STUDY

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Increasing selectivity in EU fisheries

State of play and best practices

Fisheries

Policy Department for Structural and Cohesion Policies
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RESEARCH FOR PECH COMMITTEE

Increasing selectivity in EU fisheries

State of play and best practices

Abstract

This study provides an overview of the current state of play in selectivity developments in EU fisheries by i) outlining the existing technical (gear) and tactical selectivity measures to reduce unwanted catches; ii) identifying best practices from projects that have successfully improved selectivity; and iii) analysing how EU funding have been used by Member States for promoting increased selectivity. Based on these results, policy recommendations for EU policymakers on potential actions to improve the selectivity of EU fisheries are provided.

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LIST OF ABBREVIATIONS

AI	Artificial Intelligence
BRD	Bycatch Reduction Device
CFP	Common Fisheries Policy
CFR	Community Fleet Register Number
CO_2	Carbone dioxide
DPUE	Discard Per Unit Effort
DST	Decision Support Tool
EMFF	European Maritime and Fisheries Fund
EU	European Union
ExFED	Excess Fish Exclusion Device
FAD	Fish Aggregating Device
FAMENET	Fisheries and Aquaculture Monitoring, Evaluation and local support NETwork
FAO	Food and Agriculture Organisation of the United Nations
FDF	Fully Documented Fisheries
FRESWIND	Flatfish Rigid EScape WINDow
GIS	Geographic Information System
ICES	International Council for the Exploration of the Sea
JTED	Juveniles and Trash Excluder Device
L50	Length of fish with 50% probability of being rejected by the sorting system
LED	Light Emitting Diode
LO	Landing Obligation
MCRS	Minimum Conservation Reference Size
MS	Member State

MSP	Maritime Spatial Planning
NA	Not Available
PETS	Protected, Endangered, and Threatened Species
RTI	Real-Time Incentive
SCSG	Semi-Circular Spreading Gear
SMP	Square-Mesh Panel
SR	Selection Range (defined as 70% size at selection – 25% size at selection)
SSB	Spawning Stock Biomass
SSFC	Small-Scale Coastal Fisheries
STECF	Scientific, Technical and Economic Committee for Fisheries
T0	Diamond-shaped mesh
T45	Diamond-shaped mesh turned 45º, also called 'square mesh'
T90	Diamond-shaped mesh turned 90º
UK	United Kingdom
VMS	Vessel Monitoring System
WKING	Working Group on Innovative Fishing Gears

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EXECUTIVE SUMMARY

The selectivity of a fishing method reflects its ability to select the desired species and sizes of individuals from the ecosystem in which the fishery operates. Fishing selectivity results from a combination of the selective properties of the fishing gear and the way the fishery is conducted. Fishing selectivity can be then increased, for most gears, by modifying the fishing gear configuration and/or the way it is operated. The implementation of the EU Landing Obligation (LO) has provided a strong incentive to increase the selectivity in EU fisheries. This study aims to give an overview of the current state of play in selectivity developments in the wake of the EU LO, in particular as regards the use of more selective fishing gears and the use of tactical measures, such as temporal and spatial closures, to avoid unwanted catches.

This study outlines the existing **types of selectivity measures** in EU fisheries, including the use of more selective fishing gears and implementation of temporal and spatial closures to reduce unwanted catches. Among the selectivity measures using gear technology, the study reviews the measures that have been recently developed and tested in EU fisheries for active gears, including trawls, dredges and purse seines, and for passive gears, including entangling nets, hooks and lines, and pots. For all measures, it provides a brief description of the modifications tested, and information about their effectiveness in relation to the catch of both bycatch and target species (when available). The review highlights that intense efforts in searching, developing, testing and adjusting selectivity measures to increase selectivity in EU fisheries has been deployed in the recent years. A wide diversity of measures has been developed and tested from all the main fishing gears used in EU fisheries, including the development of alternative fisheries using low-impact fishing gears. This research effort has been particularly intense on trawl fisheries. All parts of the trawls have been subject to some kind of testing aiming at increasing their fishing selectivity, in several cases leading to effective solutions. Existing selectivity measures range from the simplest to the most high-tech and innovative ones, from the most cost-effective to highly costly ones. While improvements in gear technology have been very widely explored, the research has not been as intensive on tactical measures to avoid unwanted catches, in which several promising options exist and have been successfully tested. Fishing strategies measures are also diverse, including fishing closures, real-time measures, fishers' avoidance strategies, decision-support tools, mapping unwanted catches, depth-based and time-based approaches.

Based on a literature review and on exploration of existing projects at EU and national level, the study identifies and briefly presents **best practices** implemented by projects that have successfully contributed to improve selectivity and that could be replicated in other Member States. Among these best practices, strong collaborations with fishers, building trusting transparent and long-term relationships, promoting bottom-up initiatives, and providing the right incentives for such initiatives are considered key. Other important considerations to keep in mind when developing new selectivity measures include providing solutions adapted to the local specificities, developing "fishers friendly" solutions, balancing the simplicity vs complexity of developed measures. Optimizing the testing of new measures, performing rigorous testing, giving a large visibility to existing measures while providing an easy way to understand the main results to all stakeholders, communicating widely about the existing measures should also be broadly implemented. Finally, such studies require extensive data sets and detailed knowledge about both fisheries practices, dynamics and socio-economic aspects, and species behaviour, ecology and distribution. Better knowledge is crucial to understand fisheries-species interactions and to find effective solutions to avoid unwanted catches. Making best use of the existing datasets and further advance such knowledge, promoting international data sharing, and performing an ecosystem evaluation of the broad impacts of selectivity measures, such as taking cross-taxa

conflicts into consideration, are also best practices that should be broadly applied to understand the best way to implement fishing selectivity.

To evaluate to what extent Member States have used **EU funding** for promoting innovative projects that increase selectivity, the study performed an analysis of how the European Maritime and Fisheries Fund (EMFF) dedicated to gear selectivity has been used by the Member States. The analysis shows that, over the period 2014-2023, a total of 1493 vessels from 10 Member States have benefitted from a total of EUR 12.47 million of EMFF (committed) financial support to increase gear selectivity. Large differences were found between Member States in the amount of funding (ranging from EUR 30 000 to EUR 2.83 million), in the number of vessels (ranging from 2 to 793) and in the distribution among gear types. Overall, the operations for passive gears (mostly gillnets, pots and set longlines) accounted for the largest part (EUR 6.4 million or 51.7% of all committed funding, 912 vessels or 61.1% of all fishing vessels), while active gears (mostly bottom trawls and purse seines) received EUR 4.6 million (36.7% of the total amount) for 530 vessels (35.5% of the vessels). The remaining 11.6% of the funding could not be attributed to any gear type. Nearly half of the funding was granted to small-scale coastal fishing vessels, representing 44.5% of the amount committed for 55.5% of the vessels.

Based on the results of the previous sections, the study suggests a series of **policy recommendations** for EU policymakers, on potential actions to increase the selectivity of EU fisheries.

- The management objectives aimed to be achieved with increased selectivity and their priorities should be clearly defined, because fishing selectivity is a broad term that can include many ecosystem components.
- Promoting collaboration among fishers, scientists and other relevant stakeholders, and incentivizing bottom-up approaches, appear important to favour the uptake of selectivity measures.
- Reinforcing regionalisation and increasing flexibility in management frameworks would also contribute to a better uptake.
- A results-based approach ensuring the implementation and compliance with fully documented fisheries, while promoting an easier access and sharing of fisheries dependent data, would help to confirm that measures are suitable to achieve management objectives.
- Bycatch management should be integrated into broader management objectives, in particular in the ecosystem approach to fisheries management, and monitoring should be implemented to assess the ecosystem impacts of selectivity measures.
- Finally, despite important progress in the development of selectivity measures, none of them could enable perfect fishing selectivity and the LO could result in strong negative impacts. The LO could be used as a lever to further incentivize the development and use of selective measures, for example by granting an exemption to the LO to fishers using selective measures under catch documentation.

1. INTRODUCTION

1.1. Definitions

The **selectivity** of a fishing method depends on its ability to select the desired species and sizes of individuals from the ecosystem in which the fishery operates (Cochrane et al., 2009). Fishing selectivity results from a combination of the selective properties of the fishing gear and the way the fishery is conducted. Increasing gear selectivity is one of the most common ways to reduce unwanted catch, either in terms of species selectivity (by using the differences in behaviour and morphology between species), or size selectivity (mechanically sorting the catch based on size). The tactical choices made by fishers on "where, when and how to fish" also play an important role in reducing unwanted catches.

The **bycatch** is "anything that is caught in the fishing process beyond the species and sizes of the targeted marine organisms" (Cochrane et al., 2009). Bycatch can be: i) 'regulatory', i.e. all catch that cannot be kept onboard due to regulations prohibiting their retention; ii) 'size bycatch', i.e. catches of juveniles or undersize individuals of the target species resulting from the size selectivity of the gear and influenced by market prices; iii) 'K-bycatch' i.e. catches of species with conservative life-history traits (late reproduction, small fecundity, slow growth, etc.), and lower productivities compared with the target species that can lead to conservation concerns (Hall et al., 2017). When marketable and legal, the bycatch can be kept, landed and sold; when non-marketable, it would likely be discarded for lack of economic interest for the fisher; and when 'regulatory' it cannot be kept onboard and landed due to regulatory reasons (e.g., prohibited species), and has to be discarded (Cochrane et al., 2009).

The **discards** correspond to all bycatch returned to the sea, resulting from a combination of regulatory and economic reasons and depending on the fisher's strategy (Catchpole et al., 2005; Morandeau et al., 2014).

1.2. Context

Increasing the selectivity of European Union (EU) fisheries is a high priority of the Common Fisheries Policy (CFP) and considered a key factor to progress towards sustainable fisheries. The last reform of the CFP introduced the Landing Obligation (LO) through Article 15 of the EU Regulation N°1380/2013, starting in 2015 until full implementation in all EU Member States and fisheries in 2019. The LO requires all catches of species subject to catch limits to be landed, recorded, and counted against the quotas, thereby prohibiting their discards. In the Mediterranean Sea, where there is no quota, it applies to the catches of individuals below the Minimum Conservation Reference Size (MCRS). Combined with restrictions on consumption for non-human purposes, it was expected that the LO will encourage fishers to avoid unwanted catches. Despite being mostly unpopular with the fishing sector, many fishers declared to be willing to take measures to reduce unwanted catches and discarding practices (de Vos et al., 2016; Fitzpatrick et al., 2019). The LO poses multiple challenges for EU fisheries, many of which are essentially multi-specific and multi-gear (Catchpole et al., 2017; Sardà et al., 2015; Uhlmann et al., 2019). Member States are asked to find solutions to avoid unwanted catches and reduce discards, and EU funding, in particular though the European Maritime and Fisheries Fund (EMFF), has been allocated to encourage and support operations aimed at increasing fishing selectivity.

1.3. Objectives

This study aims to give a brief overview of the current state of play in selectivity developments in the wake of the EU LO, in particular as regards the use of more selective fishing gear and the introduction of temporal and spatial closures in areas where unwanted catches are likely to be found. Specifically, this study: i) outlines the existing types of selectivity measures in EU fisheries, including the use of more selective fishing gears and implementation of tactical measures to reduce unwanted catches; ii) explores existing projects at EU and national level that have successfully improved selectivity, in order to identify best practices that could be replicated in other Member States; iii) considers to what extent Member States have used EU funding for promoting innovative projects that increase selectivity; iv) provides policy recommendations for EU policy-makers, in particular for Members of the European Parliament, on potential action to improve the selectivity of EU fisheries.

1.4. Approach and methodology

The present study is mostly based on a literature review of relevant scientific papers and reports that have been published on the topic of increased selectivity. The literature review mostly focused on the recent period (since 2013, when the LO implementation started to be on the agenda) and research performed within the EU, but in some instances, relevant research from prior periods or performed outside of the EU but with relevance to this study were included. Given the considerable number of studies, scientific publications and grey literature published on this topic during the last decade, this review does not pretend to be exhaustive, but attention was given to provide the broadest possible vision on this subject. The study includes a wide diversity of selectivity measures, including technical and tactical measures tested on a wide range of fisheries, from the simplest to the most innovative ones. The main objective of the selectivity measures being to avoid unwanted catches, both in species and size, ultimately to avoid discards; studies related to the bycatch of Protected, Endangered and Threatened Species (PETS) were also included. A wide coverage was also sought in terms of geographic extent (all EU waters, including EU outermost regions) and fishing gears (active and passive gears, demersal and pelagic fisheries). Studies performed on recreational fisheries or inland fisheries were not included.

For this review, gear selectivity measures were classified from the simplest to the most innovative and complex ones, for active gears in chapter 2, and for passive gears in chapter 3. Chapter 4 presents the tactical measures to reduce unwanted catches. In chapter 5, the best practices identified from literature review and from several EU projects are listed. Chapter 6 provides an analysis of how the EMFF was distributed among Member States to promote an increased selectivity. Lastly, policy recommendations based on the previous sections are presented in chapter 7.

N.B. Common species names are used in the main text, corresponding scientific names can be found in Annex 1.

2. SELECTIVITY MEASURES – ACTIVE GEARS

KEY FINDINGS

- Very extensive research was performed on bottom trawls, with a wide range of measures developed and tested, from the easiest to the most complex ones using the latest technological advances. Several of these measures, either simple or more complex, were effective in reducing bycatch while maintaining commercial catches.
- Most research focused on the trawl codend, with less research on the anterior parts of the trawl, yet the latter identified promising measures to reduce unwanted catches while also offering the advantage of allowing fish to escape before entering the gear, thus increasing the potential for survival.
- Several effective designs used the difference in behaviour between the upwards-rising and downward-orienting species to separate the catch in different sections of the trawls, where differentiated selectivity further occurs.
- On purse seines, measures mostly aimed at identifying the catch composition to release unwanted catches before crowding to limit illegal slipping mortality.
- Several measures, from a range of simple to more complex ones, were successfully developed in purse seines to take a sample of the catch before crowding.

The capture of active gears is based on the aimed chase of target species (Cochrane et al., 2009).

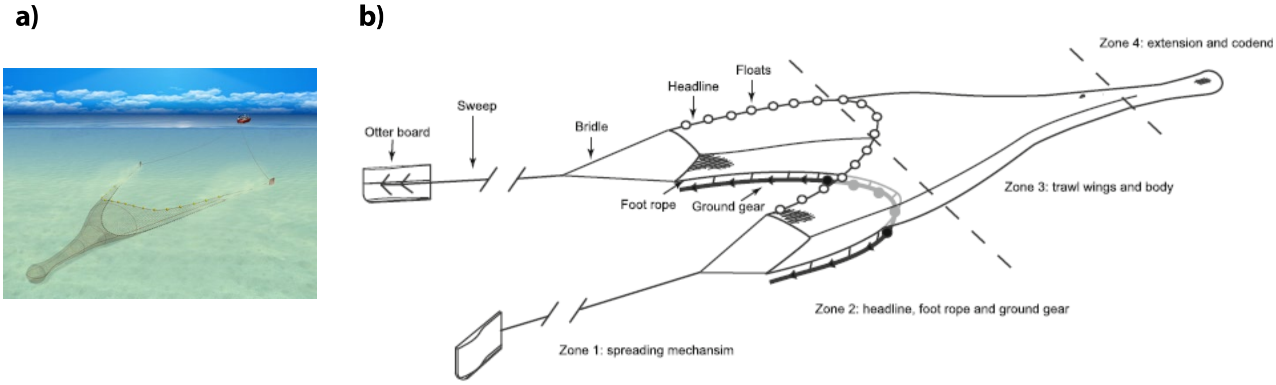
2.1. Trawls

The trawl is a "cone-shaped body of netting, usually with one codend, towed behind one or two boats to catch fish through herding and sieving" (He et al., 2021). Trawls are designed to be towed on the seabed (bottom trawls) or in midwater (midwater trawls), or in either configuration (semi-pelagic trawls). A single boat can tow one trawl (otter trawl, Figure 1a), two trawls (twin trawl), or more (multi-rig trawls). A single trawl can be also be towed by two boats (pair trawling) (He et al., 2021). Trawls are versatile fishing gears that can be used to target a wide range of species. Globally, bottom trawls were estimated to contribute to 45.5% of total annual discards (4.2 million t), with an average discard rate (t of discards*100/t of total catch) of 21.8% (Pérez Roda et al., 2019). Relatively high discard volumes were also associated with midwater trawls (0.9 million t), even if discard rates in midwater trawls were relatively low (Pérez Roda et al., 2019).

