Bycatch in Commercial Trawl Fisheries: Problems, Solutions, and the Role of Emerging Technologies

Mikael Ovegård

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Mikael Ovegård, https://orcid.org/0000-0002-4790-6526, Swedish University of Agricultural Sciences (SLU), Department of Aquatic Resources

Abstract

Trawl fisheries are generally non-selective and often result in unwanted bycatches of juvenile fish, non-quota species, and protected marine life. The ecological consequences of this bycatch include direct mortality, habitat damage, and disruptions to marine food webs. Strategies for reduction of unwanted bycatch fall into two main categories: policy instruments and gear modifications. This essay focuses on the latter, particularly gear modifications that enhance size and species selectivity. Scientific evaluation of the effect of gear modifications on the catch composition in trawls has traditionally been conducted through either paired gear experiments, where the catch of the test gear is compared to the catch of a baseline/control gear, or by recapture of the escapees (e.g. by using codend covers or collection bags). One of the main drawbacks of these methods, apart from that they generally are expensive and difficult to conduct, is that it normally leads to the death of the unwanted catch. New approaches utilizing artificial intelligence and computer vision could potentially reshape the methodologies used in this field. Underwater camera systems can now monitor fish behaviour in situ, while machine learning models automatically detect, classify, and measure fish without physical handling. These technologies reduce experimentally induced mortality, improve data quality, and allow for scalable, non-invasive evaluation of gear modifications. Ultimately, the integration of artificial intelligence into fisheries science supports the broader aims of ecosystem-based fisheries management by providing insights into species-specific selectivity and escapee vitality. This has the potential to improve science-based decision making and promotes sustainable exploitation of marine resources in alignment with the United Nations Sustainable Development Goals.

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Abbreviations

L50	Length at 50% retention
AI	Artificial Intelligence
AIC	Akaike Information Criterion
CNN	Convolutional Neural Networks
CPUE	Catch Per Unit Effort
CV	Computer Vision
EU	European Union
EBFM	Ecosystem-Based Fisheries Management
ERA	Ecological Risk Assessment
FAO	Food and Agriculture Organisation
FLEX	Flexible and pliable sorting grid
ICES	International Council of Exploration of the Sea
LO	Landing Obligation
MCRS	Minimum Conservation Reference Sizes
PERMANOVA	Permutational multivariate analysis of variance
REM	Remote Electronic Monitoring
SR	Selection Range
T45	Turning diamond mesh net 45 degrees
T90	Turning diamond mesh net 90 degrees
TED	Turtle Excluder Device
US	United States

1. Introduction

The term "bycatch" is generally referred to as the unintended capture of non-target species and/or sizes during fishing operations (Roda et al. 2019). Depending on the management context bycatch may include all non-target catch (landed or discarded at sea), or as in US law under the Magnuson–Stevens Act, be limited to fish not kept or sold, including unobserved gear-related mortality (§ 600.350 National Standard 9). In the EU, bycatch is often framed as "unwanted catches" under the landing obligation (LO) of the Common Fisheries Policy (Article 15, Regulation (EU) No 1380/2013). Bycatch can be fish, but can also include other organisms, such as marine mammals, turtles, seabirds and invertebrates. Globally, bycatches represent a large fraction of marine catches, and is one of the most persistent sustainability challenges in fisheries (FAO 2020).

While bycatch occurs across many gear types, trawl fisheries are particularly associated with high bycatch rates due to their generally non-selective nature and large spatial footprint (Kelleher 2005; Gilman et al. 2020). In mixed demersal trawl fisheries, bycatch may exceed target catch in some hauls, especially when relatively small mesh sizes are used and minimum conservation reference sizes (MCRS) or quotas restrict landings of small or non-quota species (Eayrs 2005; Davies et al. 2009). Roda et al. (2019) estimated that the annual discards (i.e. catch retained and then thrown back into the sea) from global marine capture fisheries between 2010 and 2014 was 9.1 million tonnes, of which about 46 percent (4.2 million tonnes) were from bottom trawls. However, about one-third of global marine capture also comes from trawling, providing food and employment for millions of people (Hilborn et al. 2023). While alternative fishing gears and methods may be available and economically viable in some cases, many target species would be difficult to catch without some form of trawling (Suuronen et al. 2012).

