13), REM shall be mandatory for vessels 18 m in length or larger “which pose a high risk of non-compliance with the landing obligation” and the data shall be “made available to competent authorities” and “without prejudice to the relevant rules on the protection of personal data” (European Union 2023). The specifics are to be determined by the Commission (European Union 2023). After initial pilot projects by the European Fisheries Control Agency (EFCA), a technical guide has been developed specifying the minimum technical requirements, rules of operation and other important factors of operation for REM within the EU (EFCA 2025) and similar standards have been set by all four tropical tuna RFMOs.

Despite the increasing mention of REM systems in fishery legislation globally, a “bottom-up" approach may be favoured over a strict “top-down" approach meaning that the involvement of stakeholders and positive incentives would likely improve the overall perception of REM by fishers and increase active participation (Bellanger et al. 2025; Van Helmond et al. 2020). Positive incentives for the initial adoption of a REM system or participation in REM studies could include the exemption from days-at-sea regulations or a quota uplift using national quota shares (Plet-Hansen et al. 2019; Van Helmond et al. 2020). Once a system has been implemented and fishers have first-hand experience, the acceptance of mandatory implementation and overall perception improves (Van Helmond et al. 2020). Logically, REM systems should not be used as a sole monitoring tool as this could decrease its acceptance by stakeholders (Van Helmond et al. 2020).

A well-planned, gradual adoption of REM into the industry complemented with stakeholder involvement, incentives and financial support to fishers is required to maximize the benefits obtained from REM to the industry as well as ETP species conservation.

Stakeholder involvement

Involvement of stakeholders in the development of new bycatch mitigation methods or the improvement of already existing methods as well as post-implementation support via outreach and education programmes are the base for successful bycatch mitigation in the long term (Cox et al. 2007; Iriarte et al. 2020; Moore et al. 2009; Senko et al. 2014). Successful bycatch mitigation methods are not only tools that effectively reduce bycatch but also do not disrupt day-to-day tasks and routines of fishers. Bycatch mitigation tools need to work well with the fishing equipment used and ideally need only minimal maintenance after initial implementation. It is important that stakeholders have the opportunity to voice their concerns about any potential mitigation measures and their potential impact on stakeholders' livelihoods (Alava et al. 2019).

Due to highly variable machinery on board fishing vessels, not only across different fishing métiers but also within, mitigation tools may need individual adjustments to work well and function efficiently. Working together with the stakeholders can not only test the effectiveness of mitigation measures, but further develop and improve their designs (Broadhurst et al. 2002; Crosby et al. 2013). Conversations with and experience of fishers can help with experimental design and protocol by showing what is feasible and what is not (Crosby et al. 2013).

In the case of mandatory adoption of sea lion excluder devices (SLED) in the Chilean hake fishery since 2022, a gradual top-down approach with active stakeholder involvement and engagement was implemented (Queirolo et al. 2025). The process started in 2012 with identifying the problem and future steps towards a bycatch reduction plan, followed by data collection and monitoring resulting in the gradual implementation of SLEDs from 2020 and a mandatory SLED use in May 2022 (Queirolo et al. 2025). All stages were in close collaboration with stakeholders, which allowed fishers to be part of the solution and to experience the benefits of the SLED use, themselves (Queirolo et al. 2025). Despite a low number of continued incidental catch of South American sea lions (*Otaria flavescens*) the implementation of the SLEDs into the fishery has resulted in negligible mortality rates (Queirolo et al. 2025).

Within the CIBBRiNA project, a "Safe Working Environment" characterised by mutual trust and respect for different perspectives is pursued to support and encourage collaboration and co-creation. It should be acknowledged that this requires continuous effort and commitment of all partners involved. CIBBRiNA developed cooperation principles and best practice guidelines supporting collaboration within case studies and beyond. Regardless of role or organisation, these guidelines help explore fruitful collaboration methods. The guidelines draw on published literature and experienced practitioner testimonies, captured in accompanying videos about collaboration on bycatch mitigation (Mackinson and Siemensma 2025).