Four zones exist within a trawl (Kennelly and Broadhurst, 2021) (Figure 1b):

- zone 1= spreading mechanisms, composed of the otter boards, sweeps and bridles; exploits the behavioural responses of most species present in front of the trawl to herd them inside the netting components;
- zone 2 = headline, foot rope and ground gear, considered as the entry point to the netting components, contributes to maintain the trawl vertically open on the seabed, and to stop fish from escaping under or above the trawl;
- zone 3 = trawl wings and body, commonly comprises gradually smaller meshes, with a long-tapered section aiming to concentrate swimming and tiring fish;
- zone 4 = extension and codend, usually not tapered, is where the fish retention occurs.

Figure 1: a) A single boat otter trawl in operation and b) main components of a typical otter trawl and four categorized zones



Sources: a) Image supplied by Seafish: www.seafish.org; b) Kennelly and Broadhurst, 2021

2.1.1. Mesh size

The codend has long been assumed to be responsible for most of the selection in a trawl (Millar and Fryer, 1999) and the earliest modifications to improve the size selectivity simply involved increasing the codend mesh size (Kennelly and Broadhurst, 2021). Increasing the mesh size of the extension, as tested with the Flemish panel in the Belgian beam trawl targeting sole was an effective and simple method to reduce sole catches (19.7%), especially of undersize individuals (40.3%) (Bayse and Polet, 2015). Increasing the mesh size in the forward sections of the trawl (zone 3) reduced catches of small individuals of cod and monkfish while maintaining commercial catches (Campbell et al., 2010; Kynoch et al., 2011). The 'Orkney gear' (300 mm mesh size) tested in the North Sea mixed whitefish fishery also reduced catches of megrim of all sizes, without losses of haddock and whiting (Campbell et al., 2010). In the Shetland mixed whitefish fishery, increased mesh sizes significantly reduced the catch of most species (26%-79% with 300 mm, 53%-93% with 600 mm) (Kynoch et al., 2011). Designs with larger meshes in several sections of the trawl (codend, sleave, batings, lower panel and square section) were developed by fishers to increase fishing selectivity as part of the project 50% in the English beam trawl fishery (Catchpole et al., 2018). All designs resulted in major selectivity improvement with significantly lower catches of the main quota species (undersize sole; whiting, plaice, monkfish) and of several non-quota species. Interestingly, this project led to a large uptake from all participating, and some non-participating, vessels (Catchpole et al., 2018).

2.1.2. Mesh shape

Replacing diamond-shape (T0) with square (T45) mesh throughout codends has mostly improved size selectivity for roundfish, while they were generally less effective for flatfish (Kennelly and Broadhurst, 2021). By turning meshes to 90º (T90), similar selectivity as T45 can be achieved, effectively maintaining lateral mesh openings while avoiding the recurring issue of lower netting flexibility and strength of T45 codends (Kennelly and Broadhurst, 2021). A modified trawl fitted with an extension piece using a T90 tested in the NW Mediterranean bottom trawl fisheries targeting hake and mullets, significantly reduced unwanted catches (undersize hake and red mullet), increased overall hake catches (50%) but also reduced catches of both mullets, resulting in an overall loss of commercial catch of 17% (Sola and Maynou, 2018).

2.1.3. Codend circumference

Codend circumference was found to play a role at least as important as the mesh size in the size selectivity of trawls, with an increase in codend circumference able to counteract the positive effect of an increase in codend mesh size: increasing the codend circumference by around 13–17% was found to decrease size selectivity (L50) by 9–41% in the Adriatic Sea, while increasing mesh size (56 mm instead of 48 mm) significantly increased L50 by 15-42% (Sala and Lucchetti, 2011). In the twin trawl fishery in the Baltic Sea, the increase of the circumference in a T90 codend also resulted in lower size selectivity, with higher catches of undersize (<35cm) cod, while a decrease of the circumference had inconclusive results, enabling to catch significantly less cod from 35-48 cm and more larger individuals in one trial, but significantly less large individuals (>37cm) in another trial (Feekings et al., 2019a).

2.1.4. Netting material

Single and more flexible twine in the codend often improve selectivity (Kennelly and Broadhurst, 2021). Using polyester instead of polyethylene in beam trawls resulted in significantly higher catches of undersize cod (<35cm) (Feekings et al., 2019a). Conversely, T0 codends made out of thin and flexible Dyneema twine, tested in an experimental demersal trawl fishery targeting cod in the Baltic Sea, resulted in higher size selection of cod, plaice and flounder than with traditional nettings (Herrmann et al., 2015b). This study also showed that reducing circumference in the Dyneema codends significantly increased size selection of cod but not of plaice and flounder.

2.1.5. Large mesh escape windows

Windows made from larger T0 or T45 mesh offer the advantage to only alter a small section of the trawl, allowing unwanted sizes or species to escape with few impacts on commercial catches. In the codend, such windows showed better efficiency for several, but not all, species the further aft they were positioned in the codend (Kennelly and Broadhurst, 2021). Mounted in the upper half of the codend over its entire width and the sides of the lower part, a 3.4 m long square mesh (T45) panel (SMP) tested in the Spanish otter bottom trawl fisheries targeting megrim, monkfish and hake in "Gran Sol" fishing ground (NE Atlantic) resulted in a large reduction in unwanted catches, both undersize target catch and species with lack of quota, such as cod and haddock (Fernández-Franco et al., 2022). The BACOMA codend used in the Baltic Sea trawl fishery targeting cod was also very efficient at releasing small cod through a 6 m long SMP positioned in the upper panel all the way down to most of the codline, always available in the aft end of the codend where most cod escape (Herrmann et al., 2015a). The release efficiency in the BACOMA codend largely depends on the overlap between the SMP and the catch-accumulation zone (Herrmann et al., 2015a). When in the trawl body (zone 3), most designs of lateral or top-orientated 'windows' were efficient at reducing unwanted sizes, but lateral mesh size must be carefully considered to avoid loss of commercial catches (Bonanomi et al., 2020; Kennelly and Broadhurst, 2021).

The efficiency of escape panels relies on fish actively attempting to escape through them. However, most fish drift towards the aft end of the trawl, passing the escape panel through which they could easily have escaped, without making contact with it, suggesting that the contact probability needs to be improved to increase the efficiency of escape panels (Bonanomi et al., 2020; Krag et al., 2017). Using active stimulation in the *Nephrops*-directed fisheries, the contact probability of cod with escape panels was significantly improved, resulting in improved release efficiency, without affecting the target catch of *Nephrops* (Krag et al., 2017). Herrmann et al. (2015a) improved the release of cod through a SMP placed away from the catch-accumulation zone by stimulating an escape response. The effectiveness of an escape panel mounted in the lower side of the extension was improved by using an upwardly inclined panel as guiding device to herd cod towards the panel placed beyond (Fraser and Angus, 2019). This experimental design, trialled in the Shetland mixed demersal fishery (Scotland), significantly reduced cod catches (81%) without losses of the other target species, haddock or plaice. Using two guiding panels to enhance contact with the fish, a SMP positioned on the lateral side of the trawl body (zone 3) resulted in significantly higher catches of red mullets, but lower catches of legal-sized individuals, possibly due to an excessively large mesh size (Bonanomi et al., 2020).

2.1.6. Size-selective grids

More complex, grids (with and without guiding panels and deflectors) aimed at excluding different sizes of the target species ('size-selective' grids) were mostly successful: increasing or maintaining L50s, while reducing the selection range (SR) for a few key species (Kennelly and Broadhurst, 2021). Several designs of size-selective grids were tested on fish-trawls: i) 'sort- X', a steel grid made in three sections with 55-mm bar spaces, improved selectivity for cod and haddock; ii) 'sort-V', a variation of the sort-X concept with a single steel; iii) FRESWIND (Flatfish Rigid EScape WINDows), reduced bycatch of flatfish (68%) and undersize cod (30%), but also of marketable cod (7%) (Santos et al., 2016) and iv) 'flexi-grid' in plastic and fibre glass, of easier handling than the sort-X and more commonly used, generally improved size selectivity (reduced SRs) once determined the appropriate bar spaces (Vogel et al., 2017), but could also result in substantial losses of target sizes if trying to reduce all undersize catches (Kennelly and Broadhurst, 2021).

Several size-selective sorting grids were also tested in trawls targeting crustaceans. Juveniles and trash excluder devices (JTEDs) coupled with a guiding funnel to enhance the contact probability of the catch with the JTEDs, were tested on bottom trawls to minimize the catches of undersize deep-water rose shrimp and hake in the Strait of Sicily (Mediterranean Sea) (Vitale et al., 2018). Three JTED designs were compared: i) the net of 40-mm square mesh reduced undersize catches of shrimp (60%) and hake (44%); ii) vertical steel bars spaced 20 mm reduced catches of small hakes (34%); iii) vertical steel bars spaced 25 mm reduced both catches of undersize shrimps and hakes; but all with significant losses of marketable shrimps (25%-36%) (Vitale et al., 2018). A grid with glass fibre bars developed to improve the size selection of Brown shrimp in the beam trawl fishery in the North Sea, significantly reduced small shrimps catches (Feekings et al., 2019a).

2.1.7. Species-selective grids

Some grid designs have also been developed to allow specific species to escape. To reduce the bycatch of blackmouth catshark, common in demersal trawls, an excluder grid was tested in the Tyrrhenian Sea (Western Mediterranean). With a 90 mm grid bar spacing, the excluder grid was not efficient at avoiding bycatch and resulted in lower commercial catches of greater forkbeard and Norway lobster, but a 70 mm bar spacing resulted in a better compromise between bycatch reduction while maintaining commercial catches (Brčić et al., 2015).

The Excluder, a 30 m long netting-based sorting system was developed to reduce fish bycatch as an alternative to a traditional rigid sorting grid, mandatory in the small-meshed Norway pout trawl fishery in the North Sea. The Excluder resulted in significantly lower catches for all bycatch species analysed (5-71%), while significantly increasing the overall catch efficiency of Norway Pout (32%)(Eigaard et al., 2021).

The Flex tunnel, a grid with 80 mm bar spacing, fixed in the lower section of the extension, developed and experimented in Germany, resulted in a reduction of flounder (88%) and plaice (90%) catches without significant reduction in the target catch of cod (Feekings et al., 2019a).

The Vónin Flexi Grid, designed by fishers to reduce catches of flounder in Baltic Sea cod-directed trawl fishery, consists of three flexible grids placed in the bottom of the extension, with netting behind each grid held closed with an elastic rope (Feekings et al., 2019a). If the catch become too abundant, the elastic rope expands so that the catch remains unobstructed either to the next sorting section or to the codend. Preliminary results suggest the Vónin Flexi Grid is effective when the fitness of flounders is good, but not as effective after the spawning season when the fitness is reduced (Feekings et al., 2019a).

2.1.8. Horizontal separator panels

The behavioural differences in species vertical distributions during passage through a trawl can be used to separate species into distinct compartments prior to size selection. Species such as cod, *Nephrops* and most flatfish are downward-orientating, while haddock, saithe and whiting that do not change their vertical preference in the trawl are upwards-rising (Holst et al., 2009). Horizontal separator panels placed in trawls to separate downwards-orientating from upwards-rising species are particularly successful (Holst et al., 2009; Kennelly and Broadhurst, 2021). In the *Nephrops* fisheries, an inclined net panel was tested in the Celtic Sea to separate *Nephrops* into a lower codend, from fish deflected into an upper codend, with appropriate mesh size and shape to optimise selectivity in each codend. The net panel effectively separated *Nephrops* into the lower codend, and haddock and whiting into the upper codend, significantly reducing catches of undersize haddock and whiting, while maintaining catches of commercial-sized haddock, *Nephrops*, cod, monkfish and commercial flatfish (Cosgrove et al., 2019).

2.1.9. Modifications of the trawl rigging

A modified half quad-rig sweep configuration with two middle sweeps joined by horizontal ropes, tested in the *Nephrops* Irish fisheries, increased *Nephrops* catches, reduced catches of dogfish and ray, without affecting catches of small whiting or haddock (Browne et al., 2022). The quad-rig trawl, a gear that became very widespread in the Irish *Nephrops* fisheries (~80% of *Nephrops* landings in 2014), with a rapid uptake primarily due to higher catch rates of *Nephrops,* was compared with twin-rig in the Celtic and North Seas. Quad-rig resulted in reduction in total catches of cod (up to 61%), haddock (38%), and whiting (59%), but also in higher proportions of small *Nephrops* and cod (Browne et al., 2017).

2.1.10. Modifications affecting the headline, foot rope or ground gear

Fewer in number, the modifications of the headline, foot rope and ground gear (zone 2) have generally improved through behavioural mechanisms the selectivity of fish-trawls for both roundfish and flatfish (Kennelly and Broadhurst, 2021). Improvements were obtained using longer headlines as in the 'topless trawl' in which the foot rope is located more forward than the headline allowing upwards-rising species to escape upwards. The topless effect, compared between a low vs high headline, was significant for haddock, null for *Nephrops* with both headlines, and significant only with a low headline for cod (Krag et al., 2015).

The raised fishing line increased catches of targeted whiting (87%) and haddock (37%) while reducing unwanted catches of cod (39%) and skates and rays (80%) (McHugh et al., 2017). The loss in the commercial catches of flatfish and monkfish was compensated by increased catches of other species, resulting in an overall increase in total catch value of 14% (McHugh et al., 2017).

The semi-circular spreading gear (SCSG), a new type of ground gear tested in the Barents Sea bottom trawl fishery, increased catch efficiency for large (>56cm) cod (9.2%–22.4%), reducing escape rate (57.1%–61.7%) compared with the conventional rockhopper ground gear (Brinkhof et al., 2017). The catch efficiency of both ground gear types increased with cod length (Brinkhof et al., 2017). For haddock, the SCSG resulted in a significantly higher catch efficiency (4.5%-12.3%) with a reduction in escape rate (>70%) without difference between night and day, contrary to the rockhopper gear (Larsen et al., 2018). Removing tickler chains can significantly reduce skates and sharks catches without affecting targeted haddock, whiting and flatfish, but strongly reduces catches of commercially valuable anglerfish (Kynoch et al., 2015).

FLEXSELECT is a simple counter-herding device scaring fish away from the trawl path to reduce bycatch of both roundfish and flatfish without affecting *Nephrops* catches. Tested in the *Nephrops* directed trawl fishery, FLEXSELECT reduced fish catches by 39%, with differences among species and sizes, without affecting target catches (Melli et al., 2018). FLEXSELECT is a promising tool to mitigate bycatch, offering the advantage of preventing bycatch species from interacting with the trawl, likely enhancing their survival (Melli et al., 2018).

2.1.11. Modifications affecting spreading mechanisms

Few, mostly simple, modifications of the spreading mechanisms (zone 1) such as variable warp, sweep or bridle lengths, mostly exploiting behavioural differences between species, often had a positive impact on catches of larger species, but a negative impact on catches of smaller species (Kennelly and Broadhurst, 2021). The length of sweep actually in contact with the seabed was important for catching haddock, with larger fish (>50cm) being less likely overrun by the swipes (Sistiaga et al., 2016). Simply raising sweeps off the bottom significantly reduced cod catches (33%), independently of cod length, often with greater impacts during daytime; a positive development for this fishery, even if it could lead to substantial catch losses (Sistiaga et al., 2015).

