Much ado about nothing: An example of how failed incentives thwarted the implementation of the EU landing obligation

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A B S T R A C T

With the introduction of the landing obligation in the EU common fisheries policy, there has been several initiatives to reduce unwanted catches of quota-regulated species. In this study, we present a flexible sorting grid as a potential solution for the problem of bycatch of saithe in the pelagic herring trawl fishery in the Skagerrak. The development of the grid was initiated by the industry and finalised through an industry-science collaboration project. The selectivity of the grid was evaluated through the use of an underwater camera system during conventional trawling with an industrial pelagic herring trawler. The results showed that the grid reduced the bycatch by more than 90%, from approximately 5% to 0.5% of the total catch. Given the scale of the pelagic fishery, this reduction could decrease unwanted bycatch of saithe by up to 1000 tonnes per year in the Skagerrak alone. These results were communicated to national industry and management representatives and to responsible EU management bodies and advisory councils. The work conducted within the project also drew interest at the yearly negotiations between EU and Norway. In their agreement for 2018, the EU and Norway agreed to establish a working group on technical measures in the Skagerrak tasked with reviewing selectivity of pelagic trawls as part of the terms of reference. However, in the agreed record of the delegations, the question of pelagic gear selectivity in the Skagerrak was a non-issue, although they concluded that the demersal bycatch can be substantial, that a sorting grid can reduce this bycatch and a sorting grid remains mandatory for Norwegian vessels in the Skagerrak. We argue that this result can be seen as a missed opportunity for the EU to reduce unaccounted bycatch in the Skagerrak and ensure better implementation of the landing obligation.

1. Introduction

With the latest revision, EU-legislators introduced some new management measures to deal with failures identified in previous versions of the EU common fisheries policy (CFP- Regulation (EU) No. 1380/2013). One of these measures was an obligation to land all catches of quota-regulated species (hereinafter the landing obligation; LO). This shift means that once the quota for a species is exhausted, catches must cease and cannot be discarded as before. These regulation-driven discards have been one of the identified causes for the historical failure of the CFP [1,2]. The landing obligation also stipulates that catches smaller than the minimum conservation reference size (MCRS) must be landed, but such under-sized catches may only be sold for uses other than direct human consumption. The landing obligation is hence designed to differentiate the market value of catches of large and small fish and consequently to create an economic incentive to avoid unwanted catches for fishers, i.e. a move towards a more results-based

management policy. One of the stated objectives was that the landing obligation would lead to a reduction in the total removals of exploited stocks through reduced unwanted catches. To achieve this, the fishing industry is expected to adapt by voluntarily adopting more selective fishing practices, such as more selective gears and tactical behaviour change [3]. The European LO was first introduced for all quota species caught in pelagic fisheries and for Baltic cod and salmon fisheries in 2015, with a subsequent yearly step-wise inclusion of species and fisheries starting in 2016. Since 1 January 2019, the LO has supposedly been fully implemented in all European fisheries [4].

Within several European countries, the LO introduction spawned initiatives to increase the involvement of the fishing industry in the identification, development and testing of selective gears in order to increase industry buy-in and to create a functional and documented toolbox for avoiding unwanted catches [5]. The Swedish government introduced such a scheme in 2014, the "Selective Fisheries Secretariat", managed by the Swedish University of Agricultural Sciences (SLU),

whereby the industry was tasked with identifying upcoming challenges presented by the implementation of the LO and proposing ideas for gear modifications for further development and scientific testing (see Nilsson et al. [6] for an overview of initiatives). One of the first challenges identified by the Swedish fishing industry was the bycatch of saithe (*Pollachius virens*) in pelagic trawls targeting herring in the Skagerrak.

