# Improved bycatch reduction in the mixed demersal trawl fishery for Norway pout (Trisopterus esmarkii)

**Grimaldo, Eduardo; Brinkhof, Jesse; Herrmann, Bent; Cerbule, Kristine; Grimsmo, Leif; Pettersen, Hermann**

*Published in:*
Estuarine, Coastal and Shelf Science

*Link to article, DOI:*
10.1016/j.ecss.2022.108189

*Publication date:*
2023

*Document Version*
Publisher's PDF, also known as Version of record

Estuarine, Coastal and Shelf Science 281 (2023) 108189

Contents lists available at ScienceDirect

Estuarine, Coastal and Shelf Science

journal homepage: www.elsevier.com/locate/ecss

# Improved bycatch reduction in the mixed demersal trawl fishery for Norway pout (*Trisopterus esmarkii*)

Eduardo Grimaldo [a,b,*,1], Jesse Brinkhof [a,b,1], Bent Herrmann [a,b,c,1], Kristine Cerbule [a,b,1], Leif Grimsmo [a], Hermann Pettersen [d]

[a] *SINTEF Ocean, Trondheim, Norway*
[b] *UiT the Arctic University of Norway, Tromsø, Norway*
[c] *National Institute of Aquatic Resources (DTU AQUA), Technical University of Denmark, North Sea, Science Park, Hirtshals, Denmark*
[d] *Norwegian Directorate of Fisheries, Bergen, Norway*

ARTICLE INFO

*Keywords:*
Norway pout Fishery
Catch efficiency
Bycatch reduction
Sorting grid
Excluder

ABSTRACT

In this study, we compared the bycatch reduction capacity of a trawl fitted with a standard rigid sorting grid with that of a trawl fitted with a newly developed, flexible system called the Excluder. We conducted the fishing trials in the Norway pout (*Trisopterus esmarkii*) small-meshed trawl fishery in the North Sea. Catch data were analysed by species and length using the catch comparison and catch ratio method. The Excluder significantly reduced the bycatch (in weight) relative to the standard grid for blue whiting (*Micromesistius poutassou)* (−35.6%), mackerel (*Scomber scombrus*) (−93.3%), horse mackerel (*Trachurus trachurus*) (−99.3%), herring (*Clupea harengus*) (−89.9%), haddock (*Melanogrammus aeglefinus*), (−98.6%), whiting (*Merlangius merlangus*) (−99.3%), cod (*Gadus morhua*) (−97.1%), European hake (*Merluccius merluccius*) (−98.0%), and greater argentine (*Argentina sphyraena*) (−24.5%). For Norway pout there was a marginal decrease in the overall catch efficiency of −1.4%. The observed bycatch reduction efficiency is explained by the larger sorting area of the Excluder relative to the grid's area and by the differences in behaviour between Norway pout and the bycatch species. While it contributes to reduce bycatch of quota regulated species, the Excluder also can potentially affect the profitability of the fishery.

## 1. Introduction

### 1.1. The resource

Norway pout (*Trisopterus esmarkii*) is a small, short-lived fish species in the Gadidae family that lives at depths ranging from 50 to 250 m (Raitt, 1968; Sparholt et al., 2002; Lambert et al., 2009). This species is widely distributed in eastern parts of the North Atlantic, but is most common in northern parts of the North Sea in the area east of Shetland (Fladen Ground) and along the western edge of the Norwegian Trench. Norway pout live in scattered aggregations along the seabed, usually over muddy bottom substrate. Recruitment is highly variable and strongly influences both the spawning stock and total biomass. Norwegian and Danish fishing fleets are responsible for most of the landings of this species, with only occasional landings by Sweden, the Netherlands, Germany, or the UK.

### 1.2. The Norway pout fishery

The Norway pout fishery is a multispecies demersal fishery with both wanted and unwanted bycatch species. The Norwegian and Danish fishing fleet are responsible for most of the Norway pout landings and associated bycatch species, with only occasional landings by the fleet of Sweden, Netherlands, Germany, and the UK. The fleet is composed by licenced industrial vessels, some of them specialized pelagic trawlers and others are combination vessels (purse seine/pelagic trawling). The fishery is carried out by licensed industrial trawlers, which target blue whiting (*Micromesistius poutassou*) and Norway pout, often during the same trip. The license system is complex, with different vessels have different quotas for different species, and some vessels being allowed to process by catch of white fish for human consumption. Some vessels, if they hold a quota, can take out the bycatch of large fish such as saithe (*Pollachius virens*), European hake (*Merluccius merluccius*), and monkfish (*Lophius piscatorius*), from the catch and deliver it for human

* Corresponding author. SINTEF Ocean, Trondheim, Norway.
*E-mail address:* Eduardo.Grimaldo@sintef.no (E. Grimaldo).
[1] These authors contributed equally to this work.

https://doi.org/10.1016/j.ecss.2022.108189
Received 5 May 2022; Received in revised form 3 December 2022; Accepted 12 December 2022
Available online 20 December 2022

consumption. The fishing strategies also differ among vessels. Some vessels take most of their blue whiting quota west of Ireland, whereas others save their quota in order to carry out a mixed blue whiting-Norway pout fishery in the North Sea. Norway pout is caught in small-meshed demersal trawls (16–31 mm) in a mixed fishery and is landed for reduction purposes (fish meal and fish oil). The landings peaked in 1974 at 740,000 metric tonnes and then decreased significantly after extensive regulations were imposed, including closure of a large area of Fladen, east of Shetland, and bycatch limits. During the 1990s, annual landings of Norway pout fluctuated around an average of 150,000 metric tonnes. In recent years, landings have varied greatly due to recruitment and periodic closure of the directed fishery. In 2020, the catch was 129,497 metric tonnes, of which 65,607 and 63,777 metrics tonnes were caught by Denmark and Norway, respectively (ICES, 2021).

Norway pout is a major prey species for many larger and commercially important predator species in the North Sea, and therefore, the fishery is characterized by relatively large bycatch levels. White fish species, such as cod (*Gadus morhua*), whiting (*Merlangius merlangus*), saithe, haddock (*Melanogrammus aeglefinus*), European hake, and monkfish, and pelagic species such as mackerel (*Scomber scombrus*) and herring (*Clupea harengus*) are considered to be unwanted bycatch species in the fishery. In contrast, blue whiting, greater argentine (*Argentina sphyraena*), and horse mackerel (*Trachurus trachurus*) are considered to be wanted bycatch species (Sparholt et al., 2002; Lambert et al., 2009; Cormon et al., 2016; Nielsen et al., 2016; Eigaard et al., 2012). The bycatch levels of these species have decreased in the Norway pout fishery over the years due to management measures that have been enforced in the fishery (ICES, 2016). Current reported levels of the 10 most common bycatch species caught in the Norway pout fishery by Norwegian vessels in 2020 is as follows: Blue whiting (6967 metric tonnes), Horse mackerel (2491 metric tonnes), Silver smelt *Argentina sphyraena* (1879 metric tonnes), saithe (1474 metric tonnes), herring (1341 metric tonnes), sand eel *Ammodytes marinus* (429 metric tonnes), silver cod *Gaciculus thori* (282 metric tonnes), whiting (253 metric tonnes), haddock (115 metric tonnes) (Lassen and Chaudhury, 2021).

Because Norway pout is only used for reduction purposes, the profitability of the fishery is low, and this is one of the reasons why the quotas are seldom fished. Profitability is improved by increasing the catch rates of legally accepted bycatch species (i.e., horse mackerel, blue whiting, and greater argentine). In 2012, it became mandatory to use a sorting grid with 40 mm bar spacing in the Norwegian Exclusive Economic Zone (EEZ) and 35 mm bar spacing in the European Union EEZ. Sorting grids are efficient for reducing bycatch of gadoids above minimum landing size, but grids fail at removing bycatch of small fish. Unwanted bycatch species (mackerel, herring, cod, haddock, saithe, whiting, European hake, and monkfish) reduce profitability if they are used for reduction rather than sold for human consumption. Because there are exceptions to the requirement to use sorting grids in the Norway pout fishery in the Norwegian EEZ, is it easier to control the landings of catches taken in EU waters. Due to different sets of regulations in the Norwegian EEZ and the EU zone, a requirement was introduced in 2017 that prevents fishing of Norway pout in both zones during the same trip (Norwegian Directorate of Fisheries, 2021).