2.1.12. Lights devices

Light emitting diodes (LEDs) are simple and inexpensive option to alter catch efficiency and gear selectivity. Their utility as stimuli for exploiting species behaviour was tested in several studies with variable selectivity improvements, with some nocturnal and seasonal effects depending on the species (Birch et al., 2023; Oliver et al., 2023; O'Neill et al., 2022; O'Neill and Summerbell, 2019). Lights appeared to be able to change the behaviour of some species which normally rise inside the trawl during capture, suggesting they can be used to modify the height at which fish enter the gear and direct them to different parts of the gear to improve selectivity (Birch et al., 2023; O'Neill et al., 2022; O'Neill and Summerbell, 2019). However, adding LED lights to a SMP did not significantly affect the panel release efficiency (Cuende et al., 2020). Adding lights to a raised fishing line significantly reduced cod catches (65%), but also marketable catches (Oliver et al., 2022). Adding green lights to the headline increased haddock catches (51%) with larger individuals, but only during nighttime (Oliver et al., 2023), while the contrary was observed with blue LEDs (Birch et al., 2023). Further details about these studies can be found in Annex 2.

2.1.13. Electrical stimulation

On an experimental basis, a substantial part of the Dutch beam trawl fleet was allowed to replace conventional tickler chain beam trawls with pulse trawls that use electrical stimulation to immobilise and capture fish (van Overzee et al., 2023). Compared with beam trawls targeting soles and shrimps, pulse trawls were found in several studies as being more selective and generating less discards (Poos et al., 2020; van Overzee et al., 2023; Verschueren et al., 2019). However, this fishing method is still substantially less selective than other fishing methods such as gillnets (Polet et al., 2010). Concerns with injuries induced by pulse trawls were raised, particularly on cod (40% of individuals) and in low numbers (0–2%) for other species (n=3) while no adverse effects were found on flatfishes and other fish species (n=8) (Boute et al., 2023). But these impacts remain unknown for most species and uncertainties about the mortality of fish avoiding/escaping the pulse trawls also raised concerns (ICES, 2017, 2016). Compared with beam trawls, pulse trawls were found to have reduced effects on the seafloor and subsequent reductions in fuel consumption (Rijnsdorp et al., 2020), but still substantially more than other gears such as gillnets (Polet and et al., 2010). These effects strongly depend on the way the pulse is used, which is not easy to control (ICES, 2016). Lighter, the pulse trawls allow to go in areas otherwise inaccessible to beam trawls, raising concerns about impacts on new areas, potentially nursery areas (Desender et al., 2017). Further concerns were raised regarding the impact of pulse trawls on species reproductive capacity and on (fish) eggs and larvae. Overall, little is known about these impacts, but Desender et al. (2017) observed delayed hatching rate and decreased survival for larvae in cod. The potential impacts of pulse trawls on different species and ecosystem components called for the precautionary approach to be implemented (ICES, 2016), leading the EU to ban pulse trawls and revoke all derogations since 2021.

2.1.14. Hydrodynamic devices

Hydrodynamics has also been used to modify catch efficiency and improve the selectivity of towed gears, such as veil nets in shrimp fisheries, rising panels in codend extensions or the flex deflector that modifies the flow in the gear to direct fish and crustaceans onto or closer to grids or escape panels (O'Neill et al., 2019; Santos et al., 2016). The novel Sea stars HydroTrawl, trialled in the Danish Sea star beam trawl fishery, generates a turbulent flow lifting sea stars into the path of the net, while the beam is held at a fixed distance from the seabed, ensuring a consistent fishing efficiency while reducing physical impacts on the seabed. The optimal design increased catches of sea stars while keeping mussel bycatch relatively low (Burgaard et al., 2023). The Excess Fish Exclusion Device (ExFED) consists of a fish lock placed just behind a hole in the upper trawl panel covered by a mat; initially, the mat seals the hole, but when the catch fills up to the fish lock, the water flow is diverted out of the hole and lifts the mat, to let the excess of fish escape at depth. The ExFED limits the size of the trawl catch to the target and once achieved, prevents additional catches from being retained (ICES, 2023).

2.1.15. High-tech systems using cameras and/or AI

More complex and expensive modifications involving mechanisms to release fish at certain depths or when catches reach a certain level using cameras, acoustic releases or weak-links in the codend/extension have also recently been developed and tested (Kennelly and Broadhurst, 2021). CatchCam is a small and highly resistant underwater camera filming the gear while fishing, enabling fishers to adjust their fishing to increase catches and reduce bycatch (CatchCam, 2024; ICES, 2023). TrawlMonitor is a cable-based system delivering real-time video feed from the trawl to the wheelhouse, providing quantitative information on the ongoing catching process (ICES, 2023; Krag et al., 2022). The Autotrawl system consists in a set of sensors fixed on the gear sending real-time information onboard to monitor the trawl as it is towed, that can be used to mitigate marine mammal bycatch by enabling animals swimming in the net to escape (ICES, 2023).

Recent technological advances in artificial intelligence (AI) and sensor networks led to the development of designs combining sensors, real-time videos, and AI to turn trawls more "intelligent". As part of the Game of Trawls project, an intelligent trawl informing fishers in real time of the catch composition was developed, constituting a decision-making tool for fishers (Game of Trawls, 2023). Similarly, the Smartrawl is a system designed to avoid discards and bycatch in demersal trawls, ensuring that only fish and shellfish that are intended to be landed are actually caught at sea, with a gate that can be opened to release fish in-situ (Fernandes et al., 2021). The latest AI models to detect fish and classify species are now reaching human-like accuracy, however the data to accurately interpret fish-gear interactions is still lacking, especially for temperate fishes (Abangan et al., 2023). More details can be found in Annex 3.

2.1.16. MiniSeine, an alternative fishing gear

The MiniSeine, a fishing gear derived from the Danish seine used traditionally in Denmark, has a great potential for reducing bycatch and improving sustainability of German coastal fisheries by removing the caught fish from the grasp of grey seals, reducing seabirds and mammals bycatch, seabed impacts and fuel consumption when compared with bottom trawls (Noack et al., 2019).

2.2. Dredges

Dredges are "cage-like structures often equipped with a scraper blade or teeth on its lower part, either pulled or towed to dig animals out of substrate and lift them into the cage or bag" (He et al., 2021). Dredges are mostly used to target molluscs, e.g., mussels, scallops. Dredges made up 2.0% of total discards (0.2 million t) with a mean discard rate of 13.6% (Pérez Roda et al., 2019).

2.2.1. Bycatch Reduction Device

A Bycatch Reduction Device (BRD) made of a rigid stainless steel grid mounted inside a bivalve dredge was tested in Portugal (Gaspar, 2019). Even if the proportion of bycatch was already low in this fishery (<12%), the BRD-equipped dredge resulted in further bycatch reduction (76.5%) and in lower catch of debris, but also in a decrease of the target catch (44.7%)(Gaspar, 2019).

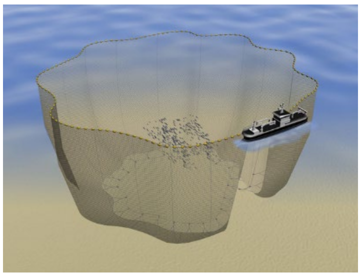
2.2.2. Hydrodynamic device

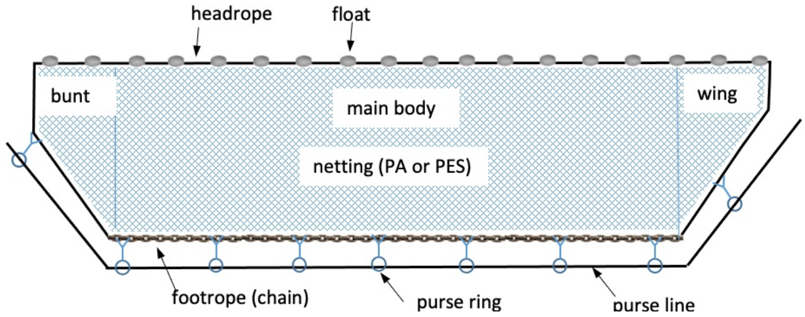
The 'Hydrodredge' is a novel design in which mechanical means, such as teeth or cutting bar that dig though the sediment causing detrimental impacts on the seabed, are replaced by a passive process using the gear hydrodynamics: precisely oriented 'cups' deflect water downward in a turbulent wave that exerts a force on the seabed sufficient to lift scallops into the water column where they are captured by the bag, with little damage to the seabed (Shephard et al., 2009). Initially developed for dredging of giant scallop, the Hydrodredge tested in the Isle of Man fishery for great scallop resulted in significantly lower bycatch proportion than traditional dredges. However, its catch efficiency was lower for great scallops (10–40%), unlike the results obtained for lighter and less embedded species such as giant scallops (Shephard et al., 2009).

2.3. Purse seines

A purse seine is a wall of netting designed to encircle a school of pelagic fish near the surface with a purse line used to close the bottom of the net (He et al., 2021)(Figure 2). Purse seines mostly target small or large pelagic species that school or aggregate close to the surface. Despite low discard rates (3.9%), purse seines generate relatively high discard volumes globally (1.0 million t), mostly resulting from large catch volumes of pelagic species (Pérez Roda et al., 2019).

Figure 2: a) Modern purse seine encircling a free-swimming fish school and b) structure and components of a purse seine for which the bunt is at the wing





Sources: a) Image supplied by Seafish: www.seafish.org; b) (He et al., 2021) Food and Agriculture Organization of the United Nations. Reproduced with permission.

Even if discarded rates tend to be low, the selectivity of purse seines is considered low once the targeted school is encircled, in particular when targeting small pelagic fish, due to small mesh sizes used in the main net body (Marçalo et al., 2019). "Slipping" is the action of releasing unwanted catches from purse seines while the catch is still in the water. Slipping was commonly used when the catch composition was not deemed appropriate, considered benign and less impacting than discarding. Yet, if not done appropriately it can lead to significant mortality of released fish which increases as the purse seine is closed and crowding densities increase (Marçalo et al., 2019). The practice of slipping has now been banned in EU fisheries unless the released fish can survive (Reg. UE No. 1380/2013, Reg. EU No. 1394/2014). Several modifications were tested in recent years to increase the selectivity of purse seines and avoid unnecessary slipping mortality. Most of them target the initial phase of fishing and aim to confirm the catch composition before crowding, when slipping is still legal (ICES, 2023).

2.3.1. Modified float-line

Adding weights over the float-line creates an opening in the top of the net from which species such as sardines can be released while the rest of the catch remains in the net (Marçalo et al., 2018). Identified during consultations with fishers, this method to mitigate slipping related mortality uses the fact that species like sardines usually swim close to the surface when caught with other small pelagic species, unlike other species (e.g., chub mackerel) which swim down in the net. Sardine survival was estimated at 43.6% for non-slipped fish, 44.7% with the modified float-line and 11.7% with the standard slipping method (i.e. fish rolled over the float-line), confirming the effectiveness of the method (Marçalo et al., 2018).

2.3.2. Acoustic

The SeinePrecog is an innovative system based on optical and hydroacoustic technologies to identify the species and size before deploying the seine (Birch et al., 2022). Combining an acoustic system and cameras, it provides information about fish size and species before the net is set to help skippers decide whether to deploy the net or not, enabling them to avoid unwanted catches. It was successfully tested for both anchovy and sardine purse seines (Birch et al., 2022).

2.3.3. Mini-trawl

The "mini-trawl" is another innovative method to help identify catch composition in purse seines (Isaksen, 2013). The mini-trawl, shot into the purse seine using a modified line thrower, samples fish into the net to find out the size distribution of the catch during the early phase of pursuing when it can still be released if considered unsuitable. The length distribution of herring sampled with the mini-trawl closely matched that of herring samples collected after being hauled aboard, proving that mini-trawl samples can be used by skippers to decide whether to continue fishing or to release the catch (Isaksen, 2013).

2.3.4. Non-entangling fish aggregating devices

In the tropical tuna purse seine fisheries, long-term bottom-up collaborative research carried out with fishers to reduce the ecological impacts associated with fish aggregating devices (FADs) enabled to identify options to minimize bycatch associated with FADs. Non-entangling FADs were designed to reduce unintentional entanglement of sharks, primarily silky sharks and sea turtles, while maintaining tuna catches (Murua et al., 2016). They are now adopted and widely used, including in EU fleets (Murua et al., 2023).

3. SELECTIVITY MEASURES – PASSIVE GEARS

KEY FINDINGS

- Passive gears have attracted less research attention to increase their fishing selectivity. They are generally considered more selective, even if some fisheries can generate high bycatch, in particular of PETS.
- For entangling nets, more effort has been dedicated to trammel nets to reduce damaged catch and to avoid interactions with marine mammals.
- The use of lights on gillnets was identified as the most promising bycatch reduction device for four groups of vulnerable megafauna commonly captured as bycatch.
- In longlines, the bait type is one of the most efficient factors affecting species selectivity, while the bait size affects size selectivity. Some innovative solutions to limit bycatch of PETS exist, but have mostly been tested outside the EU.
- Research on pots has mostly focused on developing alternative more selective and more sustainable fisheries using pots, rather than trawls or gillnets.

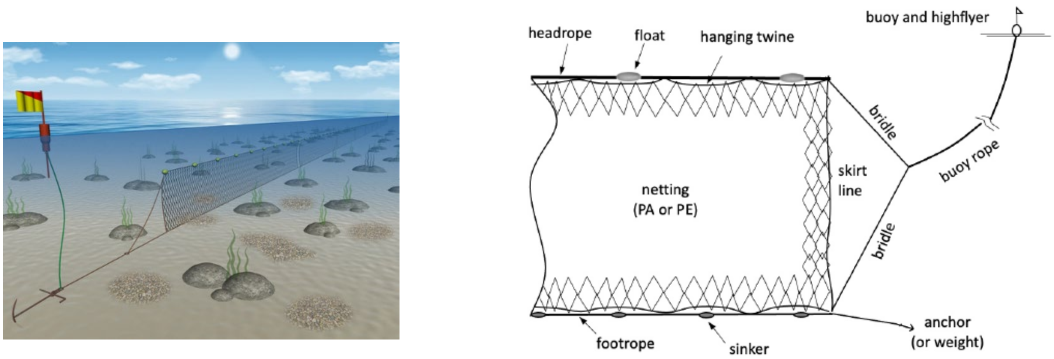
The capture of passive gears is based on the movement of the target species towards the gear (Cochrane et al., 2009).

3.1. Entangling nets

Entangling nets are “long rectangular walls of netting that catch fish by gilling, wedging, snagging, entangling or entrapping them in pockets” (He et al., 2021) either used at the surface, in midwater or near the seabed (Figure 3a). The net is held open vertically in the water by a headrope, usually with floats, and by a footrope weighted with sinkers (Figure 3b). Gillnets consist of a single wall of netting, while trammel nets consist of three layers of netting with two outer layers of large-mesh netting and an inner layer of small-mesh netting hanging slackly (He et al., 2021). They are versatile fishing gears used to catch a wide variety of fish species. Globally, entangling net fisheries have an average discard rate of about 10.1%, and produced 0.8 million t of discards, with bottom gillnets contributing the most to this discard (Pérez Roda et al., 2019).

Figure 3: a) A fleet of set gillnets set on the bottom and b) main components of a set gillnet

a) **b)**



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3.1.1. Mesh size

The study of the selectivity of 10 different inner-panel mesh sizes (16-70 mm) in the Greek trammel nets in the Aegean Sea (eastern Mediterranean Sea) showed that the smallest mesh size (16 mm) produced the highest yields for nearly all species, but also retained many small individuals (Adamidou et al., 2023). The target species (red mullet, surmullet) were caught in higher abundance with a 19 mm mesh size, while for the bycatch species, larger mesh sizes were better at retaining the largest individuals but not the small ones, with species-specific differences.