Beyond direct mortality, through capture and discarding, bycatch in trawl fisheries also causes indirect effects via habitat alteration and trophic cascades. Studies have shown that a single trawl pass can remove 5–25% of benthic organisms, with lasting consequences for benthic biodiversity and productivity (Hiddink et al. 2006). Removal of apex predators, such as sharks and rays, destabilises food webs and can shift community composition (Stevens et al. 2000). This combination of direct and

indirect effects makes trawl bycatch a central concern for fisheries management, and the reduction of it a targeted Sustainable Development Goal under the Agenda 2030 resolution adopted by the United Nations (UN DESA 2023).

In the context of fisheries bycatch, "escapees" are fish and other organisms that encounter the fishing gear but manage to avoid retention prior to hauling. This concept is distinct from discards, which refer to catch that is brought aboard and then returned to the sea, often dead or dying (Kelleher 2005). Escapees therefore represent a category of catch that is not landed, not observed in official statistics, but still exposed to stress and injury that may influence post-escape survival and long-term fitness (Suuronen 2005). Understanding the fate of escapees is important because it determines whether gear modifications aimed at improving selectivity truly reduces fishing mortality. If survival of escapees is high, selective devices can effectively conserve stocks and reduce bycatch mortality. Conversely, if survival is low, escapees contribute to "hidden mortality", an unrecorded source of fishing induced mortality, undermining the intended benefits of selective gear (Breen et al. 2007). For this reason, defining, studying, and quantifying escapees is a critical component of modern fisheries science and management.

There are two major strategies that can be applied for reducing bycatches in trawl fisheries: policy initiatives and technical conservation measures such as gear modifications. Policy initiatives include a wide range of different measures such as eco-labels (Giacomarra et al. 2021), regulations like the LO of the EU Common Fisheries Policy, marine protected areas (Gray & Kennelly 2018), seasonal restrictions (FAO 2021), and real time closures (Woods et al. 2018). However, this research essay will primarily discuss how gear modifications can be used for reducing bycatches. Additionally, it reviews current methods used to estimate the effect of gear modifications and highlight how artificial intelligence can be applied to advance our understanding of gear selectivity processes and the vitality of escapees.

2. Trawl gear design and selectivity

According to the definition of fishing operations made by the FAO (He et al. 2021) a 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. Trawls are designed to be towed across the seabed (bottom trawls) or in midwater (pelagic trawls). A semipelagic trawl is a hybrid that can be set to fish on or off the seabed. A single boat can tow one trawl (most common), two trawls (twin trawl), or more than two trawls (multi-rig trawls). A single trawl can be towed by one boat (most common) or two boats (pair trawling). Trawls are very versatile and can be used to catch many different species. The horizontal opening of trawls is most commonly maintained using hydrodynamically shaped boards or plates called trawl doors or otter boards (otter trawl). There are however also other methods used to maintain the horizontal opening of trawls, such as using a beam (beam trawl) or towing the net between two boats (pair trawl). The vertical opening of trawls is maintained using floats on the headrope, and weights on the footrope, but the pulling force through the water also act to "inflate" the trawl. On bottom trawls the footrope may be equipped with different types of "groundgears" that often consist of components such as heavy-duty ropes, chains, discs, bobbins and/or weights to ensure that seabed contact is maintained during fishing while minimizing the risk of damage to the net. Pelagic trawls generally do not have groundgear on the footrope, and the vertical opening is instead often maintained with weights attached to the lower wing ends (figure 1).

The "selection" of fish by a fishing gear can be considered to be the process which causes the catch to have a different composition to that of the fish community in the geographical area in which the gear is being used (Wileman et al. 1996). The selectivity of a fishing gear is a measurement of the selection process.

For the purpose of defining functionality of different parts of the gear and what may affect the selectivity trawls can be divided into four "zones", following the catching process (Kennelly & Broadhurst 2021):

Zone 1 – Spreading mechanisms: otter boards, sweeps, and bridles.