### 1.3. The management system and regulations for the Norwegian fleet

Although Norway pout is a joint stock between the EU and Norway, it is not jointly managed. However, the Parties agree in wishing for joint management of the Norway pout stock. The strategy is for both Parties to achieve maximum sustainable yield fisheries, and to do so they base their regulations on advice from ICES, which is based on the ICES advisory scheme for short-lived species (see for example ICES advice, 2021). The EU also obtains advice from the Scientific, Technical and Economic Committee for Fisheries. The total allowable catches (TAC) are set autonomously after annual consultations under the EU-Norway fisheries agreement.

Many of the regulations for Norwegian industrial trawling in the North Sea (targeting Norway pout and blue whiting) are in place to reduce the large bycatch problems. Explicit management objectives for Norway pout have not been defined, but the EU and Norway have implemented a precautionary approach to ensure sustainable fisheries. It is also recognized that it is important to ensure that the stock remains at a sufficiently high level to provide food for a variety of predator species. In recent years, however, quotas have been set to ensure that on January 1, after the fishing year ends, the remaining spawning stock should be greater than 150,000 metric tonnes (ICES, 2021). In 2021, the stock was in good condition, the spawning stock was considered to be large, and recruitment had been good for three years in a row (ICES, 2021). Current regulations for the Norwegian industrial trawling in the North Sea targeting Norway pout are as follows: i) area closures. Implemented in 2003 and still valid is the closure of the Egersund bank in the period between 01 November – 21 May. The Patch bank has remained closed since 2002. ii) seasonal closures, in which the industrial fishery in the Norwegian EEZ in the North Sea is only open from 1 April to 31 October (ICES, 2016); iii) minimum mesh size codend regulations for the fishery (i.e., 16 mm mesh opening) and compulsory use of a sorting grid (with some exceptions); iv) bycatch regulations to protect other fish species: the maximum bycatch of cod, haddock, and saithe in industrial trawling in the North Sea is 20% in weight by haul and by landing; the bycatch of herring is a maximum of 10%, and any bycatch of herring is taken from the vessel's quota; the bycatch of greater argentine is a maximum of 10%; maximum bycatch of monkfish is 0.5%, and landing of monkfish by trip should not exceed 500 kg (ICES, 2016; Lovdata, 2021); and v) a rigid sorting grid with a maximum 40 mm bar spacing has been mandatory in the Norwegian fishery since 2010, and in the Danish fishery a grid with a maximum of 35 mm has been mandatory since 2012 (ICES, 2016). The introduction of the sorting grid in the Norwegian and Danish fishery has led to gadoid bycatch reductions of between 80.9 and 100%, but it remains difficult to avoid small gadoids (Eigaard et al., 2012, 2021). Simultaneously, grid systems lead to a 5–10% reduction in the catch of target species and to a reduction of herring bycatch (ICES, 2016). In the Norwegian fishery, sorting grids have influenced bycatch rates, but some vessels do not always use the grid because it is not mandatory in some parts of the fishery (e.g., for those with quotas to catch and process saithe on board) (ICES, 2016).

To date, there is still great uncertainty about whether the catch registration is correct when receiving fish for reduction purposes. Consequently, the reported levels of bycatch of TAC regulated species such as much mackerel, herring, haddock, cod, whiting, is not accurate and expected to be larger than those reported. The Norwegian Directorate of Fisheries has tried to solve this problem through increasing the sampling effort of the catches at the landing stations, and by using the catch composition reported by the vessels. However, as sampling coverage is not 100%, it has not succeeded in quantifying the bycatch that goes unregistered (Norwegian Directorate of Fisheries, 2021).

The goal of the present study was to compare bycatch reduction capacity of two bycatch reduction devices in the small-mesh mixed Norway pout-blue whiting trawl fishery in the Norwegian EEZ in the North Sea. We compared a rigid sorting grid section and a flexible Excluder section. We discuss the results in terms of existing management bycatch rules for the Norwegian fleet.

## 2. Materials and methods

### 2.1. Fishing vessel, fishing grounds, and gear

We conducted the experiment on board the 53 m long pelagic trawler "Fiskebank" from 1 to 10 October 2021, in the Norway pout fishing grounds in the northern part of the North Sea, along the Norwegian trench. We used two identical Egersund 1500 meshes Expo trawls mounted with 100 m bridles and 30 m sweeps in a twin trawl setup. The sweeps were connected to two 11 $m^2$ Thyborøn type 22 pelagic doors that weighed 3.0 tons each and to a 5.5-ton roller-clump between the two trawls. The standard sorting grid section (control) was mounted in one of the trawls and the Excluder section (treatment) in the other. The two identical codends were attached to the trawls. They were 50 m long, were made of 24 mm nominal diamond full meshes in nylon, and had a circumference of 1000 meshes. The mean mesh opening of the Excluder codend and the grid codend was 24.1 mm (SD = 1.2, N = 50) and 24.1 mm (SD = 1.4, N = 50), respectively. The mesh measurements were done with a calliper, on wet meshes, and right after the last haul. During fishing, the towing speed was kept between 2.9 and 3.3 knots. The geometry and performance of the trawls was continuously monitored using trawl door spread, roll and pitch, and codend catch sensors purchased from Scanmar (Scanmar AS, Åsgårdstrand, Norway). The Excluder and grid sections were switched to opposite sides once during the cruise so that they both were fished at both port and starboard sides.

### 2.2. Bycatch reduction devices

The Excluder is a flexible net section that is inserted as an extension piece of the trawl. It consisted of a 30 m long outer net part and an 11 m square-meshed inner selection section. The outer net part of the Excluder was made of diamond meshes with a mean mesh opening of 31.4 mm (SD = 0.6, N = 50). The square-meshed inner selection section was cone-shaped and ended in an outlet in a bottom panel of the 30 m extension piece, just before the codend. The square-meshed inner selection section of the Excluder was made from 6 mm twine thickness knotless netting with a mean full mesh opening of 71.6 mm (SD = 0.8 mm, N = 50) (bar length of approx. 35.6 mm). The nominal mesh size of 70 mm for the square-meshed inner selection section was chosen based on Eigaard et al. (2021) fall-through experiment of Norway pout, whiting, herring, and haddock. To reach the codend, fish must pass through the square meshes of the inner net selective section and continue along to the codend (Fig. 1). The entrance and exit diameter of the outer net part of the Excluder was kept opened by two cylindrical kites made from heavy PVC cloths. At the end of the 11 m square-meshed inner selection section, a square PVC kite (0.6 × 0.6m) was mounted across the section to partially block the water flow and force the fish to either actively bypass the kite or attempt swimming through the square meshes of the inner selection section.

The standard metal sorting grid was 1.8 m wide and 3.5 m long and had six individual sections of 1.8 × 0.7 m lashed together. The mean bar spacing was 39.5 mm (SD = 0.8 mm, N = 50), and the mean bar width was 10.1 mm (SD = 0.5 mm, N = 50). The sorting grid was mounted in a 40 mm full mesh size netting section at an angle of 50°from horizontal with the bottom pointing backwards from the trawl mouth (Fig. 1). A guiding panel made of square meshes (20 mm bar length) was inserted in front of the grid, causing all fish to encounter the grid at its upper and middle sections, away from the outlet at the bottom of the grid.