A modified trammel net with reduced mesh size in the two outer walls, aimed at reducing catches of thornback rays without reducing landings of targeted sole, did not result in a significant difference in catches of thornback ray but caught more sole (87% by value) when compared to a standard gillnet and a standard trammel net (Ford et al., 2020). This increase in catch efficiency of sole could result in increased selectivity and reduced unwanted catches if fishers reduce fishing effort as their economic performance increases.

3.1.2. Raised trammel net and guarding net

Modifications stopping the access of scavenging organisms to the net can help mitigate the problem of excessive unwanted catches damaged by scavengers. The "Aranha", a trammel net raised off the bottom, tested in the Portuguese cuttlefish trammel net fishery, caught significantly less habitat forming organisms with similar catches of target species compared with a standard trammel net (Szynaka, 2023).

A guarding net is an extra panel of non-fishing net positioned on the lower part of the net to produce a physical barrier to climbing scavengers (Martínez-Baños and Maynou, 2018). In the caramote prawn fishery in the Ligurian Sea (western Mediterranean), the guardian net was effective at reducing unwanted catches of crabs and other invertebrates (75%) but it also reduced catches of the target species, yet to a lower extent (Sartor et al., 2018). Guarding nets tested in Egadi Islands Marine Protected Area (Central Mediterranean) similarly obtained lower catches for both discard (20%) and commercial fractions, with a commercial loss of 40% (Sardo et al., 2023). In the Murcia Region (Spain), the guarding net tested in the trammel nets targeting cuttlefish produced higher catches of commercial species (32%) and up to 95% higher catches of the targeted cuttlefish, while discards were reduced to 6% with a significant decrease in damaged catches, but no difference in undersize catches (Martínez-Baños and Maynou, 2018). In the Balearic Islands (Spain), a guarding net called "grega" tested in the trammel net fishery targeting spiny lobster, did not result in significant differences neither in the commercial catch nor in the bycatch, even if the species composition of discards differed (Catanese et al., 2018).

3.1.3. Lights

Artificial lights of two colours (white or green), tested in the Spanish trammel net fishery targeting cuttlefish in the Murcia Region (Spain), resulted in a low but significant increase in commercial catches (13%), without differences between colours, while discards were not significantly reduced (Martínez-Baños and Maynou, 2018). The use of artificial lights was also tested to reduce the bycatch of vulnerable species, such as sea turtles. Sea turtles have a well-developed visual system. This characteristic was used to develop visual deterrents (LED lamps or light sticks) that resulted in significant bycatch decrease in some fisheries (Ortiz et al., 2016). Visual deterrents (ultraviolet LEDs) illuminating set nets to avoid sea turtles bycatch, tested in the Adriatic Sea (Central Mediterranean Sea) did not affect the commercial catch composition nor its size, while only two loggerhead sea turtles were caught during the experiments, both by the control gear (i.e. without lights), suggesting lights might be efficient for bycatch reduction (Lucchetti et al., 2019). A systematic review investigating the potential of sensory deterrents to mitigate the bycatch of marine mammals, sea turtles, seabirds and elasmobranchs found that the use of lights on gillnets has so far been the only mitigation method to have resulted in a significant bycatch reduction across the four groups (Lucas and Berggren, 2022).

3.1.4. Acoustic deterrent devices or 'pingers'

Acoustic deterrent devices or "pingers" to reduce bycatch for some small cetacean species have been trialled extensively for over 20 years worldwide (FAO, 2023). Pingers were efficient to reduce the bycatch of at least 7 species (e.g., harbour porpoise), while they do not seem effective for other species (e.g., in many instances bottlenose and common dolphins) (FAO, 2023). The deployment of pingers on fishing nets around Cornwall (UK) helped to reduce net-porpoise interactions and mitigate harbour porpoises bycatch (Omeyer et al., 2020). The effectiveness of pingers in preventing bycatch depends upon the environment (depth, temperature, etc.), the experimental design, the fishery, gear type and fishing practices, the sound they create, the ambient noise level (FAO, 2023). Pingers cannot fully eliminate bycatch for any species and they do not negatively affect the target catch, but they require careful monitoring as some cases of habituation, counteracting the deterrent effect were occasionally observed (FAO, 2023). The behaviour of bottlenose dolphins interacting with set fishing nets, either equipped with or without pingers, studied along the coast of Lampedusa Island (Mediterranean Sea) showed the dolphin-net interactions significantly increased with time, and after 11 days, the number of interactions was similar with or without pingers, suggesting a loss of deterrent efficiency and a deterring solution effective only in the short-term for bottlenose dolphins (Buscaino et al., 2021).

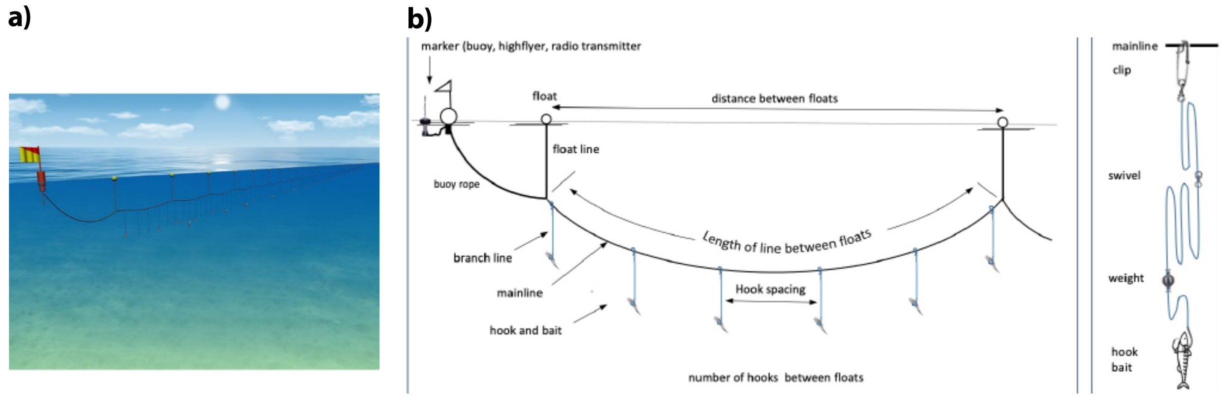
3.2. Hooks and lines

Hook-and-line gears use hooks (from one to a large number) to catch fish, either by the mouth with baited hooks or by penetrating their flesh; they may be tended or left untended (He et al., 2021). In longlines, hooks (usually baited) are connected to branch lines along a horizontal mainline (He et al., 2021)(Figure 4). They may be set on the bottom, near the surface or drifting in midwater and left untended, to attract predatory fishes. Large species and individuals with large feeding ranges being more successful in competing for bait, catches are dominated by large predatory species (Løkkeborg and Bjordal, 1992). The bycatch of PETS (sea turtles, seabirds, elasmobranchs) is one of the main concerns for longlines (Gilman et al., 2008, 2006; Watson and Kerstetter, 2006). Longline fisheries have an average discard rate of 12.3%, discarding 0.36 million t globally, with bottom longlines contributing the most (Pérez Roda et al., 2019).

3.2.1. Hook shape

The use of circle hooks instead of J-hooks (commonly used in commercial fisheries) as bycatch mitigation measure was extensively tested in pelagic longline fisheries (Reinhardt et al., 2018). In the Mediterranean longline swordfish fisheries, circle hooks did not significantly affect catch rates or lengths, nor condition upon capture, except for blue sharks. In the case of blue sharks, the higher fraction of healthy

Figure 4: a) A fleet of drifting longlines set near the surface and b) basic components and terms used to describe a drifting longline



Source: a) Image supplied by Seafish: www.seafish.org; b) (He et al., 2021) Food and Agriculture Organization of the United Nations. Reproduced with permission.

sharks (71.5% vs 22.6% with J-hooks), suggests a potential to improve their condition and survival, even if selectivity was not increased (Carbonara et al., 2023). In the Azores (Portugal) pelagic longline fishery, circle hooks resulted in significantly lower catches of swordfish and sea turtles (including small individuals), and higher catches of blue sharks, in particular juveniles, with lower proportions of deep hooking for all species, suggesting reduced injuries and mortality (Lima et al., 2023). However, faster self-shedding rates of J-hooks suggest better chance of survival than with circle hooks (Poisson et al., 2019). In the Azores deep-water bottom longline fishery, circle hooks were not suitable for bycatch mitigation as they resulted in significantly higher bycatch of deep-water sharks, without effect on the commercial catch, nor on sharks condition (Fauconnet et al., 2024). In the Spanish longline fishery targeting hake, no effect of the hook type was found (Herrmann et al., 2017).

3.2.2. Hook size

In the Spanish Mediterranean surface longline fisheries, higher bycatch of (smaller) loggerheads sea turtles was found when targeting albacore using smaller hooks, whereas larger turtles were caught when targeting bluefin tuna or swordfish using larger hooks (Báez et al., 2013). The fishery targeting swordfish had the lowest bycatch rates (Báez et al., 2013). In the Icelandic longline fisheries targeting cod, haddock, tusk, ling and wolffish, increasing hook size resulted in a lower capture efficiency for all species, with minor effects on size selectivity (Ingólfsson et al., 2017).

3.2.3. Bait size

Bait size is one of the main factors affecting size selectivity in longline fisheries (Løkkeborg and Bjordal, 1992). In the Icelandic longline fisheries targeting roundfish, larger baits resulted in increased catches of large fish and fewer undersize fish of all species, except ling (Ingólfsson et al., 2017). Bait size (along with bait type) also significantly affected the catch efficiency and size selectivity of the demersal longline fishery targeting hake in the North Sea (Sistiaga et al., 2018).

3.2.4. Bait type

Bait type is the most important gear factor affecting species selectivity in longlines (Løkkeborg and Bjordal, 1992). Alternatives to the traditional bait (whole sardine) used in the demersal longline fishery targeting hake in the North Sea mostly resulted in significant reductions (32%-90%) in catch efficiency (Sistiaga et al., 2018). Chopped herring was the only reasonable alternative bait, even if it resulted in a small (2.1%) but non-significant loss of hake catches. Alternative baits developed, mostly outside EU, from natural resources (e.g. surplus products) or synthetic ingredients (chemicals), have had limited success so far in improving catch efficiency, yet with species dependent results: catch rates of haddock were higher with several alternatives, while cod was mostly unreactive, e.g., bait bags tested in Norway (Løkkeborg et al., 2014). Bait bags could however contribute to seabird bycatch mitigation.

3.2.5. Leader material and design

The leader is the part of the branch line between the weight and the hook (Figure 4b). Replacing wire leaders by nylon leaders, easier to cut by hooked fish, was effective in reducing shark bycatch in pelagic longlines (Ward et al., 2008), even if only few experiments were carried out (Favaro and Côté, 2013). In the Azores (Portugal) deep-water bottom longline fishery, significantly lower catch rates of deep-water sharks were found in commercial longliners using nylon leaders compared with fishing experiments using wire leaders, which suggests higher numbers of bite-offs (sharks cutting the line) with nylon leaders (Fauconnet et al., 2024). In the Spanish longline fishery targeting hake, a Norwegian design with thicker leader reduced the catch efficiency of hake (16%), while modifying the leader length did not reduce catch efficiency (Herrmann et al., 2017).

3.2.6. Lights

Light lures increase catch rates of valuable species (e.g., swordfish, tunas), and became widely used in epipelagic longline fisheries targeting these species (Afonso et al., 2021). The use of blue, green and white lights in pelagic longline vessels targeting swordfish and tunas resulted in higher catches of target than bycatch species with all colours, but green lights resulted in the highest catches of target and bycatch species (73% of blue shark; 82% of turtle)(Afonso et al., 2021).

3.2.7. Electropositive and magnetic repellents

The unique sensibility of elasmobranchs to detect electromagnetic fields through their ampullae of Lorenzini was used to develop electropositive and magnetic repellents (Kaimmer and Stoner, 2008). Studies outside of EU suggest these repellents could reduce capture of sharks in longlines by up to 60% (O'Connell et al., 2014; Richards et al., 2018). 'SharkGuard' is a new bycatch mitigation device creating a powerful electric field to deter elasmobranch from biting the hook (Doherty et al., 2022). Tested in a commercial longline fishery targeting bluefin tuna, hooks fitted with SharkGuard had significantly lower bycatch rates (blue sharks 91.3%, pelagic stingrays 71.3% in average), with no significant influence on bluefin tuna catches (Doherty et al., 2022).

3.3. Pots

A pot is a small enclosure attracting animals through one or more entrances allowing entry but preventing or retarding escape (He et al., 2021). Pots are an important gear type, especially for crustaceans (e.g., lobsters, crabs, shrimps). Pots developed to target fish have had rather low catch efficiency so far, resulting in low uptake (Chladek et al., 2021), even if they could represent a more selective alternative to fishing gears such as trawls or gillnets. Globally, pots have a mean discard rate of 16.6% and generate 0.18 million t of discards annually (Pérez Roda et al., 2019).

3.3.1. Pot design

To improve the efficiency of cod pot, a novel enclosure experimental setup was used to observe cod interacting with pot entrances, day and night using an infrared camera (Chladek et al., 2021). Tests of several pot designs showed that giving cod an unobstructed view of the inside or outside when they try to enter or exit the pot respectively was a key factor, highlighting the potential of funnels to improve catch efficiency (Chladek et al., 2021). Funnels equipped with triggers significantly reduced exit rates, but with the conventional trigger entry rates were also reduced, as opposed to a trigger made of transparent acrylic glass which showed promise for increasing the catch efficiency of cod pot (Chladek et al., 2021).

3.3.2. Lights

Using a green LED lamp in the Baltic commercial cod pot fishery, catches of large cod (>38 cm) increased (80%), with no differences in catches of small cod (<38 cm) (Bryhn et al., 2014).

3.3.3. Development of alternative fisheries using pots

Pots have many advantages, including size and species selectivity, while disadvantages hindering their wider diffusion include ghost fishing, low catch of fish, narrow range of species targeted by each pot design and early stage of research (Petetta et al., 2021). In France, fish pots receive a growing interest from fishers, even if, to date, most attempts failed to catch economically valuable fish species (Méhault et al., 2022). A new pot fishery for black sea bream, species of interest identified in concertation with fishers, was developed step by step resulting in a final floating fish pot based on the behaviour of the target black seabream, with potential for high size selectivity since its mesh size was adapted to the target species and it remains open during fishing operation (Méhault et al., 2022). In the Adriatic Sea, a collapsible pot had similar catch efficiency for commercial species, with better efficiency to catch cuttlefish and lower discards than the local trammel net, with the latter catching more undersize annular sea breams (Petetta et al., 2021). The creel fishery for Norway lobster, well established off the Portuguese coast, deploy lines of baited traps at depths of 200-600 meters, in areas not accessible to trawlers (Martínez-Ramírez et al., 2021). Compared to trawling, creel fishing catches larger *Nephrops* (all legal size), in better condition and with higher value, has lower environmental impact, very low bycatch, none of species with conservation concern, and some commercial ones (Martínez-Ramírez et al., 2021). The overall catch efficiency of creel was however quite low (0.32 *Nephrops* per creel), depending on area and season, but not on soak time, showing room for improvement to consolidate creeling as an alternative to deep-water trawling for Norway lobster (Martínez-Ramírez et al., 2021).