Zone 2 – Mouth of the trawl: headline, footrope, and groundgear.

Zone 3 – Wings and body: long tapered netting that funnels fish aft.

Zone 4 – Extension and codend: the terminal section.

Figure 1. Components and terms of a typical single boat bottom trawl with otter boards. For the purpose of defining functionality trawls could be divided into four "zones": Zone 1 – Spreading mechanisms: otter boards, sweeps, and bridles that maintain the horizontal opening and herd fish toward the mouth of the trawl. Zone 2 – Mouth of the trawl: headline, footrope, and groundgear that set vertical opening. Zone 3 – Wings and body: long tapered netting that funnels fish aft. Zone 4 – Extension and codend: the terminal section where retention is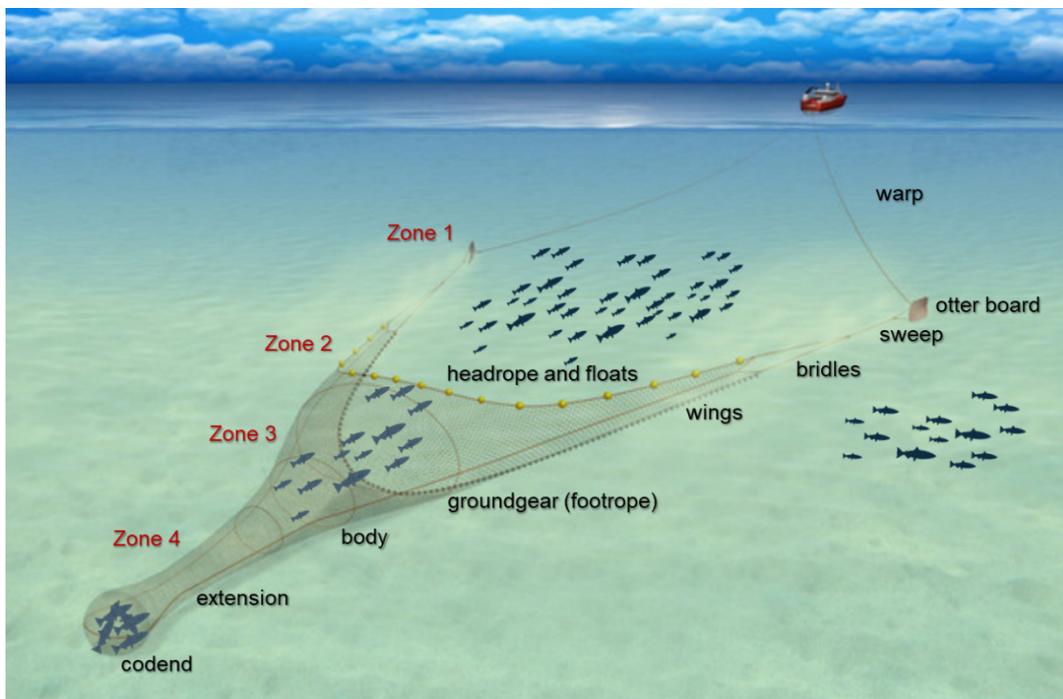 decided. The figure above is modified from "Classification and illustrated definition of fishing gears" by He et al. (2021).

3. Solutions for reducing bycatches in trawls

Based on a global synthesis of 203 peer-reviewed experiments, Kennelly & Broadhurst (2021) conclude that the most consistently effective pathway to reduce bycatch in trawls is to begin with simple posterior (extension/codend) modifications, and then behaviour-based anterior changes as needed. Below is a consolidated list of the principal solutions identified and discussed by Kennelly & Broadhurst, organized by trawl zone and mechanism (where relevant, the same solution may appear across zones due to placement flexibility.)