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5. Appendix

List of species mentioned in this report

Scientific name	English	German	Spanish	Portuguese	Dutch	Danish
Alopias superciliosus	Bigeye thresher shark	Großaugen-Fuchshai	Zorro de anteojos; zorro ojón; tiburón zorro; rabón; rabudo	Zorro-olho-grande; zorro-de-olhos-grandes	Grootoogvoshaai	
Alopias vulpinus	Common thresher; Atlantic thresher	Gemeiner Fuchshai; Drescherhai	Tiburón azotador; zorro marino; pez zorro	Raposo; zorra/zorro; tubarão-raposo; tubarão-zorro/zorra	Voshaai; gewone voshaii; Zeevos	Rævehaj
Amblyraja radiata	Starry ray; thorny skate	Sternrochen	Raya radiada	Raia repregada	Sterrog	Ritte; tærbe
Amblyraja taaf	Whiteleg skate					
Anoplopoma fimbria	Sablefish; butterfish; black cod; candlefish; snowfish; […]	Kohlenfisch			Zandvis; Pacifische koolvis; zwarte kabeljauw	
Aphanopus carbo	Black scabbardfish	Schwarzer Degenfisch	Sable negro	Peixe-espada-preto	Zwarte haarstaartvis; zwarte degenvis	Sort sabelfisk; Dolktandfisk
Ardenna grisea	Sooty shearwater	Dunkelsturmtaucher; Dunkler Sturmtaucher	Pardela sombría; pardela oscura; fardela Negra	Pardela-preta; pardela-escura	Grauwe pijlstormvogel	Sodfarvet skråpe
Carcharhinus acronotus	Blacknose shark	Schwarznasenhai	Tiburón de morro negro	Tubarão-de-nariz-preto	Zwartsnuithaai	
Carcharhinus amblyrhynchos	Grey reef shark	Grauer Riffhai	Tiburón gris	tubarão-cinzento-dos-recifes	Grijze rifhaai	
Carcharhinus galapagensis	Galapagos shark	Galapagoshai	Tiburón de Galápagos	Tubarão-de-galápagos	Galapagoshaai	Galapagoshaj
Carcharhinus leucas	Bull shark	Bullenhai; Gemeine Grundhai; Stierhai; Sambesihai	Tiburón sarda; tiburón lamia	Tubarão-cabeça-chata	Stierhaai; Atlantische grondhaai; Zambezihaai	Tyrehajen
Carcharhinus longimanus	Oceanic whitetip shark	Weißspitzen-Hochseehai; Hochsee-Weißflossenhai	Tiburón oceánico	Tubarão-galha-branca-oceânico	Oceanische witpunthaai; witpunthaai	
Carcharhinus obscurus	Dusky shark	Schwarzhai; Düsterer Hai	Jaquetón lobo; tiburón arenero	Tubarão-negro	Schemerhaai	
Carcharhinus plumbeus	Sandbar shark; brown shark; thickskin shark	Sandbankhai	Tiburón trozo; jaquetón de Milberto	tubarão-corre-costa; Tubarão Galhudo; Tubarão-cinzento	Grootvinhaai; zandbankhaai	
Caretta caretta	Loggerhead turtle	Unechte Karettschildkröte	tortuga boba; tortuga cabezona; caguama; cahuama	tartaruga-comum; tartaruga-marinha-comum; tartaruga-cabeçuda; tartaruga-mestiça; […]	Dikkopschildpad; onechte karetschildpad	Uægte karette