4. TACTICAL SELECTIVITY MEASURES

KEY FINDINGS

- Less research effort has been dedicated to studying fishing tactics to avoid unwanted catches, despite their potential to help increase selectivity.
- Dynamic fishing closures and real-time measures showed higher potential to avoid unwanted catches than static measures.
- The study of fishers' avoidance behaviour proved that discard avoidance is complex and requires a big amount of fine scale adjustments.
- Using a diversity of approaches resulting from different contexts, fisheries and challenges under the LO, using long time series datasets complementary to fishers' knowledge, several decision support tools were developed by scientists to advise fishers on how to avoid unwanted catches.

Besides technical (gear) measures, the tactical choices made by fishers on "where, when and how to fish" also play an important role in reducing unwanted catches (Reid et al., 2019).

4.1. Fishing closures

Temporary and/or spatial fishing closures, applying to all fishing activity in a given area or to a portion of it, permanently or for a defined period, are widely used technical mitigation methods. For discard mitigation, fishing closures are usually applied to hotspots of undersize individuals or to nursery grounds during a defined period of the year. To study how static area closures of different duration, size and location affected cod bycatch and spawning stock biomass (SSB) of saithe in the North Sea saithe fishery, a bio-economic model showed that, in all cases, area closures resulted in an increased SSB of saithe, concomitant with an increase in cod bycatch, requiring a trade-off between target and bycatch species (Sarah et al., 2015).

Dynamic closures provided substantially better results than static area closures when compared for 15 fisheries (including two from the EU)(Pons et al., 2022). Dynamic area closures have higher potential to reduce bycatch (57% in average) than static closures (16%) without loss of target species catch, but when the target and bycatch species are highly correlated in space and time, areas to reduce bycatch without reducing catches of target species were harder to find.

The shift of fishing effort to other areas resulting from a spatial closure has to be carefully considered (Cochrane et al., 2009), as areas and times suitable to avoid discards of one species might result in increased discards of other species. Closures used in combination with other measures can work well in encouraging fishers to use more selective gears, e.g., by allowing specific gears or devices in an otherwise closed area (Catchpole et al., 2005; Graham et al., 2007).

4.2. Real-time measures

More flexible, real-time closures can represent a solution in reaction to fishers' critique of more permanent closures. The potential of real-time closures to avoid bycatch with real-time information shared between vessels about bycatch hotspots was discussed with *Nephrops* trawl fishers in Kattegat and Skagerrak (Eliasen and Bichel, 2016). Informal information sharing is already common among fishers, but the LO constitutes an additional incentive and sharing information about bycatch hotspots is considered less critical for fishers than sharing information about good fishing grounds. When receiving warnings, the decision to move away from the hotspot would depend on the balance between the loss of target catch by moving and the loss of value by wasting quota on low paid catch by staying. The decision also depends on the available quota, i.e. a species unwanted by a vessel could be a welcome bycatch for a vessel with extensive quota. Sharing bycatch information among fishers was not seen as a risk, but if shared with authorities it was perceived as a risk to get compulsory closed areas, and sharing with the general public was seen, by some fishers, as an opportunity to prove their openness and improve their public image (Eliasen and Bichel, 2016).

Real-time information that can be used for real-time closures and move-on rules can be shared in digital platforms as tools to inform fishers on the spatial distribution of wanted and unwanted catches, as implemented in the Celtic Sea with maps sent to participating fishers to avoid bycatch of spurdog, and in Scotland with maps showing locations of high bycatch sent through a mobile app when catch values reach set thresholds, so that these locations can be voluntarily avoided (Kraak, 2023). In the North Sea, the effectiveness of real-time closures to reduce cod catches was not as much as initially expected, though still detectable (Holmes et al., 2011).

'Real-Time Incentive' (RTI) is a new suggested approach to fisheries management in which catch quotas and days-at-sea limits are replaced by a single allowance of fishing-impact credits (Kraak et al., 2012). Each fisher would be allocated RTIs that they could spent according to spatiotemporally varying tariffs, while fishing where and when they want (Kraak et al., 2012). Tested using a conceptual model, RTI performed better in controlling harvest rates of multiple species in a mixed fishery and in limiting impact on vulnerable species or ecosystem components than several traditional management systems, but it did not perform as well if the spatial distribution of choke species largely overlaps with that of other species, or if fish migrate (Kraak et al., 2015). By allowing fishers to fish where and when they want, instead of prescribing or forbidding, fishers would have to take costs of undesirable outcomes into account in their business decisions, allowing them to better balance between limiting mortality on choke and vulnerable species and optimally exploiting their target species (Kraak et al., 2015).

4.3. Fishers' strategies to avoid unwanted catches

The analysis of the fishing behaviour of a single demersal trawler in the North Sea intending to avoid unwanted catches and reduce choke species showed that avoidance took primarily place through fine-scale tactical choices rather than large displacements (Mortensen et al., 2018). The catch composition and potential to target or avoid species was greatly affected by its gregarious or solitary behaviour, with species (e.g., saithe) patchily distributed being very difficult to avoid, with most hauls catching small amounts but a few catching unexpectedly large amounts that could rapidly choke the fishery. Fishers need to make a great amount of real-time tactical decisions and trade-offs to avoid unwanted catches and the negative impacts they could have with the LO, especially when operating in mixed-fisheries (Mortensen et al., 2018).

Being given free tactics and gear selection, twelve Danish demersal trawlers from the North Sea, Skagerrak, and Baltic Sea, were challenged to reduce their discards. Each developing his own solution, almost all participants were able to meet the challenge with slightly lower discards and slightly higher landings, all managed to catch fewer choke species and a more valuable size composition resulting in similar or even higher revenues (Mortensen et al., 2017).

4.4. Decision support tools

Complementary to fishers' empirical knowledge, providing fishers with scientific knowledge on where and when bycatch is more likely to occur can be useful as decision-support tools (DST) to help them make such decisions. Scientists acting as advisors to fishers have developed DSTs using various approaches; web-based apps were also developed together with fishers to best fit them to their needs, offering an interactive way to display the information and making it readily accessible (Reid et al., 2019).

Discarding practices in mixed demersal fisheries in the Celtic Sea analysed by combining observer data from Ireland, France and the UK showed small differences in discarded species composition, but strong differences in spatial patterns between countries (Robert et al., 2019). Maps displaying the distribution of discards showed a limited potential to avoid discards, requiring trade-offs to effectively reduce unwanted catches (Robert et al., 2019). The same combined dataset was also used to produce maps identifying where catches of quota-restricted species or undersize fish occurred and were consistent through time, showing that it was possible to target legal size (>MCRS) catches whilst avoiding undersize (<MCRS) catches of the same species, and that species with restricted quota e.g., haddock can be avoided whilst targeting other commercial species e.g., whiting (Calderwood et al., 2020). A user-friendly app was developed to allow this information to be easily consulted to better inform decision making (Calderwood et al., 2020).

The spatio-temporal distribution of discards from bottom trawlers in the Eastern Ionian Sea was mapped, both in terms of Discards Per Unit Effort (DPUE) and total discard quantities. Spatial clusters of discard hotspots and their spatio-temporal persistence were also investigated. The DPUE distribution was influenced by environmental and temporal factors, while higher discard amounts were found in areas of high fishing effort (Maina et al., 2018).

To assess the amount of discards in relation to the catch and the economic impact of fishing in a given area, two bycatch ratios were modelled: i) the proportion of bycatch out of the total catch and ii) the proportion of unwanted but regulated species in the catch (Paradinas et al., 2016). The resulting bycatch ratio predictive maps provided intuitive tools to assess the fishing suitability of an area and can be combined to select economically and ecologically fishing-suitable areas. Applied to the SE Spanish Mediterranean Sea, this method enabled to identify at least two economically fishing-suitable areas where bycatch could be reduced (Paradinas et al., 2016).

Suggesting a Marine Spatial Planning (MSP) approach, a Geographic Information System (GIS) platform was developed to help users make better informed decision when considering when and where to fish. Using a real-time modelling approach, maps of discard probability, easy to interpret by fishers, were produced to help locate areas where yields can be maximized while avoiding unwanted catch (Bellido et al., 2019).

In the Azores (Portugal), the spatial distribution of 15 species of deep-water elasmobranchs, several of which being under fishing prohibition, was mapped to provide a decision support tool to help fishers avoid their bycatch. The distribution of these species was mostly influenced by depth, along with seafloor topography, and the greatest number of species occurred in seamounts and ridges, suggesting deep-water elasmobranch bycatch could be reduced by a combination of depth-based, area-based and gear-based tactics (Das et al., 2022).

4.5. Depth-based measures

Along the Spanish Mediterranean coastline, the proportion of unwanted fish follows a longitudinal gradient related to bathymetry, with higher discards in shallow waters (Paradinas et al., 2016). This gradient likely reflects the distribution of target species of local fisheries, but depth-related variations of discard ratios were also due to differences in the species composition and length-frequency distribution of fish communities, e.g., bogue, the most discarded species, is abundant between 50 and

200 m, likely explaining the high discards in shallow waters (Paradinas et al., 2016), and suggesting depth measures could be effective at reducing discards.

When applying the MSP approach (described in section 4.4) to the purse seine fishery targeting small pelagic fish along the Spanish Mediterranean coast, bathymetry was the main factor affecting discards in this fishery, with higher discards in shallow waters, reinforcing the need to better enforce the existing ban of purse seines in shallow waters (<35m) (Bellido et al., 2019).

Many deep-sea fisheries are considered unsustainable with high bycatch of vulnerable species (Allain et al., 2003; Norse et al., 2012). The biodiversity of the demersal fish community, the ratio of discarded to commercial biomass, and the ratio of elasmobranchs to commercial biomass significantly increase with depth (Clarke et al., 2015). From 600 m, the potentially negative impacts increased while the catch value decreased, until they start outweighing the commercial benefits derived from fishing between 600 and 800 m, suggesting that a maximum depth of 600 m could be effective to limit bycatch of bottom trawling (Clarke et al., 2015).

4.6. Time-based measures

Avoiding fishing at certain times of the day can sometimes contribute to limit bycatch. Night setting can be used to mitigate seabird bycatch in longlines, by avoiding fishing at times when seabird interactions are most likely and intense (Løkkeborg, 2011). Since most seabirds are visual feeders foraging during daylight hours, setting longlines at night reduces the ability of seabirds to see and seize baits and thus the number of birds attacking baited hooks (Løkkeborg, 2011).

4.7. Soak time

Soak tactics in gillnet fisheries vary between target species and seasons (Savina et al., 2017). The effect of soak tactics was compared between deployments of 12 h daytime (used in the commercial Danish summer gillnet fishery targeting plaice), 12 h nighttime and 24 h. The 12h daytime soak time resulted in higher catches of commercial size plaice and lower bycatch of dab and edible crab. The optimal soak tactic maximising commercial catch while limiting bycatch was already used by the gillnetters participating in this fishery (Savina et al., 2017).

5. BEST PRACTICES

KEY FINDINGS

- Working in close collaboration with fishers, based on trusting relationships, built up using transparency and continuity is the most effective way to increase selectivity.
- Bottom-up initiatives offer a promising way and are important to promote selectivity, but the right incentives must be provided. While some of them can be financial, working on the public image of fishers also showed great potential.
- Providing solutions adapted to local specificities, developing "fishers friendly" solutions, and balancing the simplicity vs complexity of the measures developed help to promote the uptake of selectivity measures.
- Optimizing the testing of new measures by first identifying the most promising of them, performing rigorous testing to validate their effectiveness, giving them a large visibility in an accessible way and communicating widely about them contribute to accelerate the validation and uptake of selective measures.
- Advancing knowledge on fisheries, species behaviour and ecology, promoting international data sharing, and performing an integrated evaluation of the measures, contribute to understanding the best way to implement fishing selectivity.

From the review of existing selectivity measures and from the consultation of recent EU projects, the practices considered to have best contributed to successful outcomes are listed below.

5.1. Collaborate closely with fishers

The crucial importance of collaborating with fishers is now fully recognized and implemented in most projects on fishing selectivity. A close partnership with the industry is needed in the introduction of more selective measures, their successful use relying largely on their acceptance and support (Pérez Roda et al., 2019; Suuronen and Sardà, 2007). A broad collaboration between all relevant stakeholders with complementary expertise, including fishers, scientists, managers and gear technologists, helps to create a common vision and favour the acceptance and adoption of measures (Feekings et al., 2019b; Pérez Roda et al., 2019). The co-creation of knowledge on bycatch was identified as a key process to better understand the interactions between fishers and species and to develop measures that are adapted to local specificities (Cazé et al., 2022). When identified and found together, measures have more chance to result in uptake. Murua et al. (2023) provided the successful example of bottom-up collaborative research carried out for over a decade with fishers from the tropical tuna purse seine fleets. Through participatory knowledge-exchange workshops in which scientists, fishers and key stakeholders examine and develop together ways and tools to minimize fishery impacts, co-constructed solutions were developed along with a better understanding of ecosystem and fishery dynamics. This model of long-term collaborative and inclusive research, enabling fishers to proactively collaborate in research on impact mitigation, broadly applicable to any fisheries, has contributed to improved scientific advice, voluntary compliance and adaptive management (Murua et al., 2023).

5.2. Build up trust with transparency and continuity

For such collaborations to be successful, a key consideration to keep in mind and that should be better promoted is the central role of trust. Industry-science collaborative projects can help to build mutual trust (Kraak and Hart, 2019), as in the case of the tuna purse seiners in which "fishers' increased trust and stewardship have stimulated unprecedented large-scale science-industry research projects" (Murua et al., 2023). Trust was progressively achieved through more than a decade of regular bottom-up collaborative and participatory exchanges, promoting continued open transparent discussions among stakeholders (Murua et al., 2023). Continuity and transparency are key to build trust. Even in case of conflictual relationships, consensus should not be aimed at, the presence of conflicts should be acknowledged, understanding their roots and impacts can help identify the factors hindering stakeholders to adapt (Cazé et al., 2022). Building trusting relationships is a lengthy process and requires continuity. The finite lifespan of some initiatives was one of the main issues that has limited gear uptake and prevented from transcending into the fishery, even when they had resulted in positive gear developments (Feekings et al., 2019b).

5.3. Promote bottom-up initiatives

Promoting bottom-up initiatives, enabling fishers to develop, test and use their own gear or tactics to avoid unwanted catches is a promising way to develop effective selectivity measures and to promote their uptake, participants valuing more something they have put efforts in achieving (Kraak and Hart, 2019). Fishers involved in bottom-up initiatives develop a stronger feeling of ownership, a sense of control over the new gear and a greater desire to achieve the goal (Feekings et al., 2019b). Advantages of bottom-up initiatives also include: i) promoting collaboration between stakeholders, ii) giving a more proactive role to the industry, iii) accelerating the development, test, and approval of the measure(s), iv) allowing to develop and test several measures in parallel (Feekings et al., 2019b). Several bottom-up approaches led to the development of more selective gears. However, they can also fail in cases of lack of clarity, transparency, incorrect incentives, unclear communication, distrust, or diverging perceptions (Feekings et al., 2019b). Providing the right incentives is important for such initiatives to be successful (Feekings et al., 2019b; Mortensen et al., 2018).

5.4. Provide the right incentives

Improved selectivity is often associated with short-term economic losses, which is the most common reason discouraging fishers from using new selective gears (Catchpole et al., 2005; Feekings et al., 2019b; Suuronen and Sardà, 2007). Providing financial support to compensate for initial investment and short-term economic losses can help during the transitory period to incentivize uptake. Financial incentives can take the form of additional fishing opportunities, income guarantees, funding gear construction, chartering of vessels and monetary prize (Feekings et al., 2019b). In the case of the cod plan (Reg. (EC) N°1342/2008), a decrease in cod catches had to be demonstrated to avoid the stipulated effort reductions, exemption which provided a powerful boost to the industry to rapidly develop and deploy new fishing gears and tactics (Kraak, 2023). Financial incentives often help, but not always. In the Minidisc project, some participants were found to be only interested in receiving additional quota, not in the objective of discard reduction aimed by the project (Feekings et al., 2019b; Mortensen et al., 2017).