Zone 4 – Extension & Codend
1. **Increase mesh size** in the codend to match the smallest targeted size. Often the most direct way to improve size selectivity.
2. **Change mesh geometry/orientation** (diamond mesh, square mesh, T45/T90) to enlarge lateral openings and maintain mesh openings under load.
3. **Reduce codend circumference** to stabilize and open meshes throughout the whole selective surface.
4. **Use finer/softer twine** (reduced diameter/tenacity) to make meshes open more readily and reduce abrasion/entanglement of escapees.
5. **Add escape windows** (panels with larger meshes) in the posterior part of the trawl.
6. **Install size-selective grids** in the extension or ahead of the codend and add **guiding/deflector panels** to increase contact and minimize clogging.
7. **Use species-selective grids or excluders** to remove megafauna (e.g. elasmobranchs, turtles, marine mammals).
8. **Combine grids + escape windows** to sharpen size selection and reduce the selective range.
9. **Use catch-control devices** (depth- or catch triggered releases) to prevent over accumulation, burst risk, and unintended quota overshoot.

Zone 3 – Wings & Body
10. **Horizontal separator panels** to direct species swimming higher up in the water column to one path (escape or top codend) and lower oriented species to another (bottom codend/retention), enabling species separation.

11. **Topless trawls** (partial/complete removal or slackening of the upper panel) to allow higher swimming species to escape at the trawl mouth/body.
12. **Large-mesh body or escape windows** to promote early size-based escape before fish tire and/or crowding occurs in codend.
13. **Visual cues (e.g., LEDs/headrope lighting)** to exploit species specific phototactic responses and enhance separation/escape.

Zone 2 – Headline, Footrope and Groundgear
14. **Longer headrope/adjusted headline height** to tune vertical opening relative to target/bycatch vertical distribution in water column.
15. **Footrope/groundgear tuning** (disc/rockhopper/chain etc.) to minimize debris entry and unnecessary benthic interactions that degrade selection downstream.

Zone 1 – Spreading mechanisms
16. **Sweep/bridle length/configuration changes** to alter the herding footprint and reduce encounters with non-target assemblages. This could also be paired with semi-pelagic trawl doors to reduce bottom contact and drag.

Selectivity solution 1 to 5 in the list above (mesh size, mesh geometry/orientation, codend circumference, twine diameter/tenacity and escape windows) are all mechanistically grounded in codend selectivity theory (L50/SR, see chapter 4) and flow management, which emphasize giving fish time and space to locate exits and escape through the meshes before crowding occurs. If alteration of the net of the codend is not enough, do not work due to species morphology or behaviour, or if separation/selectivity is required earlier in the catch process, the next step is to add size-selective or species-selective grids in the codend or extension piece. A grid (a.k.a. sorting grid, Nordmøre grid, TED, FLEX, etc.) is a rigid or semi-rigid set of parallel bars fitted inside a trawl with an escape opening cut into the net nearby. It creates a physical barrier that some organisms (normally smaller specimens) pass through (to the codend) while others (normally larger specimen) are guided out from the gear. Grids can also be fitted with different bar spacing in different sections, which allows for separation of both larger and smaller specimens (figure 2). When morphology and vertical swimming behaviour suggest stratification, effective options for selectivity in the body of the trawl include horizontal separator panels (figure 3) and "topless" trawls. Targeted visual cues (e.g. LEDs) on headrope or in large mesh panels in the trawl body can further enhance separation for responsive taxa. Compared to the posterior part there are relatively few alterations that can be made to change the selectivity of the anterior part to the trawl. Adjustment of the trawl vertical opening, groundgear and sweep/bridle/door

configurations can, however, both have large effect on the species composition of catches and align with low-impact, fuel-efficient objectives.