### 2.3. Data collection

After each tow, a sample of the catch (12 full baskets totalling approximately 340 kg)) from each codend was taken spread during the pumping period. Each sample was sorted by species, and the weight of each species was recorded. Each fish in each sample was length measured to the nearest centimetre below, except for Norway pout and blue whiting, which were subsampled (subsamples varied between 8 and 16 kg). After recording species, weight, and length distributions to the nearest centimetre below, all samples and sub-samples were raised to total catch numbers by weight factors. The total catch per trawl was estimated for each haul by the skipper inspecting the catch indicators in the refrigerated sea water (RSW) tanks and noting the change in volume after the catches were transported from the respective codends, and onboard the vessel. The subsampling factors were calculated by multiplying the subsample factor based on the weight from the fish measured divided by the total sample weight and the sample weight divided by the

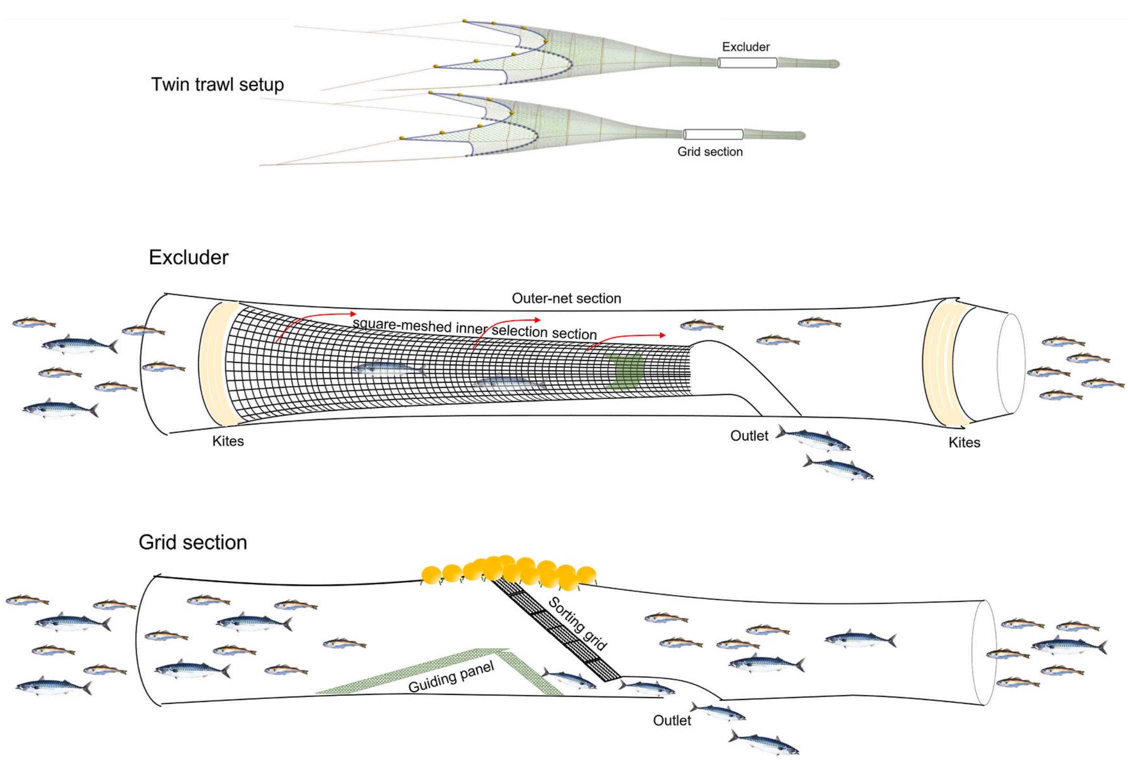


**Fig. 1.** Schematic representation of the twin trawl setup and the sorting devices. The target species (Norway pout) and bycatch species (for instance mackerel) enter the Excluder and the grid section simultaneously. In the Excluder, Norway pout swim through the square-meshed inner selection section and end up in the codend. Mackerel are not able to pass though the square-meshed inner selection section and are guided out of the Excluder. In the grid section, Norway pout swim through the sorting grid and end up in the codend. Mackerel are not able to pass though the grid and are guided out of the grid section.

total catch weight.

### 2.4. Modelling the size-dependent catch efficiency of the trawls with different bycatch reduction devices

The catch data were analysed by modelling the size-dependent catch efficiency (Herrmann et al., 2017) using the statistical software SELNET (Herrmann et al., 2016). This method models the length-dependent catch comparison rate ($CC_l$) summed over hauls, and its experimental form is described by the following equation:

$$CC_l = \frac{\sum_{j=1}^{m}\left\{\frac{nt_{lj}}{q_{tj}}\right\}}{\sum_{j=1}^{m}\left\{\frac{nt_{lj}}{q_{tj}} + \frac{nc_{lj}}{q_{cj}}\right\}} \tag{1}$$

where $nc_{lj}$ and $nt_{lj}$ are the numbers of fish of each species that were length measured in each length class $l$ for the standard grid (control) and Excluder (treatment) trawls in haul $j$. $qc_j$ and $qt_j$ are sampling factors quantifying the fraction, based on weight, of the catch in the codends that were length measured in the respective hauls. $m$ is the number of hauls in which sufficient numbers of each species were caught to be included in the analysis. The functional form for the catch comparison rate $CC(l,\ v)$ was obtained using maximum likelihood estimation by minimizing the following equation:

$$-\sum_{l}\left\{\sum_{j=1}^{m}\left\{\frac{nt_{lj}}{q_{tj}} \times ln(CC(l,v)) + \frac{nc_{lj}}{q_{cj}} \times ln(1.0 - CC(l,v))\right\}\right\} \tag{2}$$

where $v$ is the parameter describing the catch comparison curve defined by $CC\ (l,v)$. The outer summation in equation (2) is the summation over length classes $l$. When the catch efficiency of the standard grid and that of the Excluder trawl is similar, the expected value for the summed catch comparison rate would be 0.5 (baseline). Therefore, this baseline can be applied to judge whether there is a difference in catch efficiency between the two trawls. The experimental $CC_l$ was modelled by the function $CC(l,v)$ using the following equation:

$$CC(l,v) = \frac{exp(f(l, v_0, ...., v_k))}{1 + exp(f(l, v_0, ..., v_k))} \tag{3}$$

where $f$ is a polynomial of order $k$ with coefficients $v_0$ to $v_k$. The values of the parameters $v$ describing $CC(l,v)$ were estimated by minimizing equation (2), which was equivalent to maximizing the likelihood of the observed catch data. We considered $f$ of up to an order of 4 with parameters $v_0$, $v_1$, $v_2$, $v_3$, and $v_4$. Leaving out one or more of the parameters $v_0$ … $v_4$ led to 31 additional models that were also considered as potential models for the catch comparison $CC(l,v)$. Among these models, estimations of the catch comparison rate were made using multi-model inference to obtain a combined model (Burnham and Anderson, 2002). The ability of the combined model to describe the experimental data was evaluated based on the $p$-value. The $p$-value, which was calculated based on the model deviance and the degrees of freedom, should not be $< 0.05$ for the combined model to describe the experimental data sufficiently well, except for cases for which the data were subject to over-dispersion (Wileman et al., 1996). Based on the estimated catch comparison function $CC(l,v)$, we obtained the relative catch efficiency (also called the catch ratio) $CR(l,v)$ between the two trawls using the following equation:

$$CR(l,v) = \frac{CC(l,v)}{(1 - CC(l,v))} \tag{4}$$

The $CR(l,v)$ is a value that represents the relationship between the catch efficiency of the Excluder and the standard grid trawl. If the catch efficiency of both trawls is equal, then $CR(l,v)$ equals 1.0. A $CR(l,v)$ of 1.5 would mean that the Excluder trawl catches 50% more of the species with length $l$ than the standard grid trawl. In contrast, a $CR(l,v)$ of 0.8 would mean that the Excluder trawl catches only 80% of the species with length $l$ compared to the standard grid trawl.