Herring destined for the market for human consumption is mainly targeted in the Skagerrak on the slopes of the Norwegian trench from August through October. It is fished with pelagic pair or single trawls close to the surface in the night time hours, when the herring are feeding in the upper pelagic zone, or with semi-pelagic single trawls operating at greater depths during daytime hours, when the herring congregate closer to the bottom. According to self-reported (logbook) data for the years 2015–2017, eight to eleven Swedish vessels participated annually in this fishery and together conducted an average of 103 fishing trips during peak season (August to October). Average total landings amounted to 7241 tonnes of which herring constituted 7132 tonnes. Reported bycatch of saithe averaged around 3 tonnes per year thus constituting 0.04% of total landings. Total yearly herring catches for all nations fleets in the Skagerrak during 2015–2017 were around 20 thousand tonnes [7]. The annual review of catch and observer coverage data (INTERCATCH) in the ICES assessment working groups show that a few tonnes of saithe bycatch per year was reported to ICES for the same time period. The Swedish scientific onboard observer programme, in accordance with the EU data collection framework (DCF), does not cover pelagic fisheries which means that prior to this study there was limited knowledge of bycatches in this fishery.

Despite the minor bycatches of larger fish species recorded in the official data sources from the pelagic herring fishery in the Skagerrak, some of the participating vessels motivated the need to reduce bycatches because saithe intermixture could be substantial in certain years. Information was also available from Norway where pelagic trawling for herring was banned in the Skagerrak 2008 due to intermixture of undersized herring and bycatches of other species, in particular saithe. In spite of these indications, no attempts to assess the bycatch issues were done in the EU countries participating in the fishery. Since pelagic vessels in Sweden have been operating under ITQs since 2009, and saithe bycatches were historically unrecorded, the pelagic vessels had no track record and thus no access to the saithe quota. In addition, the demersal fleet, for which saithe is an important commercial species, had little interest in allocating part of the limited Swedish quota to such bycatches in the pelagic fleet. The pelagic fleet therefore perceived that the saithe bycatch issue as an obvious challenge for the highly valuable herring fishery once the LO for the pelagic fishery was introduced in 2015, due to the risk that these bycatches would prematurely close the herring fishery in the Skagerrak.

According to the producer organisation that organises the participating vessels (Swedish Pelagic Federation Producer Organization; SPFPO), bycatches of saithe occur primarily in the semi-pelagic fishing operations during the daytime hours. To solve this problem, the SPFPO suggested a project under the Selective Fisheries Secretariat initiative to develop a size-selective sorting grid for large semi-pelagic herring trawls. Sorting grids for separation of wanted catch from unwanted catch have been successfully introduced in several demersal fisheries [8]. However, with the exception of the fisheries within the Norwegian [9] and Faroese waters [10], few attempts have been made to implement this technology in pelagic trawls. The large size of the pelagic trawls makes it more difficult to find suitable materials and designs that can withstand the forces encountered during operation and handling of the large pelagic or semi-pelagic trawls. A previous attempt to test a steel grid design used in the Norwegian fisheries on a Swedish pelagic herring trawler failed as the grid could not be retrieved on the net-drum of the vessel without breaking (Anders Gustavsson, personal comment). Rather than using a steel grid, this project aimed to develop a sorting grid made with a flexible, yet rigid material, which could be fully compressed when retrieved on the net-drum and then expand to its designed shape when

operating in the water.

The purpose of this paper is to describe the sorting grid development process, provide results from the scientific evaluation of the grid's selectivity and describe and discuss how the findings from this project were received and handled by the industry and managers.