Across all the described selectivity solutions the effectiveness of the modifications are fishery- and species-specific. Grid performance depends on size contrasts and behaviour, mesh geometry effects differ for flatfish vs roundfish, and operational factors (tow duration, catch volume) can substantially change the selectivity of the gear through crowding effects (Kennelly & Broadhurst 2021).
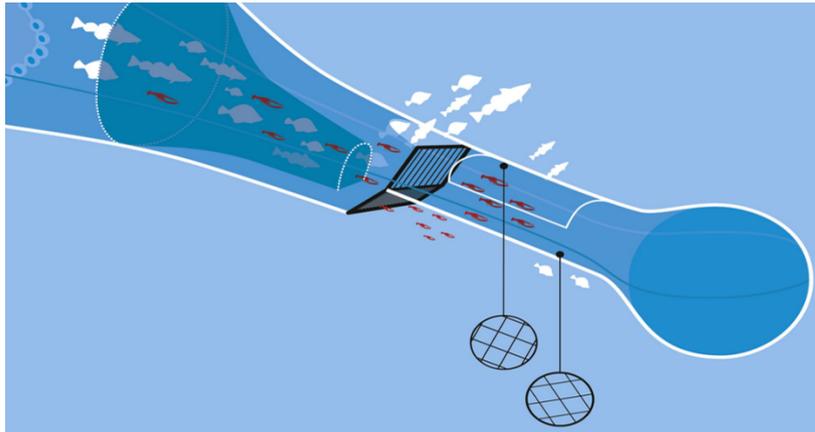
Figure 2. Illustration of a codend with a "Swedish grid" and square mesh escape window in the top panel after the grid. This combination grid has smaller bar spacing in the lower half to release small species and undersized specimen of target species, and larger bar spacing in the upper part (target species passing through) that removes fish larger than the target species. The square mesh escape window allows unwanted catch that can pass through the grid to escape, particularly species with different vertical distribution/behaviour from the target species.
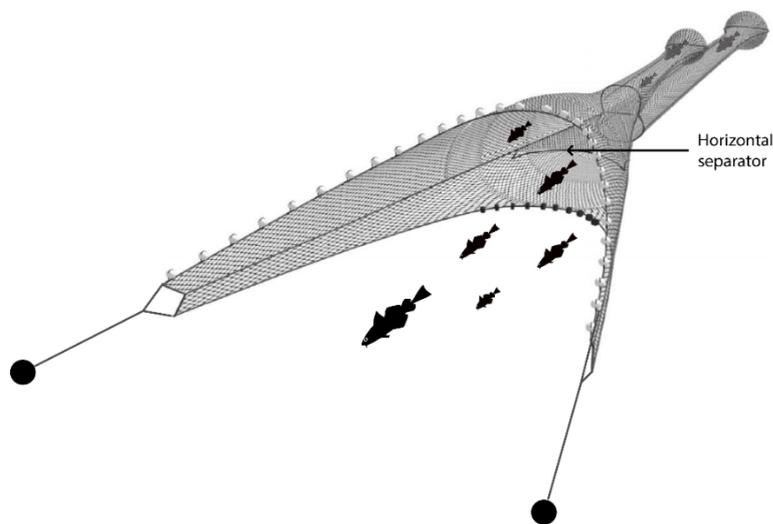
Figure 3. Illustration of trawl with horizontal separator panel that enables separation of species with different vertical distribution and behavioural responses. On encounter with the gear, some species exhibit an upward reaction and are guided to the upper path/codend, whereas others typically dive or remain close to the seabed and are directed to the lower path/codend. By using different mesh size in the two codends the vertical separation of the catch can also be complemented by difference in size selection. Illustration modified from Ferro et al. 2007.

4. Traditional method for evaluation of trawl gear selectivity

According to ICES "Manual of methods of measuring the selectivity of towed fishing gears" (Wileman et al. 1996) scientific evaluation of trawl gear selectivity generally proceeds in three linked stages: (1) choosing an experimental design that estimates retention as a function of fish length, (2) planning and executing sea trials and (3) analysing the catches with statistically sound models to produce selection parameters with uncertainty and an interpretation that is relevant to managers.