To provide significant differences for catch efficiency between the trawls, we estimated confidence limits for $CC(l,v)$ and $CR(l,v)$. The confidence limits ($CI$) were estimated using a double bootstrapping method (Herrmann et al., 2017), which accounts for between-haul variability (the uncertainty in the estimation resulting from between-haul variation of catch efficiency in the trawls) as well as within-haul variability (the uncertainty about the size structure of the catch for the individual hauls, including the effect of subsampling). However, contrary to this double bootstrapping method, in the current study the outer bootstrapping loop accounting for between-haul variation was performed paired for the Excluder and standard grid, taking full advantage of the experimental design in which the trawls were fished in a twin trawl setup (in parallel). By multi-model inference in each bootstrap iteration, the method also accounted for the uncertainty due to uncertainty in model selection. We performed 1000 bootstrap repetitions and calculated the Efron 95% $CIs$ (Efron, 1982). To identify sizes of species with significant differences in catch efficiency, we checked for length classes in which the 95% confidence limits for the catch ratio curve did not include 1.0. Finally, a length-integrated average value for the catch ratio was estimated directly from the experimental catch data using the following equation:

$$CR_{average} = \frac{\sum_{l}\sum_{j=1}^{m}\left\{\frac{nt_{lj}}{qt_j}\right\}}{\sum_{l}\sum_{j=1}^{m}\left\{\frac{nc_{lj}}{qc_j}\right\}} \tag{5}$$

where the outer summation $\sum_l$ covers the length classes in the catch during the experimental fishing period.

### 2.5. Species dominance

Catch dominance curves are often used to quantify information about the pattern of relative species abundances for a given sample. Here, we use catch dominance curves based on weight to quantify the dominance of the individual species in the catch. Generally, dominance curves are based on ranking of species in a sample in decreasing order of their abundance (Clarke, 1990). This implies that the species ranking could potentially vary among stations, making it difficult to compare dominance curves among different gears. Therefore, we kept the species ranking fixed according to the species ID (Table 1). We then estimated the catch dominance curve for each net configuration using the following equation (Warwick et al., 2008):

$$d_{ij} = \frac{q_{ij} \times n_{ij} \times w_{ij}}{\sum_{i=1}^{K}\{q_{ij} \times n_{ij} \times w_{ij}\}} \tag{6}$$

where $j$ represents the haul and $i$ is the species index (species rank) that was predefined. $n_{ij}$ is the number of individuals of the species $i$ being counted in the subsample in haul $j$. $w_{ij}$ is the weight of the counted subsample of species $i$ in haul $j$, whereas $q_{ij}$ is the fraction of species i in the catch being counted in haul $j$. $K$ is the total number of species considered.

To better represent species dominance patterns, we also estimated the cumulative dominance curves as follows:

$$D_{Ij} = \frac{\sum_{i=1}^{I}\{q_{ij} \times n_{ij} \times w_{ij}\}}{\sum_{i=1}^{K}\{q_{ij} \times n_{ij} \times w_{ij}\}} \quad \text{with } 1 \le I \le K \tag{7}$$

where $I$ is the species index summed up to in the nominator.

The 95% $CIs$ for the dominance patterns were estimated using (6) and (7) inside each of the bootstrap iterations applied to estimate the uncertainties for the catch comparison and catch ratio curves.

**Table 1**
Total and mean catches. Summed catch (kg) per species over 12 hauls using the twin trawl setup with one trawl with the sorting grid (control) and the other trawl with the Excluder (treatment). Mean catches in weight per haul. Values in parentheses represent the 95% CI which were obtained were obtained by the double bootstrapping method based by using the information of total catch per species.

| Species | Trawl with Sorting grid | | Trawl with Excluder | | % Reduction in weight |
|---|---|---|---|---|---|
| | Total catch | Mean catch | Total catch | Mean catch | |
| Norway pout | 67,032 | 5586 (3989–7197) | 66,069 | 5506 (4269–6796) | −1.4 (−15.3–16.0) |
| Blue whiting | 75,038 | 6253 (3335–9924) | 48,302 | 4025 (2260–6084) | −35.6 (−47.2 to −20.7) |
| Greater argentine | 4372 | 364 (42–970) | 3301 | 275 (32–683) | −24.5 (−47.3– 18.3) |
| Horse mackerel | 38,125 | 3177 (2282–4049) | 272 | 23 (4–54) | −99.3 (−99.9 to −98.2) |
| Herring | 34,248 | 2854 (1396–4708) | 3458 | 288 (123–523) | −89.9 (−93.0 to −86.2) |
| Mackerel | 27,564 | 2297 (672–4277) | 1858 | 155 (41–282) | −93.3 (−97.9 to −83.0) |
| Haddock | 8356 | 696 (310–1127) | 118 | 10 (3–18) | −98.6 (−99.5 to −97.2) |
| Cod | 151 | 13 (0–30) | 4 | 0 (0–1) | −97.1 (−104.0 to −5.0) |
| European hake | 588 | 49 (14–95) | 12 | 1 (0–3) | −98.0 (−100.2 to −93.2) |
| Whiting | 7733 | 644 (390–963) | 51 | 4 (1–8) | −99.3 (−99.8 to −98.6) |
| SUM | 263,207 | | 123,445 | | |

## 3. Results

We conducted 14 hauls using the twin trawl setup during the fishing trials in October 2021, but we discarded two of them from the analysis because one of the trawls was damaged during towing. The catches varied between 9000 and 37,000 kg for the trawl with the grid and between 1500 and 17,000 kg for the trawl with the Excluder. These hauls contained sufficient catches of Norway pout, blue whiting, herring, mackerel, horse mackerel, whiting, haddock, European hake, and greater argentine to be included in the catch comparison analysis (Table 1). The quantities of other species, such as cod, were too low for inclusion in the catch comparison analysis. However, these species constituted only 0.6% of the total catch in weight. Because cod were counted, we included this species in the species dominance analysis.

For the main target species, Norway pout, no significant difference ($p < 0.0001$) was observed in the catch (in weight) (Table 2) or the length frequency distributions (Fig. 2) between the trawl with the Excluder and the trawl with the sorting grid. The catch rate indicated a small but non-significant increase of the catch in the trawl with the Excluder (103.81, CI: 86.74–125.61), which in weight represented 1.4% (Tables 1 and 2).

The Excluder reduced the catch of wanted bycatch species (blue whiting, greater argentine, and horse mackerel) by 35.6%, 24.5%, and 99.3%, respectively (Table 1). For blue whiting, the catch ratio was highly length dependent; there was a large and significant reduction in catch ratio for individuals larger than 22.0, but no significant differences were detected for the smaller individuals (Table 3, Fig. 3). For greater argentine, the catch ratio also showed a tendency of length dependency, but the difference was not significant. For horse mackerel, the CI were very wide and therefore it is not possible to conclude whether there was a significant length dependency. When averaged over all length classes, the catch ratios for blue whiting and horse mackerel were significantly lower for the trawl with the Excluder than for the trawl with the sorting grid, with the estimated catch ratios of the trawl with Excluder being 67.9% and 0.8% of the trawl with the sorting grid, respectively (Table 3, Fig. 3).

**Table 2**
Fit statistics for Norway pout. Catch comparison results and number of fish observed between the Excluder and the grid.

| | Norway pout |
|---|---|
| *p*-value | <0.0001 |
| Deviance | 81.68 |
| DOF | 16 |
| $CR_{average}$ | 103.81 (86.74–125.61) |
| Number of fish Excluder | 2124 |
| Number of fish grid | 2177 |