Additional or alternative incentives can also be powerful. In the Gitag projects, good uptake was fostered by granting derogation to use gears that may not comply with legislation, in addition to financial support for gear development and wide results dissemination (Feekings et al., 2019b). The incentive, more subtle in the Danish anchor seining project, consisted in developing a new gear with reduced undersize catches to replace the regulatory but not viable gear (Feekings et al., 2019b). Allowing entry into otherwise closed areas can also be very effective (Graham et al., 2007). Among the non-monetary incentives, the recognition and credit of fishers as key players in the sustainability of their activity, the promotion of a good public image of fishers trying to increase fishing selectivity was particularly effective (Catchpole et al., 2018; Feekings et al., 2019b). In the project 50%, the only financial incentive was funding the new gear; in addition, extensive dissemination in the media of the active role of fishers in reducing discards was enough to incentivize participation (Catchpole et al., 2018; Feekings et al., 2019b). Social sciences can help identify drivers of fishers' behaviour and the most appropriate incentives (Kraak and Hart, 2019).

5.5. Adjust to local specificities

Selectivity measures must be tailored to regional contexts to embrace the wide diversity of species, fisheries, and ecosystems. As presented in chapters 2 and 3, some measures are effective for some species in some fisheries but not in others. Reid et al. (2019) pointed out the diversity of approaches developed to help fishers avoid bycatch. No single approach was possible across all examples, which was probably not desirable since each had its own specific issues and context. The way fish are distributed, the requirements of the LO and the limitations in fishing, all widely vary (Reid et al., 2019). Fishers can play an important role in facilitating a more regionalised approach by actively participating in the identification of needs and in the development of new measures (Eliasen et al., 2019). Collaborating with local fishers is probably the best way to identify the specific needs and constraints and to develop locally adapted solutions. Once tailored locally, measures must be tested in the local context within the local fishery to confirm their effectiveness.

5.6. Develop "fishers friendly" solutions

One of the first rules when working on fishing selectivity is to monitor the effect of the tested measure on the target catch. To ensure industry acceptance and adoption of selectivity measures, one should be aware that the fishing sector has a limited capacity to accept the loss of catches of target species. The acceptable level of target catch loss in order to increase selectivity should be assessed (Pérez Roda et al., 2019). Some compensation e.g., additional days at sea or quota, increased market value or increased flexibility, can be granted to offset the loss of target catch (Pérez Roda et al., 2019; Suuronen and Sardà, 2007). Besides the target catch, other factors affecting the fishing activity should also be considered when developing new selectivity measures. Unrealistic measures that do not account for the operational, technical, and economic constraints of the fishing activity are unlikely to result in uptake. The factsheets produced by ICES WKING (ICES, 2023) are an excellent example of such consideration (Annex 4). For each design, they provide information on its technical complexity, easiness to deploy/retrieve, risk to the safety of crew, among many other factors (ICES, 2023). They also include an analysis of how the Political, Economic, Social, Technological, Environmental and Legal factors (P.E.S.T.E.L) have impacted the gear uptake. Reducing bycatch comes with benefits for the operational side of fishing, as it means getting a cleaner catch, reducing sorting time, increasing storage, and optimizing storage space onboard, along with ecological benefits (Feekings et al., 2019b). Better promoting these benefits can help convince fishers to use more selective measures.

5.7. Simplicity vs complexity

The costs associated with new technologies and the perceived increase in economic risks and safety issues when operating more complex gears contribute to decrease uptake of new selective devices (Feekings et al., 2019b). Measures offering simple low-cost solutions with minimum initial investment are more likely to result in uptake. To increase trawl selectivity, Kennelly & Broadhurst (2021) suggested to start by evaluating modifications to the codend, as they are usually simple and cost-effective and more likely to be used by fishers, before moving towards other parts. Simple and cost-effective measures should be evaluated first, before considering more complex and costly modifications as they might not perform better than simpler solutions (Kennelly and Broadhurst, 2021). Complex modifications can certainly have a specific utility in some fisheries to reduce unwanted catches, but they would probably only be usable by a limited number of vessels. The high initial investment and high maintenance costs of complex modifications, coupled with the increased complexity in using them, would likely result in low uptake by most fishers. To optimize the development of complex systems, an interesting approach was implemented in the SMARTFISH project, with the experimentation of each developed high-tech device taking place in several different fisheries and countries for cross-validation of their effectiveness.

5.8. Optimise the testing of new measure(s)

Considering the extensive number of potential designs, devices and combinations that could be tested for most fisheries (as seen in chapters 2 and 3) and the high costs and time required to carry out at-sea trials, it is sound to start by identifying the most promising measures that should be considered first for testing at sea. Prior identification helps to prioritise and optimise research efforts, in particular at-sea trials to be carried out locally. They can be identified either through discussions and ideas from fishers or through a literature review of the most promising measures found elsewhere for similar species and/or fisheries.

Meta-analytical or other review approaches are increasingly being used to examine the results obtained in experiments and to identify, whenever possible, generalisable patterns over diverse situations (e.g. (Fryer et al., 2017; O'Neill et al., 2020), offering valuable help to identify such solutions. The meta-analytical approach developed by Melli et al (2020) is also noteworthy. Combining BRDs would likely provide further potential for bycatch reduction, but the number of possible combinations is prohibitive to test them all experimentally. Melli et al. combined available data on several independently tested BRDs to predict the theoretical selectivity of all their possible combinations. This approach enabled to identify 15 most promising combinations worth experimental testing, out of 100. However, this approach can only be applied to a limited number of species for which several BRDs have already been tested.

Another interesting approach to optimize scientific testing while accelerating the identification of the most promising gear designs is the framework for industry-led initiatives proposed by Feekings et al. (2019b). In this framework, the gear would first be developed and tested by fishers under catch documentation, allowing several gears to be tested in parallel and initial refinements by the fishers themselves. Once developed, the most promising designs identified would be subjected to rigorous scientific testing to validate their effectiveness (Feekings et al., 2019b).

To get the most out of at-sea experiments, data collection should include detailed information about the gear and modification tested, fishing conditions and catches of all (target and bycatch) species, even if it only aims at one or a few species (Kennelly and Broadhurst, 2021).

5.9. Perform rigorous testing

If at-sea trials are first conducted by non-scientists, extra care must be given to ensure the protocol is followed by participants as they may not be aware of the effects of not complying with it (Mortensen et al., 2017). A key challenge is to develop quality control to identify issues and provide feedback to fishers during the trial to avoid discovering the issues afterwards when it is too late to improve the setup (Mortensen et al., 2017). In any case, a rigorous scientific testing remains essential to confirm the effectiveness of new measure(s). To be done robustly and reach reliable conclusions, scientific testing must be carried out as part of dedicated at-sea research cruises, ideally together with fishers onboard commercial fishing vessels, as close as possible to actual fishing conditions, so that the results can be directly applicable to commercial fisheries. The trial results should be communicated back to fishers to enable "a double loop learning system resulting in solution refinement and/or adoption" (Murua et al., 2023). Experimental designs should ensure a sufficiently high number of replicates to achieve statistically significant results and avoid confounding variables (Kennelly and Broadhurst, 2021). Promoting rationalization and consistency of experimental designs would be beneficial for future syntheses e.g., meta-analyses (Kennelly and Broadhurst, 2021). The effectiveness of the gear(s) should also be tested once in use in fisheries to confirm the desired outcomes have been achieved (Nikolic et al., 2015).

5.10. Make existing solutions visible and easy to understand

Giving visibility to existing solutions is essential. Several EU projects in which various solutions aimed at increasing selectivity were tested, took care to compile their results and make them easily and broadly accessible. The information was summarized and displayed in an easy-to understand way, using simple language, often in a visual way to make them more "appealing" and straightforward, e.g., gear factsheets and user-friendly apps. The use of simple metrics is also important to reduce the risks of misinterpretation by non-scientists, e.g., percentages of discard or bycatch reduction are easier to interpret than selectivity curves (Kennelly and Broadhurst, 2021). The uncertainty and variability associated with the results should also be communicated.

5.11. Communicate widely

A wide communication of the results obtained in the search for solutions to increase selectivity should also be promoted. The scarcity of publicly available documentation, with results unreported or difficult to access, can hinder the uptake of good ideas beyond people involved in the initiatives (Feekings et al., 2019b). Rarely done, negative results should also be reported (Lucchetti et al., 2023). This communication can take several forms, e.g., webpages, publicly available reports and scientific papers (ideally in open access). Policy briefs are also a good way to communicate with decision makers so that research results can readily support fisheries management. The same level of information should be available and shared with all relevant stakeholders to create a common vision and promote acceptance and adoption of measures (Pérez Roda et al., 2019).

5.12. Make best use of fisheries data and promote data sharing

A good understanding of both environmental and socio-economic dynamics of the fisheries concerned by the bycatch problem is crucial (Pérez Roda et al., 2019). Data collected by observers onboard commercial fishing vessels are particularly valuable data, in most cases, the only source of information on bycatch and discard. Fine-scale information on the spatial distribution of fisheries is also crucial. In many cases, it relies on VMS data, which can be difficult to access due to mistrust in how it is used. Scientific fishing surveys provide long time-series necessary to obtain a sufficiently long-term view to understand and monitor the impacts of fishing activities on marine resource populations. The collection of socio-economic data often lags behind, yet it is particularly valuable to assess the potential consequences of measures on the fishing sector, information that can also help to promote the uptake of selectivity measures. In transboundary seas or ocean basins where fisheries from different countries co-occur, data sharing from these countries should be promoted, e.g., as performed by Robert et al.

(2019) and Calderwood et al. (2020). Combining observer data from three countries, these studies provided the full distribution of unwanted catches in the Celtic Sea, allowing to go beyond the reduced view from each country dataset if taken separately. Such approach should be encouraged and used as often as possible.

5.13. Integrate knowledge on species behaviour and ecology

Significant progress in the research to increase gear selectivity has been achieved by a better understanding of fish behaviour. Understanding how bycatch vs target species behave when exposed to different conditions, how their senses work and how they would react to different stimulus offer promising avenues for the reduction of unwanted catches. This valuable knowledge is still limited for many species, but recent technological developments should enable to rapidly fill the gaps, e.g., Abangan et al. (2023). To identify tactical measures to avoid bycatch, an in-depth knowledge on species ecology and dynamics is required. This knowledge relies on an extensive quantity of data and long-time series that are not available for all species. Tactical measures to avoid unwanted catches should be explored more, as they provide a deeper understanding of species-fisheries interactions, also relevant to other management objectives.

5.14. Integrate all ecosystem impacts

The broad impacts of selective measures on the whole ecosystem should be considered. Many bycatch management measures use a piecemeal approach that can result in unintended cross-taxa conflicts, i.e. measures designed to reduce bycatch of one or a few species may increase bycatch of another species (Gilman et al., 2019). Gear modifications offering higher chances of survival should be promoted, e.g., in anterior parts of the trawls (Kennelly and Broadhurst, 2021; Melli et al., 2018). An ecosystem assessment can also help identify cases when selective fishing results in negative effects, e.g., selective removal of larger individuals of hermaphrodite species, or when the targeted species are considered vulnerable (Lloret et al., 2018).

6. EU FUNDING FOR INCREASED SELECTIVITY

KEY FINDINGS

- In total, 1493 vessels were funded by the EMFF to improve their selectivity, with a total amount of funding committed of EUR 12.47 million over the period 2014-2023.
- Ten Member States used the EMFF funding for operations dedicated to gear selectivity, with large differences among Member States in the amount of committed funding, the number of vessels and the distribution among gear types.
- More than half of the funding was granted to passive gears, for 61.1% of the vessels, using mostly gillnets, pots and hooks and lines, while active gears benefitted from 36.7% of this funding, for 35.5% of the vessels, using mostly bottom trawls and purse seines.
- Small-scale coastal fishing vessels benefitted from 44.5% of the committed funding for 55.5% of the fishing vessels, while the vessels above 24m length were granted 22.5% of the funding for 6.7% of the vessels.
- The beneficiaries were mostly micro and small enterprises (98.9% of the funding and 99.5% of the vessels). Most operations contributed to the funding of only one vessel.

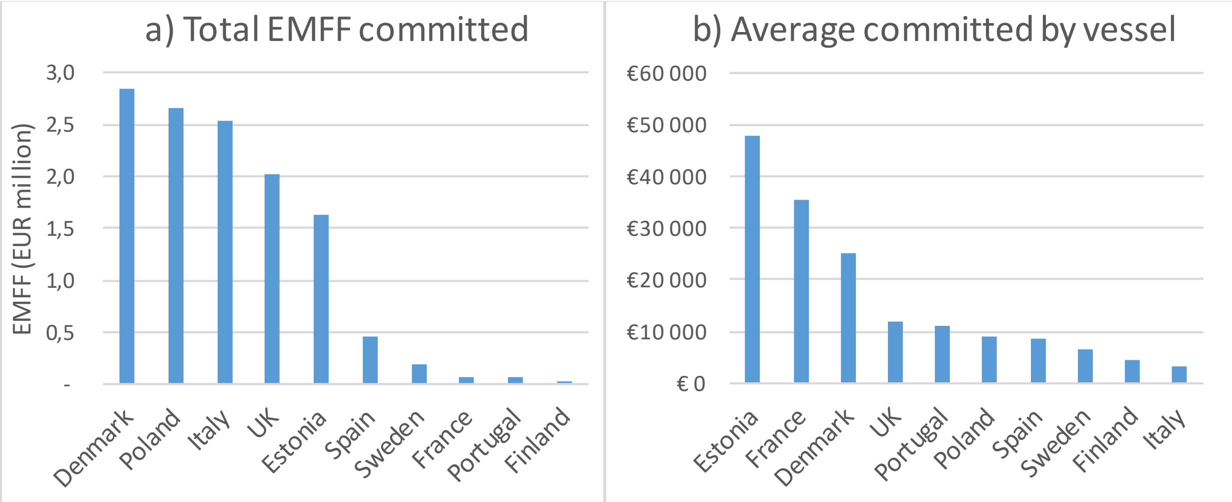
To evaluate to what extent Member States have used EU funding for promoting innovative projects that increase selectivity, an analysis of how the European Maritime and Fisheries Fund (EMFF) dedicated to gear selectivity has been used by the Member States was performed. For the purpose of this study, FAMENET provided the summary of all operations supported by EMFF reported by Member States (Infosys reporting, EMFF Article 97.1), under the specific measure "Limiting the impact of fishing on the marine environment and adapting fishing to the protection of species" (EMFF Article 38) and specifically dedicated to gear selectivity (specific code of investment type "35 – Selectivity of gear"). The data, spanning the period 2014 – 2022, consisted of the number of vessels having benefited from the EMFF financial support, the amounts spent (as of 31.12.2022) and committed (until the end of the EMFF programme by 31.12.2023) summarized by Member States, main fishing gear and vessel size category. Information about the beneficiaries' enterprise size (Eurostat, 2016) was also provided.

In total, 1493 vessels were funded by the EMFF to improve their selectivity, with a total amount of funding committed of EUR 12.47 million, 81.4% of which (EUR 10.15 million) was already spent by the end of 2022. Among the beneficiaries, 55.4% of the committed funding (EUR 6.9 million) was granted to micro enterprises, for 41.8% of the number of vessels (n=624), and small enterprises accounted for 25.5% of the funding (EUR 3.1 million) and 14.4% of the vessels (n=215). This information was not reported for 17.9% of the funding (EUR 2.2 million) and 43.3% of the vessels (n=646), but nearly all of them were micro enterprises. Only a small part went to medium enterprises (1.1% of the funding and 0.5% of the vessels) and none was attributed to large enterprises. Most operations contributed to the funding of one vessel only.