4.1 Experimental design

Evaluation of the effect of gear modifications on the catch composition in trawls has traditionally been conducted through either paired gear experiments, where the catch of the test gear is compared to the catch of a baseline/control gear, or by recapture of the escapees by using codend covers or collection bags. Choice of experimental design often depends on whether a true population (catch + escapees) sample can be obtained without disturbing gear performance. The covered codend and collection bag approach encloses the test gear in a small mesh cover to retain the escapees, allowing for direct estimation of the length distribution entering the gear and retained in each haul. This method is broadly applicable but easily biased by cover interference and may therefore not represent true commercial fishing conditions (Wileman et al. 1996b; Krag et al. 2009). Where covers or collection bags are impractical or could bias the result, the catch of the test gear is generally compared to a baseline or control gear through some sort of paired-gear setup. The paring can be through alternate hauls (same vessel, sequential test vs control), parallel hauls (two vessels towing test vs control simultaneously), twin trawls (one vessel towing two side-by-side trawls, one test and one control), and trouser trawls (a divided single trawl feeding two codends, one test and one control). Each method has trade-offs in cost, precision, and susceptibility to unequal fishing power or spatial–temporal population change (Wileman et al. 1996).

When the control in a paired-gear setup is a fine-mesh codend intended to retain all sizes of the species entering the gear (and catches are analysed with the SELECT

framework; see 4.3), or when a cover or collection bag are used, the resulting selectivity estimate is commonly termed "absolute selectivity". It provides the length-dependent retention of the gear relative to the population entering it, making the estimated selectivity parameters independent of the underlaying population composition. By contrast, "relative selectivity" arises from comparative fishing where two gears are fished without an explicit estimate of the entering population (e.g., test vs conventional gear). Such designs quantify differences between gears but cannot, on their own, estimate each gear's absolute retention probabilities.

Adaptations of experimental design may be needed for special selective devices (escape windows, grids) depending on whether the objective is to estimate combined trawl selectivity (device + codend) or the performance/selectivity characteristics of each device. Important considerations when planning gear trials is commercial realism (grounds, season, trawling speed, catch rates), adequate numbers of fish in the selection range, and explicit strategies to diagnose or mitigate unequal fishing power between test and control (e.g., swapping sides/vessels, using suitable mesh sizes for controls, or modelling bias). If the experimental fishing requires multiple hauls during periods of several days or weeks the gear should be interchanged and tested in randomized order across cruise halves to avoid confounding by changing conditions (Wileman et al. 1996).

4.2 Sea trials

Data required for evaluation of gear selectivity generally consist of weights of all species in the catch and collection of individual length measurements (typically 1 cm intervals for larger species of fish, 0.5 cm for smaller fish, and 0.1 cm for carapace length of crustaceans) of target species. During the sea trials, sufficient sampling of the catch is essential for achieving robust results in the following statistical analyses. Herrmann et al. (2016) showed that the uncertainty in estimated selection parameters decreased with increasing number of fish measured and that this relationship could be described by a power model. The sampling effort needed to achieve a specific uncertainty level for the selection parameters was always lower for the covered codend method compared to the paired-gear method. In many cases, the number of fish that would need to be measured to maintain a specific uncertainty level was around 10 times higher for the paired-gear method than for the covered codend method (there are, however, other potential biases connected to the use of covers, see section 4.1). Consequently, it is necessary to adapt sampling in the field in accordance with experimental design. In a gear selectivity analysis that includes multiple hauls, which is the most likely scenario when the selective properties of a gear are to be assessed, there are two sources of uncertainty in the parameters estimated: between-haul variation and within-haul variation. The magnitude of this

variation depends on both gear- and haul specific variables (such as gear design and haul duration) as well as variability in the species and size composition of the fished population. It is therefore impossible to set a fixed number of individuals or proportion of the catch that needs to be sampled beforehand to obtain a specific level of uncertainty in the estimated results. As a rule, as many individuals as possible should be measured and efforts should be made to avoid biased sub-sampling in large catches (sample across all layers/containers). Apart from the catch data, gear configuration such as cover design, rigging, warp length, etc., should be documented at each haul for supporting reproducibility of the study.

4.3 Statistical modelling of gear selectivity

Analyses of trawl selectivity experiments normally include statistical modelling of species length-dependent retention to assess the effect of tested gear modification (Millar 1992; Wileman et al. 1996; Herrmann et al. 2012). The aim of such models is to capture and account for the structural and random components of the selectivity experiment. The structural parts specify probabilities, and include:

- The retention probability, as specified by the selection curve.
- In case of paired-gear setup, the probability that a fish will enter the test gear (relative fishing power).
- When the catch is sub-sampled, the probability that a fish will be measured.