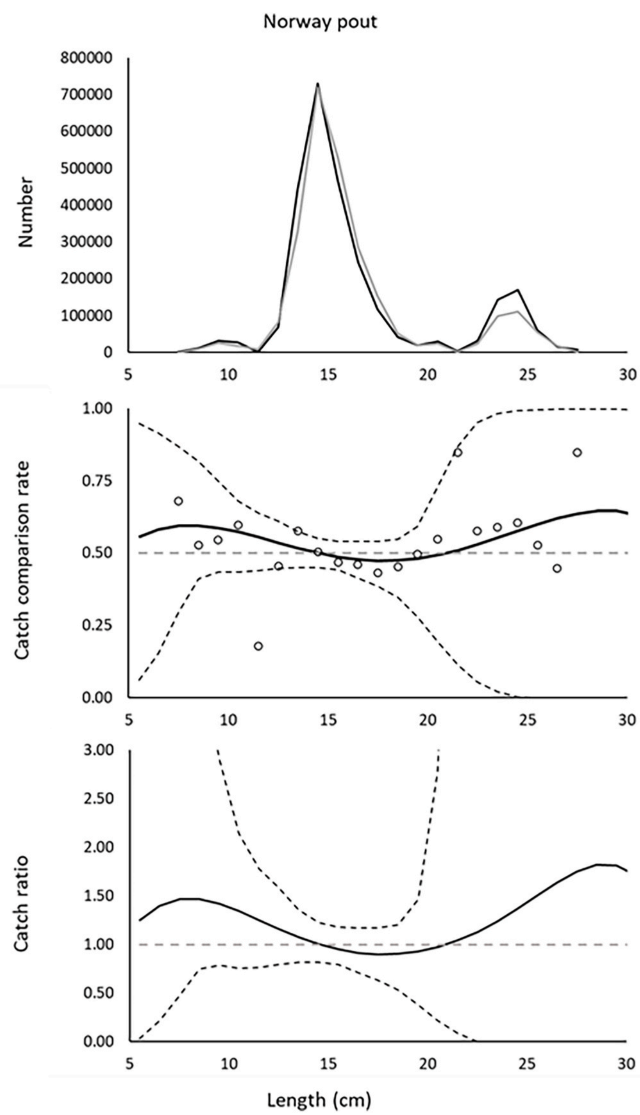


**Fig. 2.** Catch comparison and catch ratio analysis for Norway pout. Upper graph: the length frequency distribution of Norway pout captured by the trawl with the Excluder (black line) and the trawl with the sorting grid (grey line). Middle: the modelled catch comparison rate (black line). Circles represent the experimental rate. Lower: the estimated catch ratio curve (black curve). The 95% CI is represented by the black stippled curves. The grey stippled lines at 0.5 and 1.0 represent the point at which both gears have an equal catch rate.

**Table 3**
Fit statistics. Catch comparison results and number of fish observed between the Excluder and sorting grid for blue whiting, greater argentine, and horse mackerel.

| | Blue whiting | Greater argentine | Horse mackerel |
|---|---|---|---|
| $p$-value | <0.0001 | <0.0001 | <0.0001 |
| Deviance | 59.32 | 46.71 | 373.57 |
| DOF | 19 | 15 | 9 |
| $CR_{averge}$ | 67.92 (55.60–87.28) | 100.76 (82.12–130.52) | 0.75 (0.13–1.96) |
| N fish measured Excluder | 4008 | 997 | 30 |
| N fish measured grid | 3928 | 599 | 2057 |

For all unwanted bycatch species that normally are destined for human consumption (herring, mackerel, haddock, European hake, and whiting), the Excluder reduced the catch of these species compared to the grid by 89.9%, 98.3%, 98.6%, 98.0%, and 99.3%, respectively (Table 1). For all of these species, the catch ratios were highly length dependent; there was a large and significant reduction for individuals larger than 24.0 cm for herring, 25 cm for mackerel, and 21 cm for haddock, but no significant differences were detected for the smaller individuals (Table 4, Fig. 4). When averaged over all length classes, the catch ratios for herring, mackerel, haddock, European hake, and whiting were significantly lower for the trawl with the Excluder than for the trawl with the sorting grid, with the estimated ratios of the trawl with the Excluder being 14.1%, 8.4%, 3.9%, 13.3%, and 2.9% of the trawl with the sorting grid, respectively (Table 4, Fig. 4).

The cumulative dominance analysis (Fig. 5) shows dissimilarity between the catch composition of the trawl with the Excluder and the trawl with the sorting grid, and significant differences were found for all pelagic species. While the proportion of target and wanted bycatch species summed up 95.5% in the trawl with the Excluder, it reached 70.1% in the trawl with the sorting grid. The unwanted bycatch species herring and mackerel that together constituted approximately 27.5% in the trawl with sorting grid were reduced to around 3% in the trawl with the Excluder.

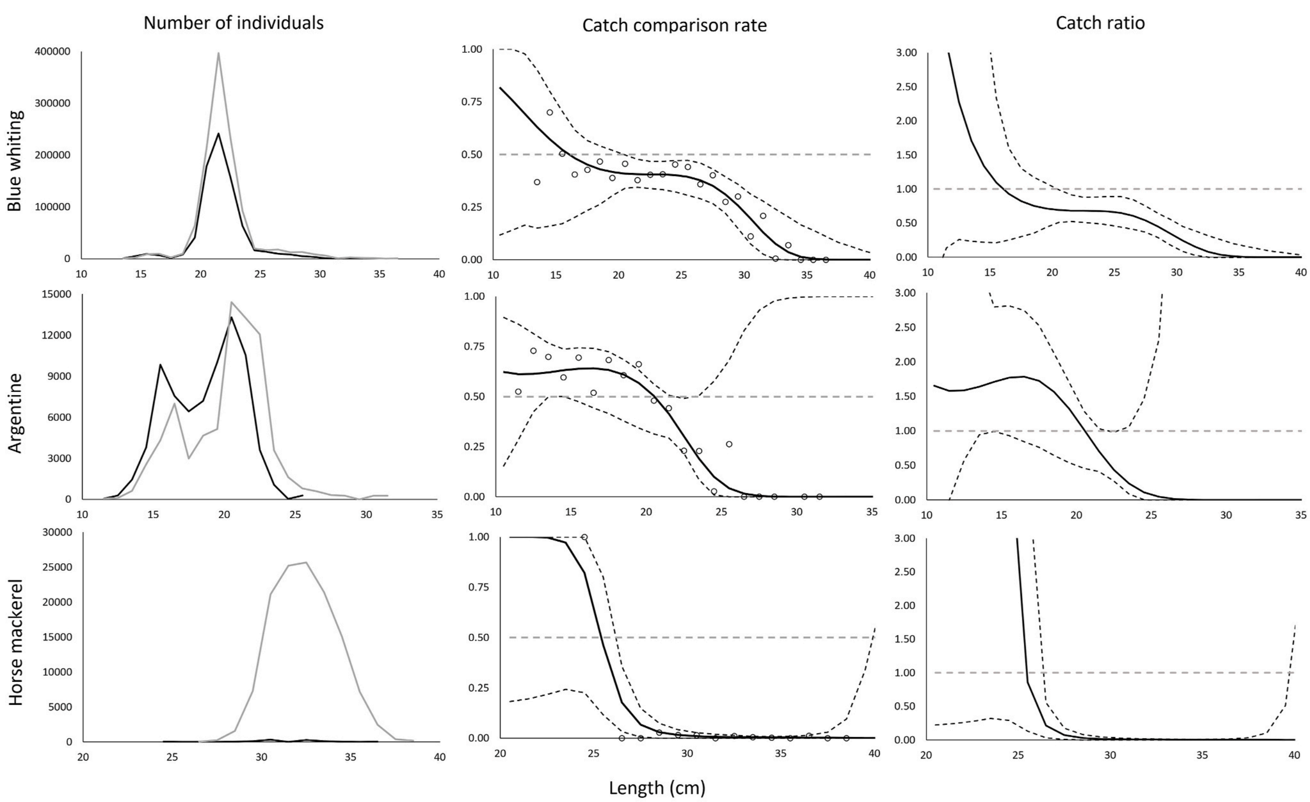


**Fig. 3.** Catch comparison and catch ratio analysis for blue whiting, greater argentine, and horse mackerel. Left column: the length frequency distribution of fish captured by the trawl with the Excluder (black line) and the trawl with the sorting grid (grey line). Middle: the modelled catch comparison rate (black line) with 95% CIs (black stippled curves). Circles represent the experimental rate. Right: the estimated catch ratio curve (black curve) with 95% CIs (black stippled curves). The grey stippled lines at 0.5 and 1.0 represent the point at which both gears have an equal catch rate.