In terms of Member States (MS), 10 different MS have used the EMFF funding to promote operations aiming at increasing gear selectivity. The average funding committed was EUR 1.25 million, ranging from EUR 2.83 million for Denmark to EUR 0.028 million for Finland (Figure 5a). Five MS (Denmark, Poland, Italy, the UK and Estonia) benefitted from 93.5% of the total EMFF committed (Figure 5a), further highlighting the large differences that exist between MS. The number of benefiting vessels by

MS ranged between 2 and 793, for an average amount committed by vessel ranging between EUR 3 200 and 48 000 (Figure 5b).

Figure 5: Total committed EMFF and average amount by vessel by Member States

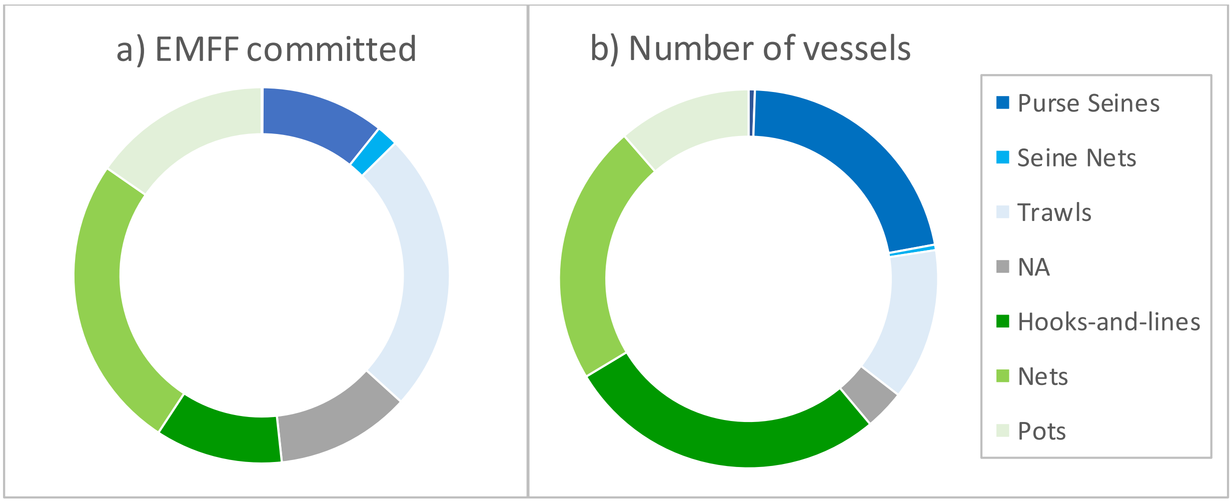


Data source: FAMENET

In terms of main fishing gears, the EMFF support committed was of EUR 4.6 million (36.7%) for active gears, and EUR 6.4 million (51.7%) for passive gears, representing 530 (35.5%) and 912 (61.1%) vessels, respectively. For 51 vessels (3.4%) and a total amount of EUR 1.4 million committed (11.6%), it was not possible to link the CFR of the vessel to its main gear, and this information was reported as NA. The details of the distribution of the EMFF committed and the number of vessels by main gear type, displayed in Figure 6, show that for passive gears, nets benefited from the largest EMFF amount (EUR 3.0 million, mostly gillnets 94% of nets), followed by pots (EUR 1.9 million) and hooks and lines (EUR 1.4 million, mostly set longlines, 96% of hooks and lines), but also that hooks and lines corresponded to the highest number of vessels (n=410). For active gears, the highest amount went for trawls (EUR 3.0 million), but more purse seiners benefited from the fund based on the number of vessels (n=322). The average committed by vessel ranged between EUR 1 260 for dredges to EUR 33 140 for seine nets.

Denmark dedicated most of the EMFF to bottom trawls (68.2% of the amount committed, 63.7% of vessels), followed by gillnets (17.3% EMFF, 21.2% of vessels). For Estonia, most vessels were not identified to the gear level (NA, 65.3% of funding, 38.2% of vessels), the rest was mostly attributed to gillnets (19.7% of funding, 35.3% of vessels). For Spain, purse seiners were the main beneficiaries (78.8% of funding, 61.5% of vessels). For Finland, it was pots (59.6% of funding, 50.0% of vessels), the rest being not identified (NA). In France, 84.8% of funding went to gillneters, 50% of vessels, the rest went to trammel netters. In Italy, set longliners received 47.4% of funding for 48.2% of vessels, followed by purse seines with 38.5% of funding for 36.6% of vessels, the rest was shared among different other gear types. In Poland, 67.8% went to gillnetters, 68.0% of vessels, followed by pots (16.0% of funding, 16.8% of vessels). In Portugal, it was bottom trawls (35.9%, 16.7%), trammel nets (30.5%, 16.7%) and gillnets (22.1%, 16.7%). In Sweden, gillneters (30.8%, 30.0%), midwater trawls (20.8%, 13.3%) and pots (17.6%, 20.0%). In the UK, pots received the main part (64.7%, 62.7%).

Figure 6: Total committed EMFF amount and number of vessels by main gear types



Data source: FAMENET
Note: Dredges are not represented because the amount and number of vessels are too small to be visible. Active gears are displayed in shades of blue, passive gears in shades of green.

In terms of vessel size categories, small-scale coastal fishing (SSCF), defined as "fishing carried out by fishing vessels of an overall length of less than 12 metres and not using towed fishing gear" by the Regulation (EU) No. 508/2014, benefited from 44.5% of the committed funding (EUR 5.5 million), distributed among 826 vessels (55.5%). Other vessels smaller than 12m received EUR 1.0 million (8.2%) for 253 vessels (17.0%). For vessels between 12-24m in length, a funding of EUR 2.1 million (16.6%) was granted to 260 vessels (17.4%). For vessels over 24m, it was EUR 2.4 million (22.5%) for a total of 100 vessels (6.7%). The average amount committed per vessel varied between EUR 2 070 for vessels smaller than 12m not belonging to SSFC and EUR 22 790 for vessels larger than 24m (NB. an average amount of EUR 22 490 was committed for the vessels "NA").

To conclude, the analysis of the EU funding distributed among Member States to increase gear selectivity through the EMFF, showed that only 10 Member States used this funding for gear selectivity. However, other funding sources exist and might have been used with this aim as well. A rather small percentage of the EMFF was allocated to trawlers, while trawl fisheries are widely recognized as less selective. On the other hand, a relatively high proportion of the EMFF has been allocated to fisheries using gillnets and pots. Pots are probably one of the most selective fishing gears, with many discarded individuals still alive when returned to the water. Such high funding of pot selectivity is therefore surprising. There is an obvious mismatch between the results of the EMFF analysis and the results of the literature review on recent scientific research carried out on gear selectivity, highlighting a lack of cohesion and different priorities between the fishing industry and the scientific community.

7. POLICY RECOMMENDATIONS

KEY FINDINGS

- Fishing selectivity can be a broad topic. The management objectives to be achieved with increased selectivity and the priorities of these objectives should be clearly defined.
- Increased collaboration among stakeholders and bottom-up approaches should be further promoted and incentivized. Publicising good behaviour and regulatory trade-offs are likely to help, along with regionalisation and increased flexibility.
- Data collection is fundamental, and fully documented fisheries should be effectively implemented together with a results-based approach.
- Fishing selectivity should be an integral part of the ecosystem approach to fisheries management, and monitoring should access the broad impacts of the implementation of selective measures and whether management objectives are reached.
- The LO could be used as a lever with a trade-off between its enforcement and the use of selective measures, under catch documentation.

Based on the results of the previous sections, some policy recommendations are suggested.

7.1. Clearly define management objectives and priorities

Fishing selectivity is a broad term that can be applied to a wide range of ecosystem components. Fishing selectivity depends on the definition of target species, while unwanted catches can be fuzzy, e.g., some have commercial value and are welcome. Fishing selectivity should not be used as a management objective, but as a lever to reach broad management objectives (Fauconnet and Rochet, 2016). Clearly defining the objectives to be reached with increased selectivity is essential. The priorities of these objectives must also be defined, since the "perfect" fishing gear and/or tactics which would only catch commercial-sized individuals of the target species does not exist and never will. Selectivity can only be directed at some components of the ecosystem that have to be clearly defined, while attention should be given to take account of potential cross-taxa conflicts, since improvements for some species can do worse to others (Gilman et al., 2019). Some trade-offs must be made. Prioritization in the distribution of EU funding towards the least selective fishing gears could accelerate the overall increase in selectivity in EU fisheries.

7.2. Promote collaboration and bottom-up approaches

A wide range of solutions to increase selectivity have been developed and scientifically tested, however the uptake by fishers mostly lags behind (Kraak, 2023). Promoting gear uptake is now essential for an actual increase of fishing selectivity in EU fisheries. Among best practices (chapter 5), a close collaboration between stakeholders is essential to achieve increased selectivity. These collaborations should be favoured, and their continuity in time necessary to build up trust should be sustained. Co-management arrangements can give fishers a sense of belonging, strengthen trust and break down the barriers between stakeholders (Kraak and Hart, 2019). Involving fishers into management decisions and into the search for solutions would also likely accelerate the adoption and wide use of selectivity measures (Eliasen et al., 2019; Feekings et al., 2019b). The Technical Measures Regulation (EU) 2019/1241 explicitly allows for bottom-up approaches, but only a few such approaches have been implemented to date (Kraak, 2023). Unfortunately, the momentum and drive towards bottom-up initiatives seem to have halted, likely due to the loss of incentive from the industry since top-ups of quotas under the LO are not conditional upon participation anymore (Kraak, 2023). Bottom-up approaches should be further favoured and incentivized.

7.3. Reinforce regionalisation

Fisheries, ecosystems, markets widely differ within the EU and require regionalisation, i.e. the tailoring of measures to regional contexts. When tailored to regional specificities, selectivity measures have more chance to be considered legitimate and to be used. Regionalisation is expected to improve regulations legitimacy, lead to more suitable measures and increase compliance (Kraak, 2023). Since 2019, the Technical Measures Regulation has embraced regionalisation, and these measures take more regional specificities into account (Kraak, 2023). Part of the management has been transferred to regional groups, but fishers still perceive it as top-down; the rules remain complex micromanagement and it is unsure whether it has increased compliance (Kraak, 2023). Efforts to promote regionalisation should be maintained and reinforced. The central role fishers can play in facilitating a more regionalised technical regulation by actively participating should be further promoted (Eliasen et al., 2019).

7.4. Increase flexibility

The uptake of newly developed selective gears was in some cases stopped due to legal reasons, highlighting the need to increase flexibility in the management frameworks (Feekings et al., 2019b). A faster legal acceptance of newly developed measures should be granted (Eliasen et al., 2019; Feekings et al., 2019b). The right balance between robust assessments and avoidance of overly prescriptive requirements should be applied when evaluating proposals for new measure to avoid discouraging innovation (Kraak, 2023). By opening for faster approval of gear use under a regionalised technical regulation regime with regular adjustments of management plans, a more flexible system of gear development and evaluation can be reached (Eliasen et al., 2019).

Under rigid fisheries management frameworks, fishers have limited possibilities and incentives to adjust the selectivity of their gears to the specific fishing conditions, while they need flexibility in the choice of gear, in order to adapt the selectivity of the gear to available quota and cope with variability in catch composition and market conditions (Eliasen et al., 2019).

More responsive and flexible regulatory mechanisms, such as the use of dynamic management measures offer a wide range of benefits, even if they are more difficult to implement and enforce. Such dynamic approaches would not only enable to adjust to the variability of species and fisheries dynamics in order to avoid unwanted catches, but they will also be increasingly necessary and valuable as species-fisheries interactions change in response to climate change (Pons et al., 2022).

7.5. Incentivize uptake of selective measures

Despite many trials to test selective gears, the uptake of such gears remains extremely low even in fisheries with high unwanted catches (Kraak, 2023). The incentive of LO to avoid unwanted catches did not materialize because the LO was not effectively enforced; instead the catches increased with quotas topped up with (previous) discard amounts, while the discard practices have barely changed (Borges, 2020; Kraak, 2023). The evaluation requested under the Technical Measures Regulation, to check whether the objectives were achieved only assesses the results in terms of reduced unwanted catches, but not whether the means, e.g., creating the right incentives, have been implemented, and the challenge still remains to create incentives to lead to the desired behaviour (Kraak, 2023). As seen in chapter 5, financial support can help but other incentives can also be powerful.

The influence of the group behaviour is very important and enhanced compliance can be reached by fostering pride about sustainable fishing practices and publishing stories in the press about fishers that complied (Kraak and Hart, 2019). Traceability and transparency could also to be used in more innovative ways to promote good fisher behaviour, e.g., using a QR code to link the fish to the fisher who caught it and promote the way it was fished (Kraak and Hart, 2019). Enforcement costs could be reduced to increase instead investments in activities improving voluntary compliance (Kraak and Hart, 2019).

Regulatory trade-offs can also be strong incentives. Allowing fishing in otherwise closed areas if using given selective devices or gear types (Graham et al., 2007), giving derogation to use gears that may not comply with the legislation, or finding solutions to replace the regulatory but not viable gear (Feekings et al., 2019b) can prompt strong incentives for fishers to use more selective gears. Temporary and/or spatial restrictions should be set in combination with other selective measures, but the shift of fishing effort to other areas have to be considered carefully before implementation to avoid unintended impacts (Sigurðardóttir et al., 2015). Highlighting the benefits of increased selectivity for fishers by creating a transparent association between improving selectivity and improved fishing opportunities would also create obvious incentives (Kraak, 2023).

7.6. Results-based management and Fully Documented Fisheries

A results-based management focusing on outcomes rather than inputs (when, where and how to fish) as proposed by STECF was included in the Technical Measures Regulation that now explicitly allows for "pilot projects that develop a system of full documentation of catches and discards based on measurable objectives and targets, for the purpose of a results-based management of fisheries" (Kraak, 2023). However, even if some steps towards catch based metrics were made, after 2019, it was considered that results-based management has still failed to be implemented (Kraak, 2023). The required comprehensive monitoring, control and enforcement, and quantification of the catch, e.g. fully documented fisheries (FDF), have not been established (Kraak, 2023).

Data collection should be consistent with management objectives so that the effectiveness of the management plan can be measured and revised or modified where needed (Pérez Roda et al., 2019). Knowledge on fisheries bycatch is key. Observer data have coverage limited to a small proportion of total fishing effort (Uhlmann et al., 2014), as well as deployment and observer biases (Benoît and Allard, 2009) that can affect data accuracy. Yet to date observer data are the main way to have information on bycatch and discard in most fisheries, even if Remote Electronic Monitoring (REM) is increasingly used, and closed-circuit television (CCTV), i.e. video surveillance will soon be implemented to monitor the LO for vessels considered "high risk", as recently approved by the new EU Fisheries Control Regulation (European Parliament, 2023). It would be important to increase this data coverage, quantity and accuracy. FDF with discards routinely reported by fishers in logbooks should be effectively implemented and enforced so that an exhaustive reporting and monitoring of all catches would be available. Fishers should be asked to accurately report, e.g., signing a statement of accurate reporting before they start filling out logbooks (Kraak et al., 2016).

Knowledge on fisheries practices and dynamics is essential to increase fishing selectivity. As seen among best practices, data sharing between MS is a valuable approach to provide broader more complete knowledge. However, such data sharing is often complicated, sometimes not possible. The access to and sharing of fisheries dependent data should be facilitated. Precise knowledge of fine-scale fishing effort is needed to avoid unwanted catches. Access to VMS data, that would be worth to extend to all vessels, on a scale adapted to preserve anonymity, should be facilitated.