Scientific name	English	German	Spanish	Portuguese	Dutch	Danish
Centrophorus. squamosus	Leafscale gulper shark	Blattschuppiger Schlingarhai; Brauner Dornhai	Quelvacho negro; Lija Negra	Lixa	Schubzwelghaai	Brun pighaj
Centroscymnus coelolepis	Portuguese dogfish	Portugiesenhai	Pailona	Carocho; pailon-preta	Portugese ijshaai	Portugisisk haj
Centroscymnus crepidater	Longnose velvet dogfish	Langnasen-Samtdornhai	Sapata negra		Langsnuitijshaai	
Centroscymnus owstonii	Roughskin dogfish		Sapata lija		Ruwe ijshaai	
Cetorhinus maximus	Basking shark	Riesenhai	Tiburón peregrino	Tubarão-peregrino; tubarão-frade	Reuzenhaai	Brugde
Clangula hyemalis	Long-tailed duck; coween	Eisente	Pato havelda	Pato-de-cauda-afilada; pato-de-rabo-longo; pato-rabilongo	Ijseend	Havlit
Cyclopterus lumpus	Lumpfish; lumpsucker	Seehase; Lump; Lumpfisch; Lump-Fisch	Lumpo jibado	Peixe-lapa	Snotolf; lompvis	Stenbider kvabso; hrygna
Delphinus delphis	Short-beaked common dolphin	Gemeiner Delfin	Delfín común	Golfinho-comum-de-bico-curto, Golfinho comum	Kortsnuit gewone dolfijn	Almindelig delfin
Dicentrarchus labrax	European seabass; Bass; white bass; sea perch; […]	Europäischer Wolfsbarsch; Seebarsch	Lubina; lobina; róbalo; robalo; robaliza	Robalo; robalo-legítimo; robalete	Europese zeebaars; zeebaars	Havbars
Dipturus batis	Blue skate; grey skate	Glattrochen	Noriega; raya noriega		Vleet	Skade
Dipturus intermedius	Flapper skate		Raya flapper	Raia-flapper	Flapperrog	
Dissostichus eleginoides	Patagonian toothfish; Chilean sea bass; mero; icefish	Schwarzer Seehecht	Merluza Negra; robalo; róbalo de fondo; bacalao de profundidad	Merluza-negra	Antarctische diepzeeheek	
Fulmarus glacialis	Northern fulmar; Arctic fulmar	Eissturmvogel; Nordatlantischer Eissturmvogel	Fulmar boreal	Fulmar-boreal; pombalete-do-norte; pardela-branca	Noordse stormvogel; mallemok	Mallemukken
Gadus macrocephalus	Pacific cod	Pazifischer Kabeljau				
Gadus morhua	Atlantic cod	Atlantischer Kabeljau; Dorsch	Bacalao común; bacalao del Atlántico; bacalao de Noruega;	Bacalhau-do-atlântico	Kabeljauw	Torsk; atlantisk torsk