**Table 4**
Fit statistics. Catch comparison results and number of fish measured between the Excluder and the grid for unwanted bycatch species.

| | Herring | Mackerel | Haddock | European hake | Whiting |
|---|---|---|---|---|---|
| $p$-value | <0.0001 | 0.1281 | <0.0001 | <0.0001 | <0.0001 |
| Deviance | 67.24 | 22.49 | 151.30 | 72.32 | 110.37 |
| DOF | 14 | 16 | 20 | 16 | 25 |
| $CR_{average}$ | 14.08 (09.53–19.36) | 8.39 (00.00–11.95) | 3.90 (01.71–07.50) | 13.33 (03.42–61.90) | 2.88 (01.39–04.90) |
| N fish measured Excluder | 878 | 852 | 63 | 10 | 53 |
| N fish measured grid | 2643 | 2950 | 691 | 37 | 386 |

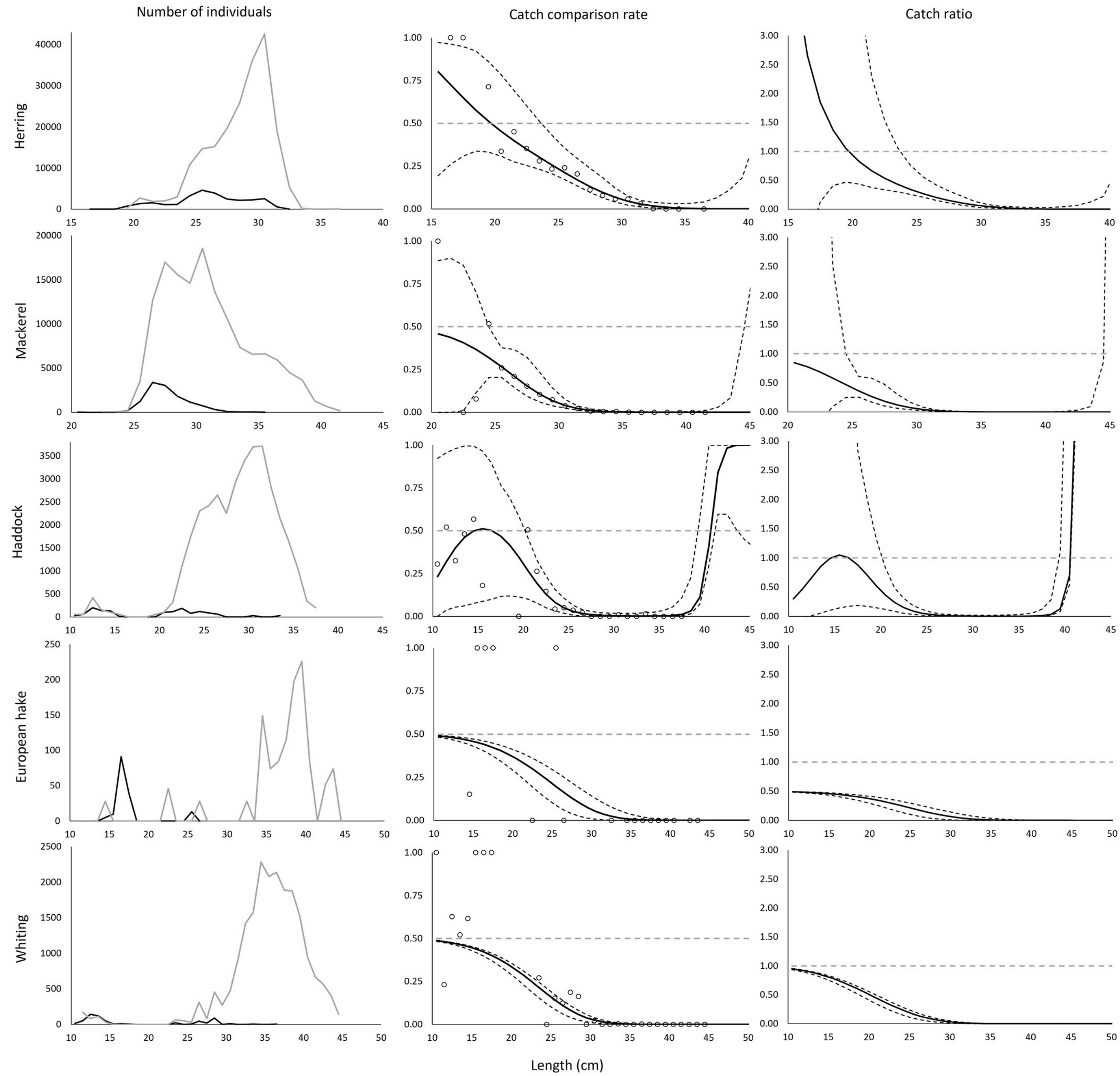


**Fig. 4.** Catch comparison and catch ratio analysis for unwanted bycatch species. Left column: the length frequency distribution of fish captured by gear with the Excluder (black line) and gear with the sorting grid (grey line). Middle: the modelled catch comparison rate (black line) with 95% CIs (black stippled curves). Circles represent the experimental rate. Right: the estimated catch ratio curve (black curve) with 95% CIs (black stippled curves). The grey stippled lines at 0.5 and 1.0 represent the point at which both gears have an equal catch rate.

## 4. Discussion

In several trawl fisheries targeting small-sized fish species, the unwanted bycatch of juveniles, which often are of the same size as the target species, is a persistent issue (ICES, 2016; Larsen et al., 2018; Eigaard et al., 2021). The mixed fishery for Norway pout in the North Sea is one such fishery (Eigaard et al., 2012, 2021). Small-meshed trawls with a minimum mesh size of 16 mm in the codend are little, or non-selective, and can contain large quantities of unwanted bycatch species. Although the introduction of the sorting grid has significantly reduced the catches of large gadoids, small gadoids and other unwanted bycatch species can still be caught in large quantities (Eigaard et al., 2012; ICES, 2016). Moreover, there is great uncertainty as to whether the catch registration is correct when landing mixed catches for reduction purposes, but bycatch levels of these species are expected to be relatively high (Norwegian Directorate of Fisheries, 2021). Over time, the Norwegian Directorate of Fisheries has tried to solve this problem by increasing the effort of sampling the landings of vessels in the fleet. Therefore, a selection system that can help reduce the bycatch issues in the North Sea mixed fishery for Norway pout is needed.

Contrary to Dickson (1960), Bailey et al. (1983), and Wileman and Main (1994), who did not find any difference in behaviour that could be used to separate Norway pout from bycatch species destined for human consumption, the Excluder section tested in this experiment was very efficient at separating different fish species, even those in similar length classes. The Excluder section significantly reduced the bycatch of

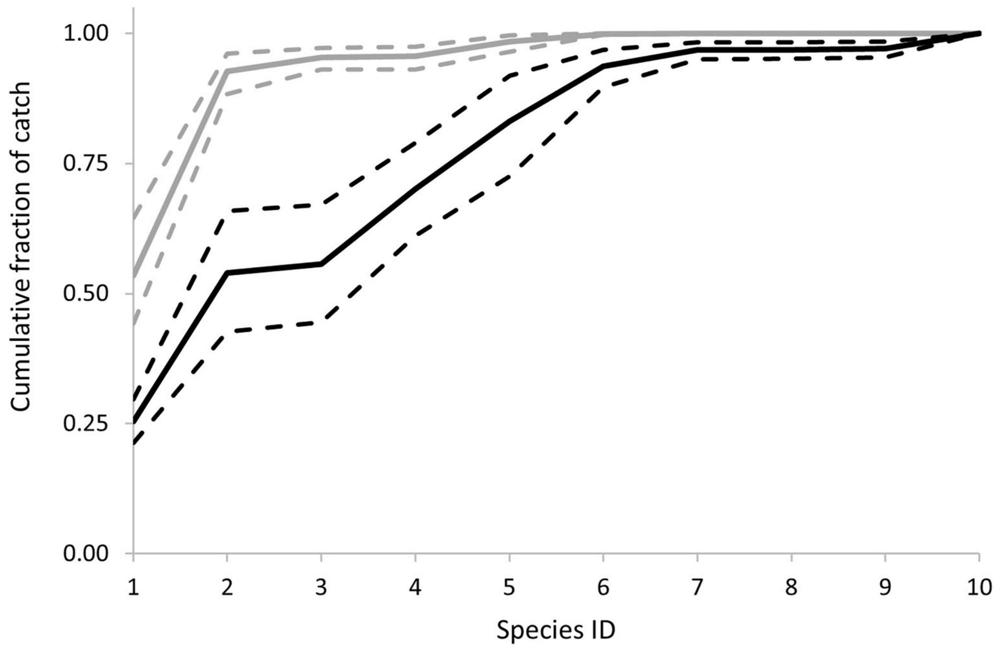


**Fig. 5.** Cumulative species dominance in weight for the Excluder (grey line) and the grid (black line) with 95% *CIs* (stippled lines). The X-axis shows the species ID: 1 Norway pout, 2 blue whiting, 3 Greater argentine, 4 Horse mackerel, 5 Herring, 6 Mackerel, 7 Haddock, 8 Cod, 9 European hake, 10 Whiting. The Y-axis shows cumulative dominance.