7.7. Integrated bycatch management and monitoring

Fishing selectivity should be an integral part of the ecosystem approach to fisheries management. When implementing selectivity measures, special attention should be given to potential cross-taxa conflicts, since improvements for some species can do worse to others (Gilman et al., 2019) and shifts of fishing effort to other areas can lead to unintended impacts (Sigurðardóttir et al., 2015). The relative species vulnerabilities and capacities to withstand given levels of fishing mortality should be considered when defining management priorities. Integrated management should include all catch related process, taking into consideration all gear impacts, including on habitats, benthic communities, even on CO2 emissions. Some negative effects of increasing selectivity might exist for some species or fisheries (Lloret et al., 2018). Monitoring should be systematically implemented to assess the impacts of the introduction of new measures.

7.8. Use the LO as a lever

Even if the LO was mostly unpopular when it started to be implemented, it seems quite clear that it has acted as an accelerator to find solutions to increase fishing selectivity in European fisheries. Despite big progress towards increased selectivity, no perfect solutions have been found, high variability exists and the problem of choke species is too complex in some cases (Kraak, 2023). Challenges were announced with the LO, (e.g., (Catchpole et al., 2017; Sardà et al., 2015; Uhlmann et al., 2019) and they are confirmed. The objective of perfect selectivity is impossible to reach, especially in multi-species and multi-gear fisheries as in the EU. The LO has accelerated research to improve selectivity but overall, the uptake of selective measures has been low, and the real impacts of EMFF are difficult to tell yet. Since the LO is mostly not enforced yet, incentives for fishers to use or find alternatives are reduced. Worse even, discarding continues unchanged while the fishing effort has actually increased due to quota uplifts (Borges, 2020). Enforcing the LO might not give better results, and it could cause highly negative impacts on fisheries. Promoting voluntary compliance has more chances to result in uptake. As an alternative, the LO could be used as a lever with a trade-off between its enforcement and the use of selective measures, under catch documentation. In other terms, exemption from the LO could be granted to fishers using selective measures while compromising to implement FDF and to regularly accept onboard observers to control and monitor the effectiveness of these measures in real fishing conditions.

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ANNEX 1 – SPECIES SCIENTIFIC NAMES

Common name	Scientific name
Anchovy	*Engraulis encrasicolus*
Annular seabream	*Diplodus annularis*
Atlantic cod (or cod)	*Gadus morhua*
Atlantic herring (or herring)	*Clupea harengus*
Bogue	*Boops boops*
Blackmouth catshark	*Galeus melastomus*
Black seabream	*Spondyliosoma cantharus*
Bluefin tuna	*Thunnus thynnus*
Blue shark	*Prionace glauca*
Blue whiting	*Micromesistius poutassou*
Brill	*Scophthalmus rhombus*
Brown shrimp	*Crangon crangon*
Caramote prawn	*Penaeus kerathurus*
Chub mackerel	*Scomber japonicus*
Common dab (or dab)	*Limanda limanda*
Common sole (or sole)	*Solea solea*
Cuttlefish	*Sepia officinalis*
Deep-water rose shrimp	*Parapenaeus longirostris*
Edible crab	*Cancer pagurus*
European hake (or hake)	*Merluccius merluccius*
European pilchard (or sardine)	*Sardina pilchardus*

Flounder	*Platichthys flesus*
Giant scallop	*Placopecten magellanicus*
Greater forkbeard	*Phycis blennoides*
Greater sandeel	*Hyperoplus lanceolatus*
Great scallop	*Pecten maximus*
Grey gurnard	*Eutrigla gurnardus*
Haddock	*Melanogrammus aeglefinus*
Harbour porpoise	*Phocoena phocoena*
Ling	*Molva molva*
Loggerhead sea turtles	*Caretta caretta*
Long rough dab	*Hippoglossoides platessoides*
Megrim	*Lepidorhombus whiffiagonis*
Monkfish	*Lophius piscatorius*
Northern squid	*Loligo forbesii*
Norway lobster (or Nephrops)	*Nephrops norvegicus*
Norway pout	*Trisopterus esmarkii*
Pelagic stingray	*Pteroplatytrygon violacea*
Plaice	*Pleuronectes platessa*
Red gurnard	*Chelidonichthys cuculus*
Red mullet	*Mullus barbatus*
Saithe	*Pollachius virens*
Silky shark	*Carcharhinus falciformis*
Spiny lobster	*Palinurus elephas*

Surmullet	*Mullus surmuletus*
Swordfish	*Xiphias gladius*
Thornback ray	*Raja clavata*
Tunas	*Thunnus spp.*
Turbot	*Psetta maxima*
Tusk	*Brosme brosme*
Whiting	*Merlangius merlangus*
Wolffish	*Anarhichas lupus*

ANNEX 2 – DETAILS OF LIGHT EXPERIMENTS FOR TRAWL SELECTIVITY

Light emitting diodes (LEDs) are simple and inexpensive option that can increase catch efficiency. Their utility as stimuli for exploiting species behaviour was tested in several studies with variable selectivity improvements, with some nocturnal and seasonal effects depending on the species (Birch et al., 2023; Oliver et al., 2023; O'Neill et al., 2022; O'Neill and Summerbell, 2019).

The effect of **continuous lines of light** on the height at which fish enter demersal trawls was investigated using a cable illuminated by a LED on the leading edge of the separator panel and on the fishing line (O'Neill and Summerbell, 2019). During autumn, daytime trials, the illuminated cable only influenced common dab, while during spring and trials held at night, it significantly reduced the proportion of haddock, whiting, plaice, common dab and red and grey gurnards swimming above the panel (O'Neill and Summerbell, 2019). The species composition also depended on the panel height, demonstrating how illuminated cables can be used to modify the height at which fish enter the gear and direct them to different parts of the gear to improve the trawl selectivity (O'Neill and Summerbell 2019).

Four **lighting configurations** were tested **on an inclined grid** place in the extension, with either none of the grid was illuminated, only the bottom-half, only the top-half, or the whole grid (O'Neill et al., 2022). Most species were less likely to enter the upper codend when the grid was illuminated (no matter the configuration) and a diel variation was observed for all species: a lower proportion of haddock and whiting and a greater proportion of flatfish at night than during the day (O'Neill et al., 2022). For some species, the results were more subtle: for cod, illuminating the grid had no effect during the day; for common dab, an effect was observed only when the bottom-half was illuminated, none with the top-half; for long rough dab, illuminating the whole grid had the greatest effect, followed by only the top-half, while only illuminating the bottom-half had the lowest effect (O'Neill et al., 2022).

Similarly, Cuende et al (2020) tested the effect of adding **LED lights at two different positions of a SMP** to increase the contact between the fish and the SMP in order to increase the release efficiency of the panel, but did not find significant effect neither for hake nor for blue whiting.

Experiments of adding artificial LED lights to the trawl raised fishing line (Oliver et al., 2022) or to the trawl headline (Oliver et al., 2023) were conducted in the Celtic Sea mixed-demersal fishery.

- **When lights were added to the raised fishing line**, a significant 65% reduction in cod catches, compared with the raised fishing line alone (already contributing to 30-40% reduction in cod catches compared with a traditional bottom trawl), a positive finding since cod is a low quota species in the Celtic Sea (Oliver et al., 2022). The ability of fish to react to the lights was size dependent, larger fish being likely more capable of dipping under the line in response to the lights than smaller fish, resulting in substantial reductions in large whiting, hake, cod and haddock, and leading to a loss of marketable catches that turn this modification currently commercially unviable (Oliver et al., 2022).
- **When green lights were added to the headline**, haddock was the dominant species (90% of all commercial species landed) with 60% of haddock catches occurring at nighttime. The lights contributed to a 51% increase in haddock catch weight (with larger individuals), 64% in value, during nighttime, while a reduction of 9% was found during daytime (Oliver et al., 2023).

The effect of introducing artificial light on a commercial trawler operating in the English southwest mixed demersal fishery was studied by comparing total catch and species vertical separation between two identical separator trawl simultaneously towed, one of which was equipped with **blue LEDs along the headline** (Birch et al., 2023). When using lights, catches-at-length of haddock were lower during the night and marginally higher during the day, while catches of grey gurnard, megrim and whiting were not affected. The lights also affected the vertical separation of various species: in the lower codend more haddock were retained during both day and night using the lights; also more grey gurnard, whiting and Northern squid, but only during the day (Birch et al., 2023). As such, it seems that lights were able to change the behaviour of some species which normally rise inside the trawl during the capture process, such as haddock (Birch et al., 2023).

ANNEX 3 – DETAILS OF NEW TECHNOLOGIES INVOLVING CAMERAS AND AI FOR TRAWL SELECTIVITY

More complex and expensive modifications involving mechanisms to release fish at certain depths or when catches reach a certain level using cameras, acoustic releases or weak-links in the codend/extension have also recently been developed and tested in trawl fisheries (Kennelly and Broadhurst, 2021).

The **CatchCam** is a small and highly resistant wireless underwater camera that can be deployed anywhere on the fishing gear enabling fishers to film their gear while fishing. The footages are accessed on recovery of the fishing gear by streaming for the camera to a phone or tablet where they can be visualized to check if the gear is working properly, and adjust fishing to increase catch and reduce bycatch (CatchCam, 2024; ICES, 2023).

TrawlMonitor is a cable-based system, optimized for simple and robust commercial use, that delivers a high-quality and clear live-feed from the trawl to the wheelhouse in real-time during demersal trawling, delivering quantitative information on the ongoing catching process (ICES, 2023; Krag et al., 2022). Clear video feed from the trawl quantitatively indicating the catch composition that entered the trawl in real-time were successfully delivered during the SmartFish EU project. Developed, tested and demonstrated, TrawlMonitor is now ready for commercial uptake according to Krag et al. (2022).

The **Autotrawl** system is a set of sensors attached to the gear feeding back real-time information to a computer onboard, which helps to monitor the trawl as it is towed underwater (ICES, 2023). The Autotrawl system was originally designed to improve trawl efficiency, helping to ensure that the entrance of the net remains open during all phases of the trawl, but it can also allow animals, such as dolphins, that swim into the net a chance of escape, and as such was suggested as a potential tool that can also be used to mitigate marine mammal bycatch (ICES, 2023).

Recent technological advances in the fields of artificial intelligence (AI) and sensor networks have also led to the development of several designs combining sensors, real-time videos and AI designed to turn trawl fisheries more "intelligent".

As part of the **Game of Trawls** (Giving artificial monitoring intelligence to fishing Trawls) project, a trawl equipped with an underwater camera, an acoustic communication device, sensors and an embedded computer performing powerful analysis software using AI was developed (Game of Trawls, 2023). The intelligent trawl constitutes "a decision-making tool for fishers", informing them in real time of the species captured, their size and their abundance. Depending on the presence of targeted or non-targeted species, the trawl can be used in fishing mode or in flight mode in order to avoid having an impact on the seabed (Game of Trawls, 2023).

Similarly, the **Smartrawl** is a technological development designed to avoid discards and bycatch in demersal fishing trawls, ensuring that only fish and shellfish that are intended to be landed are actually caught at sea (Fernandes et al., 2021). The Smartrawl system consists of a stereo camera with lighting in the trawl extension to obtain high quality images of fish traversing into the codend through the trawl net. These images are analysed by an onboard computer with AI to determine species and size. A signal is then sent to a 'gate' located in the trawl extension: the gate is opened if an unwanted fish is identified, so that the fish is released back in-situ underwater; while the gate is closed if the fish is wanted, so that the fish passes into the cod end to be captured (Fernandes et al., 2021). First designed to be self-contained without information being passed to the skipper, the system has been modified to allow fishers to act upon their trawls to catch exactly what they want, according to market conditions and available quota, while avoiding bycatch (Fernandes et al., 2021).

The latest AI models to detect fish and categorize species are now reaching human-like accuracy, however the data to accurately interpret fish interactions with fishing gears, essential for selectivity studies to advance and integrate AI methods in assessing the effectiveness of modified gears, is still lacking, especially for temperate fishes (Abangan et al., 2023).

ANNEX 4 – NEW FACTSHEET TEMPLATE OF INNOVATIVE GEAR FROM ICES WKING 2023

Technical information			
Title of the Innovative gear / Innovation			
Year		**Source supplier name**	
Region *(click next box for drop-down list)*	Select a Region	**FAO Area** *(Division, L2)*	*See Annex 6*
Gear sub-category *(click next box for drop-down list)*	Select gear sub-category	**Gear code**	*See Annex 7*
Baseline gear	*Define / describe the baseline gear* *(Baseline standards are derived from either existing Regulations or commonly used unregulated)*		
Target species *(click hyperlink)*	Use FAO 3-alpha code	**Bycatch species** *(click hyperlink)*	Use FAO 3-alpha code
Definition of the Innovative gear	*Define/describe the innovative gear / Innovation*		
Technical specificities	*Describe and compare the technical specificities/differences between the baseline gear and the Innovative gear*		
Outcomes expected	*Outline/describe the main outcomes expected and/or tested from the innovative gear*		
Drawing / picture of the Innovative gear	*Expand the row if necessary*		
Other relevant information	*URL / References*		
Performance and technical assessment			
Main criteria *(list the main criteria affected)*	*For example, selectivity, catch, environmental impact*	**Additional criteria** *(additional criteria or benefits from using this gear)*	*For example, reduced GHG emissions, energy savings*
Technological complexity level *(section §3.2)*	Options: Minimal, Medium, or Significant complexity.	**Technology readiness level (TRL)** *(See section §3.2)*	Options for TRL category: High, Medium, or Low. Option for TRL scale: TRL1-TRL9.
Environmental improvement *(section §3.1.5)*	Score the three main Criteria. Options: not applicable, negative, incremental, transformative, disruptive. 1) Selectivity; 2) Catch efficiency; 3) Impact.		
Capital cost category *(section §3.4)*	Options: Low, Moderate, or High.	**Return on Investment** *(section §3.4)*	Options: negative, minor, substantial, or significant.
Is the innovative gear easier to deploy and retrieve compared to the baseline?			Options: no difference, yes easier, no more difficult, unsure, or maybe.
Is the innovative gear easier to maintain and repair compared to the baseline?			Options: no difference, yes easier, no more difficult, unsure, or maybe.
Does using the innovative gear present a lower risk to the health and safety of crew compared to the baseline?			Options: no difference, yes easier, no greater, unsure, or maybe.
Are the financial costs associated with using the innovative gear disproportionately higher than the potential benefits (e.g., economical, operational, environmental) of using it?			Options: yes higher, no lower, unsure, or maybe.

P.E.S.T.E.L. Framework *(section §3.5)*	
Overall, what impacts do you think have **political factors** had on uptake of this gear?	Options: has encouraged up-take, it is a barrier, do not know, not applicable.
Optional: Please provide more details on your above choice	
Overall, what impacts do you think have **economic factors** had on uptake of this gear?	Options: has encouraged up-take, it is a barrier, do not know, not applicable.
Optional: Please provide more details on your above choice	
Overall, what impacts do you think have **social factors** had on uptake of this gear?	Options: has encouraged up-take, it is a barrier, do not know, not applicable.
Optional: Please provide more details on your above choice	
Overall, what impacts do you think have **technological factors** had on uptake of this gear?	Options: has encouraged up-take, it is a barrier, do not know, not applicable.
Optional: Please provide more details on your above choice	
Overall, what impacts do you think have **environmental factors** had on uptake of this gear?	Options: has encouraged up-take, it is a barrier, do not know, not applicable.
Optional: Please provide more details on your above choice	
Overall, what impacts do you think have **legal factors** had on uptake of this gear?	Options: has encouraged up-take, it is a barrier, do not know, not applicable.
Optional: Please provide more details on your above choice	

Source: ICES (2023)

This study provides an overview of the current state of play in selectivity developments in EU fisheries by i) outlining the existing technical (gear) and tactical selectivity measures to reduce unwanted catches; ii) identifying best practices from projects that have successfully improved selectivity; and iii) analysing how EU funding have been used by Member States for promoting increased selectivity. Based on these results, policy recommendations for EU policymakers on potential actions to improve the selectivity of EU fisheries are provided.

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