Scientific name	English	German	Spanish	Portuguese	Dutch	Danish
			bacalao noruego			
Galeocerdo cuvier	Tiger shark	Tigerhai	Tiburón tigre	Tubarão-tigre	Tijgerhaai	Tigerhaj
Galeorhinus galeus	School shark; tope; tope shark; snapper shark; soupfin shark	Hundshai; Grundhai	Cazón; tiburón vitamínico	Perna-de-moça; Cação; tubarão-da-sopa	Hondshaai; toonhaai	Gråhaj
Ginglymostoma cirratum	Nurse shark	Atlantischer Ammenhai	Tiburón nodriza; tiburón gato	Tubarão-lixa; cação-lixa; cação-barroso; cação-gata; lambaru	Verpleegsterhaai ; voedsterhaai	
Grampus griseus	Risso's dolphin	Rissodelfin, Rundkopfdelfin	Calderón gris, delfín gris	Golfinho-de-risso	Grijze dolfijn, risso's dolfijn	Rissosdelfin; halvgrindehval
Halichoerus grypus	Grey seal	Kegelrobbe	Foca gris	Foca-cinzenta	Grijze zeehond	Gråsæl
Hypanus americanus (formerly Dasyatis americana)	Southern stingray	Amerikanischer Stechrochen; Südlicher Stechrochen				
Illex spp.	Shortfin squid		Calamares potas			
Isurus oxyrinchus	Shortfin mako shark; blue pointer; bonito shark	Kurzflossen-Mako; Makohai	tiburón mako; marrajo común; de aleta corta	tubarão-mako; tubarão-mako-cavala	Kortvinmakreelhaai; makohaai; mako	
Leucopleurus acutus	Atlantic white-sided dolphin	Weisssseiten-Delfin	Delfín de flancos blancos	Golfinho-de-laterais-brancas-do-atlantico	Witflankdolfijn	Hvidskæving; hvidside
Lagenorhynchus albirostris	White-beaked dolphin	Weissschnauzen-Delfin	Delfín de hocico blanco	Golfinho-de-bico-branco	Witsnuitdolfijn	Hvidnæse
Lamna nasus	Porbeagle	Heringshai	Marrajo sardinero	Tubarão-sardo	Haringhaai; Neushaai	Sildehaj
Lampris guttatus	Opah; cravo; moonfish; kingfish; Jerusalem haddock	Gotteslachs	Opah; cravo; pez sol; pez real; luna real; isabelita	Peixe-cravo	Koningsvis	Glansfisk
Larus spp.	Gulls	Möwen	Gaviotas	Gaivotas	Meeuwen	Mågefugle
Leucoraja naevus	Cuckoo ray	Kuckucksrochen	Raya cuco; raya santiaguesa; escayuda	Raia de dois olhos	Grootoogrog;koekoeksrog	
Merluccius gayi gayi	Chilean hake	Seehecht*	Merluza chilena	Merluza*		
Mirounga angustirostris	Northern elephant seal	Nördlicher See-Elefant	Elefante marino del norte; septentrional	Elefante-marinho-do-norte; elefante-marinho-boreal; foca-	Noordelijke zeeolifant	Nordlige søelefant

Scientific name	English	German	Spanish	Portuguese	Dutch	Danish
				elefante-do-norte		
Mola mola	Ocean sunfish; common mola	Mondfisch; Sonnenfisch; Klumpfisch	Pez luna; mola	Peixe-lua; mola	Maanvis; klompvis	Klumpfisk; månefisk
Morus bassanus	Northern Gannet	Basstölpel	Alcatraz común; alcatraz Atlántico	Ganso-patola; Ganso-patola-do- atlântico; alcatraz-do-norte	Jan-van-gent	Sulen
Otaria flavescens	South American sea lion; Patagonian sea lion	Mähnenrobbe; Patagonischer Seelöwe; Südamerikanischer Seelöwe	Lobo marino sudamericano; otario de la Patagonia; lobo marino de un pelo; […]	Leão-marinho-da-patagônia; leão-marinho-do-sul	Manenrob; Patagonische zeeleeuw	
Phoca vitulina	Harbour seal	Gemeiner Seehund	Foca común, foca de Puerto, foca moteada	Foca-comum	Gewone seehond	Spættet sæl
Phocarctos hookeri	Hooker's sea lion; New Zealand sea lion	Neuseeländischer Seelöwe	León marine de Nueva Zelanda	Leão-marinho-da-nova-zelândia; leão-marinho-de-hooker	Nieuw-Zeelandse zeeleeuw	
Phocoena phocoena	Harbour porpoise	Schweinswal	Marsopa común	Toninha-comum, Boto	Bruinvis, Gewone bruinvis	Marsvin
Phocoena sinus	Vaquita	Kalifornischer Schweinswal; Golftümmler; Vaquita	Vaquita marina; cochito	Vaquita-marinha	Californische buinvis; Vaquita	Golfmarsvinet; Vaquita
Prionace glauca	Blue shark; great blue shark	Blauhai	Tintorera; tiburón azul	Tubarão-azul; cação-azul; Tintureira	Blauwe haai; grote blauwe haai	Blåhajen
Procellaria aequinoctialis	White-chinned petrel; Cape hen; shoemaker	Weißkinn-Sturmvogel	Pardela gorgiblanca; petrel de barba blanca; fardela negra grande; petrel de mentón blanco	Pardela-preta; pardela-de-mento-branco	Witkinstormvogel	
Pteroplatytrygon violacea	Pelagic ray	Pelagischer Stechrochen	Raya pelágica	Raia-pelágica	Violette pijlstaartrog; pelagische pijlstaartrog	
Puffinus tenuirostris	Short-tailed shearwater; slender-billed shearwater	Kurzschwanz-Sturmtaucher	Pardela de Tasmania	Pardela-de-cauda-curta; pardela-da-tasmânia	Dunbekpijlstormvogel	Tyndnæbbet skråpe
Raja clavata	Thornback skate; thornback ray	Nagelrochen	Raya común; raya de clavos	Raia-lenga	Stekelrog; gewone rog	Sømrokken
Raja microocellata	Smalleyed skate; smalleyed ray	Hellfleckiger Rochen; Kleinäugiger Rochen			Kleinoogrog	
Raja miraletus	Brown skate; brown ray	Spiegelrochen; Pfauenaugen-Nagelrochen	Raya de espejos			
Rhizoprionodon terraenovae	Atlantic sharpnose shark	Atlantischer Scharfnasenhai	Cazón de playa	Tubarão-bico-fino-do-Atlântico	Atlantische scherpsnuithaai	