The selection curve $r(l)$ describes the probability that a fish of length l is retained, conditional on having entered the gear. It is the main function used to describe size selection in trawls (Wileman et al. 1996) and is generally modelled with a two parametric sigmoid function, most commonly the logistic form:

$$r(l) = \frac{1}{1 + \exp\ (-(\alpha + \beta l))}$$

where α and β are parameters to be estimated. Sigmoidal curves are chosen because they are interpretable and normally fit the gradual rise in retention from near 0 for small fish to near 1 for large fish. From the fitted curve, two selectivity parameters follow directly:

The length at 50% retention (**L$_{50}$**): $L_{50} = -\frac{\alpha}{\beta}$

and the selection range (**SR**): $SR = L_{75} - L_{25}$

The L_{50} locates the curve's midpoint and the SR measures steepness, and together they provide comparable metrics of selectivity between different gear types and trials independent of the size distribution in the fished population. Conceptually, the selectivity curve is the bridge between gear design and management. Changing mesh size, mesh orientation, twine, or adding grids/windows shifts α, β (hence L_{50}, SR), altering the proportion of juveniles retained and the resulting fishing mortality-at-size used in stock assessments and regulations.

The random components in selectivity experimental data are commonly modelled using maximum likelihood methods (Wileman et al. 1996). In covered codend and collection bag trials the number retained individuals in the test codend is treated as binomially distributed (fish entering the trawl is retained in either the codend or in the cover). In paired-gear designs, when the model also must account for the probability of entering the test codend, the SELECT ("Share Each Length's Entry into the Catch Total") model is established as a statistically rigorous approach (Millar 1992). The SELECT model state that for each length class, the share of fish entering the combined test + control that ends up in the test gear is a function of the test gear's selection curve and the relative fishing power between the gears (p). Estimating p within the maximum likelihood framework (rather than fixing it to 0.5) corrects common biases and improves goodness-of-fit when fishing powers differ. Model adequacy is generally assessed with deviance and residual diagnostics, and alternative curve families are compared by Akaike Information Criterion (AIC). Subsampling is handled by modelling the actual sampling fractions explicitly (rather than scaling to totals), a key requirement when catches are large. Estimation of mean selection parameters and confidence interval for the selection curve are commonly produced by pooling with bootstrap over hauls or using a mixed-effects framework (Fryer 1991). The statistical analyses described above are typically preformed using designated software, such as SELNET (Herrmann et al. 2012) or the SELECT package in R (Millar 2024).

4.4 Alternative methods to estimate bycatch

Although likelihood-based estimation of length dependent retention is a standard method for calculating the selectivity of gears, the amount of unwanted bycatch can also be estimated based on other parameters than the length.

Alternate haul or paired designs (same vessel, same ground, standardized tow duration/speed) allows for estimation of species and/or market category shifts via simple catch ratios or CPUE differences (Wileman et al. 1996; O'Neill & Mutch 2017). Twin trawl or multi-codend separators sample contemporaneously and allow for within-haul comparisons of species composition and/or market categories (e.g.

legal/undersized). Multivariate composition analyses (e.g. PERMANOVA) and analyses of indicator species can also be used to test whether the modification shifts assemblage structure by species or commercial categories (ICES 2020; 2023; Feekings et al. 2023). Effects on species composition can also be analysed used BACI (Before–After/Control–Impact) experimental design, where composition is compared before/after adoption against a control fleet or area, consistent with evaluations of technical measures and the landing obligation (European Commission: Joint Research Centre, Scientific, Technical and Economic Committee for Fisheries (STECF) 2025).

5. Methodological advancement through artificial intelligence

As described in the previous chapter, evaluations of the effect of gear modifications on the catch composition in trawls has traditionally been conducted through either paired geared experiments, where the catch of the test gear is compared to the catch of a baseline/control gear, or by recapture of the escapees (e.g. by using codend covers or collection bags) (Wileman et al. 1996). One of the main drawbacks of these methods, apart from that they generally are expensive and difficult to conduct, is that it normally leads to the death of the unwanted catch. This mortality is not only problematic if the unwanted catch consist of sensitive and/or protected species, but the use of marine vertebrates for experimental purposes is also considered and ethical problem (Sloman et al. 2019; Madsen et al. 2022) that should be reduced as far as possible according to legal frameworks and the 3R principles (Directive 2010/63/EU; Russell and Burch, 1959).