unwanted cod, whiting, haddock, and European hake by 97.1%, 99.3%, 98.6%, and 98.0%, respectively, without altering the catch of the target species, Norway pout. The Excluder also reduced the bycatch of other unwanted bycatch species, such as mackerel and herring, by 93.3% and 89.9%, respectively. However, the Excluder also reduced the bycatch of wanted bycatch species such as blue whiting (by 35.6%), horse mackerel (by 99.3%), and greater argentine (by 24.5%). The Excluder bycatch reduction was species and size dependent, meaning that larger fish were unable to pass through the Excluder's square-meshed inner selection section and consequently were released from the trawl. This was the case for most white fish species, except for the smallest length classes. The smallest individuals (<22 cm) of blue whiting and greater argentine were able to pass through the square-meshed inner selection section of the Excluder and get caught, whereas larger length classes (>22 cm) were released. Bigné et al. (2018) reported that depth seemed to be correlated with bycatch levels, with juveniles of whiting, herring, and especially Norway pout generally preferring shallower waters. However, the correlation between depth and length classes and/or bycatch levels was not assessed in this study. The observed bycatch reduction efficiency is explained by the larger sorting area of the Excluder relative to the grid's area, and by the differences in behaviour between Norway pout and the bycatch species. The square PVC kite mounted in the Excluder (Fig. 1) apparently trigger an avoidance behaviour on Norway pout making them swim through the square meshes of the Excluder inner selection section. This avoidance behaviour seems not to be as strong other species and are gently guided out of the Excluder.

As the results of this study show, the poor selectivity of the 40 mm sorting grid system leads to the landing of large amounts of mackerel (27.4 metric tons) and herring (34.2 metric tons) for reduction purposes and therefore to poor utilization of the quotas of these species. In this context, the use of the Excluder system can remove bycatch of these species during bottom trawling and allow these species to be fished for human consumption purposes (by pelagic trawling for instance), and thereby obtain a higher price per kilogram. In the case of the bycatch of white fish species (cod, haddock, whiting, European hake, and saithe), the grid system is probably efficient to release most legal-size fish, but it fails to remove the smallest individuals. Consequently, these fish, which have almost no market value, end up being used for reduction purposes together with Norway pout. This is a bad example of ecosystem-based management, and it has a negative impact on the stock biomass (Eigaard and Holst, 2004). In contrast, the Excluder is a better selection system because most likely it releases most juvenile fish unharmed, thus enhancing future recruitment. However, the Excluder technology may also lead to reduced catch of wanted bycatch species, such as horse mackerel and blue whiting, which would result in economic losses for the fishers if all of the catches are delivered for reduction purposes (meal and oil). Thus, the Excluder technology creates a dilemma for both fishers and the management system. From the management perspective, the Excluder technology contributes to the transition from a typical mixed fishery towards a single-species fishery. With this strategy, the bycatch sorted out by the Excluder can be caught within the specific traditional seasonal fisheries for Atlantic mackerel and North Sea herring for human consumption. Because the value per kilogram for these two species when caught for human consumption is much higher than that of fish caught for reduction purposes, single-species fisheries for the bycatch species may represent an adaptation that is more valuable to fishers than that of today's traditional sorting grid technology. However, this may not always be the case.

Considering that the average price of mixed catches delivered for reduction purposes (oil and meal) was 3 NOK/kg in September 2021 (Norges sildesalgslag, 2021a), the value of the catches (Table 2) was 789,621 NOK for the trawl with the grid and 370,335 NOK for the trawl with Excluder. Thus, the catch from the trawl with the grid gives a larger income (plus 419,286 NOK) than that of the trawl with the Excluder. During this sea trial, 25,706 kg of Atlantic mackerel and 30,790 kg of North Sea herring were sorted out by the Excluder technology. The fisher's first-hand prices for these species destined for human consumption were 13.00 NOK and 7.00 NOK per kilogram, respectively, in September 2021 (Norges sildesalgslag, 2021b), yielding a value of 549, 708 NOK. Added to the value of the rest of the catch delivered for reduction purposes (370,335 NOK), the total value of the catch would be 920,043NOK using the Excluder. Compared to the total value of the catch using the sorting grid when delivered for reduction purposes (789, 621 NOK), use of the Excluder would result in a 16.5% more income for this trip.

The Norwegian and EU fleets targeting Norway pout in the North Sea are subjected to different technical regulations to reduce bycatch. While the EU fleet uses sorting grids with 35 mm bar spacing, the Norwegian fleet uses grids with 40 mm bar spacing. The system in which a 40 mm sorting grid is mandatory for those Norwegian vessels without the capacity to process the bycatch of large white fish (e.g., saithe) leads to large amounts of white fish, including juveniles and other bycatch of pelagic species, being landed for reduction purposes. The 35 mm sorting grid required for the EU fleets may be better suited to reducing bycatch of white fish, but large amounts of bycatch still are landed for reduction purposes (ICES, 2016). Additionally, Norwegian vessels have different combinations of quota rights, thus keeping some of the bycatch species is a key strategy to increase profitability in the fishery. We do not know if there is a difference between catch rates of Norway pout for 35 mm and 40 mm sorting grid, but we would assume that the 35 mm would have higher probability of losing part of the target catch. Likewise, we expect that the bycatch reductions levels found in this study would be most likely less pronounced if a 35 mm would have been used instead the 40 mm grid.

In 2021, the fleet landed 71,954 tons out of the 255,319 tons of the advised TAC of Norway pout in the North Sea (ICES, 2022), leaving nearly 72% of the sustainable catch and potential revenue in the water. Similar to other mixed fisheries around the world (e.g., in the Gulf of Alaska and along the west coast of the US) (McQuaw and Hilborn, 2020), it is apparent that the low utilization of quota of Norway pout in the North Sea mixed fishery could be attributed to a combination of factors affecting the fishery. One of them is the large levels of bycatch of TAC regulated species choke species and market price limitations when landings are destined for reduction purposes rather than for human consumption.

## 5. Conclusion

The standard 40 mm grid system used in the Norwegian EEZ is not good enough to reduce the bycatch of mackerel, herring, and gadoid fish species. This study documents that its use in the fishery leads to the landing of large amounts of these species for reduction purposes. By assuming that the species and size distributions encountered during the experimental fishing are representative of the commercial fishery, a widespread replacement of the grid with the Excluder would not only lead to a substantial reduction in bycatches. However, while it contributes to reduce bycatch of quota regulated species, the Excluder also can potentially affect the profitability of the fishery. Unwanted bycatch species such as mackerel and herring could be targeted separately and landed for human consumption, while juveniles of gadoid species would be potentially released unharmed, thus enhancing future recruitment.