Scientific name	English	German	Spanish	Portuguese	Dutch	Danish
Sardina pilchardus	European pilchard	Sardine; Atlantische Sardine; Europäische Sardine	Sardina europea; sardina común		Europese sardine; sardien	Sardin; europæisk sardine; almindelig sardin,
Scomber colias	Atlantic chub mackerel; Tinker mackerel	Thunmakrele; Mittelmeermakrele; Blasenmakrele	Caballa del Atlántico			
Scomber scombrus	Atlantic mackerel; Boston mackerel; Norwegian mackerel; Scottish mackerel; mackerel	Makrele	Caballa del Atlántico; verdel	Sarda; cavala	Makreel	Makrel; atlantisk makrel
Scophthalmus maeoticus	Black Sea turbot	Schwarzmeer-Steinbutt	Rodaballos; limandas; gallos		Tarbotachtigen*	Pighvar*
Sphyrna lewini	Scalloped hammerhead	Bogenstirn-Hammerhai; Gekerbte Hammerhai	Iburón martillo común; pez martillo común; cornuda negra; cornuda común	Tubarão-martelo-recortado; cação-martelo-recortado	Geschulpte hamerhaai; Lewins hamerhaai	
Squalus acanthias	Spiny dogfish	Dornhai	Cazón espinoso / Mielga	Galhudo malhado; galhudo	Doornhaai	Almindelig rødhaj
Stenella coeruleoalba	Striped dolphin	Blauweisser Delfin, Streifendelfin	Delfín listado	Golfinho-riscado, toninha-riscada	Gestreepte dolfijn	Stribet delfin
Thunnus thynnus	Atlantic bluefin tuna; northern bluefin tuna	Roter Thun; Großer Thun; Nordatlantischer Thun; Blauflossen-Thunfisch	Atún rojo; atún común; atún de aleta azul	Atum-rabilho; atuarro	Blauwvintonijn	Atlantisk tun; blåfinnet tun
Trachurus trachurus	Atlantic horse mackerel; European horse mackerel; common scad	Bastardmakrele; Holzmakrele; Stöcker; Suri	Jurel; chicharro	Carapau; chicharro	Horsmakreel; Atlantische horsmakreel	Hestemakrellen
Tursiops truncatus	Common bottlenose dolphin	Grosser Tümmler, Tümmler	Delfín mular	Golfinho-roaz; Roaz-corvineiro; roaz	Tuimelaar	Øresvin
Xiphias gladius	Swordfish; broadbill	Schwertfisch	Pez espada	Espadarte	Zwaardvis	Sværdfisk

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