The development of underwater camera systems provides an alternative to the traditional methods for the evaluation of gear modifications. Instead of catching the escapees and bring them out of the water for sampling of basic metrics such as species and number, it is now possible to collect this data in the fish's natural environment (Simon et al. 2020). Observation of the catch in the gear, and observation of the escapees exiting the gear, can also provide valuable insights regarding the behaviour of the animals in relation to selectivity processes (Bayse & He 2017) and the vitality of those individuals that are released back into the wild (Petetta et al. 2025). Analysing the collected video from trawl gear experiments, especially if it contains multiple hauls with durations of several hours, and possibly thousands of fish observations, can however be a challenge.

Recent advancement of artificial intelligence (AI) within the field of computer vision (CV) have enabled machines to interpret and understand visual data such as images and videos. Its goal is to replicate human vision capabilities through computational models, allowing systems to identify, process, and respond to visual inputs automatically. This technology is already an integrated part across industry branches, from facial recognition and autonomous vehicles to medical imaging and industrial automation (Szeliski 2022). At its core, CV involves tasks like image classification, object detection, segmentation, and tracking. These are powered by deep learning models, particularly convolutional neural networks (CNNs), which extract meaningful features from raw image data (Krizhevsky et al. 2012; LeCun et al. 2015).

In terrestrial ecological research, CV has revolutionized how scientists study biodiversity and monitor environmental changes. Automated camera traps equipped with object detection models can identify and count animal species in the wild, reducing manual labour and increasing accuracy (Norouzzadeh et al. 2018). Satellite and drone imagery analysed through segmentation models allow for monitoring deforestation, tracking animal migrations, and assessing ecosystem changes (Wäldchen & Mäder 2018). These methods provide scalable, non-invasive ways to collect and analyse vast ecological data, critical in conservation efforts and climate studies.

The use of CV in the development of selective fishing gear could provide new insights of selectivity processes by quantifying what fish actually do inside and around selective devices (grids, escape panels, separator frames, square-mesh windows, excluders, etc.). These metrics can then, in turn, be used to design better gears and to evaluate the efficiency of different modifications. By using stereo systems (or other scaling methods like lasers) it is possible to add size measurements, and relate behaviour and passage probability to length, without the need to handling fish. "DeepVision" is an example of an in-trawl stereo camera system built to count and measure fish inside trawls (https://www.deepvision.no/). CV could potentially also be used to quantify ecologically relevant factors that previously have been difficult to measure adequately, such as the vitality of the escapees (e.g. by quantifying irregular behaviour or visible morphological damages). This technology also has great potential for operational monitoring and to better follow-up on implementation of selective gears. Remote Electronic Monitoring (REM) in combination with CV can provide "fully documented catch", which means that every fish caught by a vessel, retained and discarded, is recorded and verifiable at the haul level so that the total catch is known, not just landings (Feekings et al. 2023).

Increased knowledge of gear modifications on catch composition and survival of trawl escapees are a key for reducing ecosystem pressures while maintaining viable fisheries, and is therefore a central part of modern Ecosystem-Based Fisheries Management (EBFM) (Jennings & Revill 2007). At the ecosystem level, incorporating gear selectivity and bycatch/escapee survival into Ecological Risk Assessments (ERA) can help to identify vulnerable species and habitats, guiding spatial management tools such as area closures or gear restrictions (Zhou et al. 2019). Beyond the points above, recognising the role of selectivity and escapees supports broader sustainability goals. It ensures that selective fishing practices deliver true conservation benefits rather than symbolic compliance, aligns with the precautionary principle (González-Laxe 2005), and contributes to achieving United Nations Sustainable Development Goal 14 on the sustainable use of oceans.

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