## CRediT authorship contribution statement

**Eduardo Grimaldo:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Funding acquisition, Formal analysis, Conceptualization. **Jesse Brinkhof:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Bent Herrmann:** Writing – review & editing, Methodology, Investigation, Formal analysis, Conceptualization. **Kristine Cerbule:** Data curation, Formal analysis, Visualization. **Leif Grimsmo:** Investigation, Methodology, Writing – original draft. **Hermann Pettersen:** Data curation, Investigation, Methodology.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

## Acknowledgments

We thank the crews of the trawler "Fiskebank" for their valuable help during the fishing trials. We also thank Terje Hemnes from Åkrehamn Trålbøteri AS and Arvid Sæstad and Livar Valdemarsen from Egersund Trawl AS for providing the grid section and the Excluder section that were tested in this experiment. This study was financed by the Norwegian Industrial Seafood Fund.

## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ecss.2022.108189.

## References

Bailey, R.S., Galbraith, D., Hutcheon, J.R., Walsh, M., 1983. Experimental Fishing for Norway Pout Using a Horizontally Divided Trawl. ICES CM 1983/G, p. 60.

Bigné, M., Nielsen, J.R., Bastardie, F., 2018. Opening of the Norway pout box: will it change the ecological impacts of the North Sea Norway pout fishery? ICES J. Mar. Sci. 76 (1), 136–152. https://doi.org/10.1093/icesjms/fsy121.

Burnham, K.P., Anderson, D.R., 2002. In: Model Selection and Multimodel Inference: A Practical Information-Theoretic Approach, second ed. Springer, New York. 2002.

Clarke, K.R., 1990. Comparisons of dominance curves. J. Exp. Mar. Biol. Ecol. 138, 143–157. https://doi.org/10.1016/0022-0981(90)90181-B.

Cormon, X., Ernande, B., Kempf, A., Vermard, Y., Marchal, P., 2016. North Sea saithe (*Pollachius virens*) growth in relation to food availability, density dependence and temperature. Mar. Ecol. Prog. Ser. 542, 141–151. https://doi.org/10.3354/meps11559.

Dickson, W., 1960. The problem of headline height. World Fish. 9 (9), 38–48.

Efron, B., 1982. The jackknife, the bootstrap and other resampling plans. In: SIAM Monograph No. 38, CBSM-NSF Regional Conference Series in Applied Mathematics. Stanford University, California, 1982.

Eigaard, O.R., Holst, R., 2004. The effective selectivity of a composite gear for industrial fishing: a sorting grid in combination with a square mesh window. Fish. Res. 68 (1–3), 99–112. https://doi.org/10.1016/j.fishres.2004.02.002.

Eigaard, O., Hermann, B., Nielsen, J.R., 2012. Influence of grid orientation and time of day in a small-meshed trawl fishery for Norway pout (*Trisopterus esmarkii*). Aquat. Living Resour. 25, 15–26. https://doi.org/10.1051/alr/2011152.

Eigaard, O.R., Herrmann, B., Feekings, J.P., Krag, L.A., Sparrevohn, C.R., 2021. A netting-based alternative to rigid sorting grids in the small-meshed Norway pout (Trisopterus esmarkii) trawl fishery. PLoS One 16 (1), e0246076. https://doi.org/10.1371/journal.pone.0246076.

Herrmann, B., Krag, L.A., Feekings, J., Noack, T., 2016. Understanding and predicting size selection in diamond-mesh cod ends for Danish seining: a study based on sea trials and computer simulations. Mar. Coast. Fish. 8 (1), 277–291. https://doi.org/10.1080/19425120.2016.1161682.

Herrmann, B., Sistiaga, M., Rindahl, L., Tatone, I., 2017. Estimation of the effect of gear design changes on catch efficiency: methodology and a case study for a Spanish longline fishery targeting hake (*Merluccius merluccius*). Fish. Res. 185, 153–160. https://doi.org/10.1016/j.fishres.2016.09.013.

ICES, 2016, 2016 Aug 23–25. Report of the Benchmark Workshop on Norway Pout (*Trisopterus Esmarkii*) in Subarea 4 and Division 3a (North Sea, Skagerrak, and Kattegat), vol. 35. ICES CM 2016/ACOM, Copenhagen, Denmark, p. 69.

ICES, 2021. Norway pout (*Trisopterus esmarkii*) in subarea 4 and division 3.a (North Sea, skagerrak, and kattegat). In: Report of the ICES Advisory Committee, 2021. ICES Advice 2021. https://doi.org/10.17895/ices.advice.7812 nop.27.3a4.

ICES, 2022. Norway pout (*Trisopterus esmarkii*) in subarea 4 and division 3.a (North Sea, skagerrak, and kattegat), 2022. In: Report of the ICES Advisory Committee. ICES Advice 2022. https://doi.org/10.17895/ices.advice.19772446. nop.27.3a4.

Lambert, G., Nielsen, J.R., Larsen, L., Sparholt, H., 2009. Maturity and growth population dynamics of Norway pout (*Trisopterus esmarkii*) in the North Sea, skagerrak and kattegat. ICES J. Mar. Sci. 66 (9), 1899–1914. https://doi.org/10.1093/icesjms/fsp153.

Larsen, R.B., Herrmann, B., Sistiaga, M., Brinkhof, J., Grimaldo, E., 2018. Bycatch reduction in the Norwegian Deep-water Shrimp (*Pandalus borealis*) fishery with a double grid selection system. Fish. Res. 208, 267–273. https://doi.org/10.1016/j.fishres.2018.08.007.

Lassen, H.J., Chaudhury, S., 2021. Norway Sandeel, Pout and North Sea Sprat Fisheries. DNV Business Assurance. Marine Stewardship Council fisheries assessments. 3rd Surveillance Report.

Lovdata, 2021. Technical regulations for the Norway pout fishery 2022 (In Norwegian: Forskrift om regulering av fisket etter øyepål i 2022). https://lovdata.no/dokument/LTI/forskrift/2021-12-13-3502.

McQuaw, K., Hilborn, R., 2020. Why are catches in mixed fisheries well below TAC?, 2020 Mar. Pol. 117, 103931. https://doi.org/10.1016/j.marpol.2020.103931. ISSN 0308-597X.

Nielsen, J.R., Olsen, J., Håkonsson, K.B., Egekvist, J., Dalskov, J., 2016. Danish Norway pout fishery in the North Sea and skagerrak. Working document, 23–25 August 2016. In: Report of the Benchmark Workshop on Norway Pout (*Trisopterus Esmarkii*) in Subarea 4 and Division 3a (North Sea, Skagerrak, and Kattegat), vol. 35. ICES Document CM 2016/ACOM, Copenhagen, Denmark, p. 69.

Norwegian Directorate of Fisheries, 2021. Regulation meeting - Norway pout fishery. Topic no. 24/2021. file:///C:/Users/egri/Downloads/SAK-24-2021-oyepaal%20(1).pdf (In Norwegian).

Raitt, D.F.S., 1968. The population dynamics of Norway pout in the North Sea. Marine Research 5, 1–23.

sildesalgslag, Norges, 2021a. Prices for human consumption. https://www.sildelaget.no/no/kvoter-og-fangst/statistikk/omsetning/?SelectedReport=TurnoverSoFar&SelectedExtraction=Consumption.

sildesalgslag, Norges, 2021b. Prices for oil and meal. https://www.sildelaget.no/en/catches-and-quotas/statistics/turnover/?SelectedReport=TurnoverSoFar&SelectedExtraction=MealAndOil.

Sparholt, H., Larsen, L.I., Nielsen, J.R., 2002. Non-predation natural mortality of Norway pout (*Trisopterus esmarkii*) in the North Sea. ICES J. Mar. Sci. 59, 1276–1284. https://doi.org/10.1006/jmsc.2002.1305.

Warwick, R.M., Clarke, K.R., Somerfield, P.J., 2008. k-Dominance Curve. In: Jørgensen, S.E., Fath, B.D. (Eds.), Encyclopedia of Ecology. Academic Press, Oxford, pp. 2055–2057.

Wileman, D.A., Main, J., 1994. Attempts to Develop a Species Selective Trawl for Fishing Pout. ICES CM 1994/B, p. 94.

Wileman, D.A., Ferro, R.S.T., Fonteyne, R., Millar, R.B., 1996. Manual of Methods of Measuring the Selectivity of Towed Fishing Gears. ICES Coop. Res. Rep.. No. 215.