2. Materials and methods

To ensure that the industry was satisfied with the design and performance of the grid, the development project was divided into two parts. The finalisation of the grid's design and all fishing operations were the responsibility of the crew on an industrial pelagic trawler contracted by the SPFPO "GG 330 Carmona af Dyrön" (LOA 50 m, Engine 2000 kW, gross weight 1023 tonnes). Once the crew was satisfied with the performance of the grid, an evaluation of the grid's selectivity was performed by scientific personnel from SLU. The first set of sea trials consisted of 15 hauls and was conducted from 10 August through 4 October 2015. Video recordings with an underwater camera system (Trawl Camera, JT electric Ltd., Faroe Islands) were used both during the hauls that were dedicated to gear performance tests (i.e. the camera was moved to different locations between hauls to get an overview of different parts of the grid and the trawl) and during hauls when video was also collected for evaluation of selectivity (i.e. camera was fixed in one location viewing the exit hole). Evaluation of the performance of the grid during these 15 hauls suggested that additional modification of the size and flexibility of the grid could improve selectivity. As a result, a second set of sea trials were conducted in September of 2016, consisting of 8 hauls with a modified grid setup. All hauls during the sea trials (except haul no. 3 in 2015) were executed at typical commercial herring fishing grounds in the Skagerrak (ICES subdivision 20) at depths ranging from 114 to 180 m (Fig. 1). Hauls were conducted both during the day and night. To match the conditions where bycatch occurred according to those in the industry only the hauls conducted during daytime hours at greater depths were used for the evaluation of selectivity. Personnel from SLU were onboard as observers during all hauls except the final
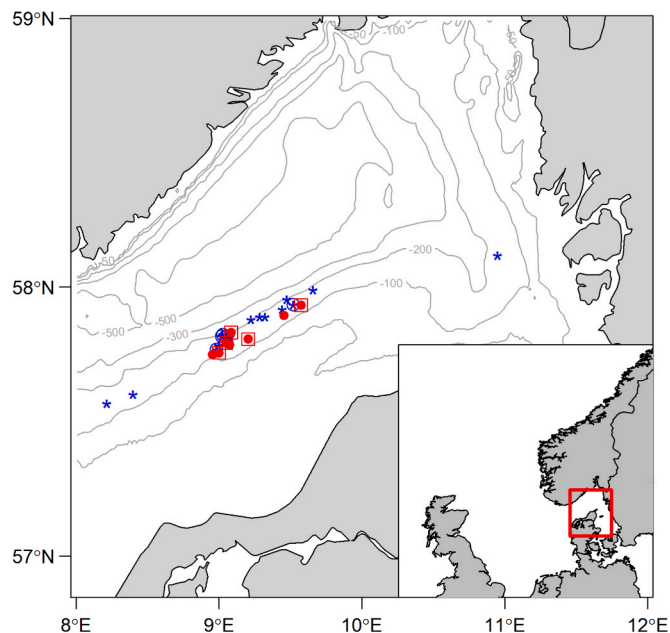

Fig. 1. Map showing the positions of the fishing locations of the sea trials in 2015 (blue stars) and 2016 (red dots). Encircled locations represent hauls used for evaluation of selectivity. The single blue star farthest to the east represents haul no. 3 in 2015, which was a short performance test haul conducted with cameras on top of grid and open codend. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

haul in 2015.

3. Sorting grid design and gear

The objective of the sorting grid was to separate larger specimens from smaller specimens and release the larger specimens from the trawl through an exit hole, while the smaller specimens would pass through the sorting grid and be retained in the codend. The grid used in this study was designed by SPFPO and the fishing gear manufacturer COSMOS TRAWL A/S, Skagen, Denmark, and was manufactured by RG ROM Gummi in Lemvig, Denmark. It was based on a grid design used previously in the Faroese blue whiting fisheries [11] and was constructed of polyurethane moulded into rectangular sections, consisting of cross-sectional circular bars in the outer frame and cross-sectional droplet shaped bars in the inner ribs. Polyurethane was chosen for its durability and elastic properties. In order to function under normal fishing operations, SPFPO required that the grid be flexible enough to be rolled up on the net drum without any additional working load. The cross-sectional droplet shape of the inner bars was intended to reduce the drag and turbulence behind the grid by mounting the wider end towards the mouth of the trawl, against the water flow, and the thinner end towards the codend, with the water flow. Each of these grid sections measured 100 cm in length and 60 cm in height, with a bar spacing of 55 mm and a height of 189 mm. To create the full size of the grid, the sections were initially put together using plastic cable ties, which broke on the first haul and were then replaced with Dyneema® twine. The grid was mounted in a section of trawl net (mesh 32 mm, length approximately 6 m) positioned at a 65–70 degree angle such that the top of the grid was closer to the mouth of the trawl (Fig. 2). At the bottom of the grid, an opening in the trawl net formed an exit hole. The downward angle of the grid was intended to guide the fish that were not able to pass through the grid towards the exit hole. To maintain the symmetry of the trawl under operation, Dyneema® ropes were attached from the bottom of the grid, crossing the exit hole, to reinforcement netting in the bottom of the trawl section. No guiding funnel was used. The grid section was inserted in the junction for shifting to different codends in the non-tapered section approximately 80 m in front of the codend of a semi-pelagic herring trawl (Gloria helix 1088, 32 mm codend mesh). When fully opened, the trawl mouth measured 90 m in width and 36 m in height. Trawling was conducted as under normal commercial practice
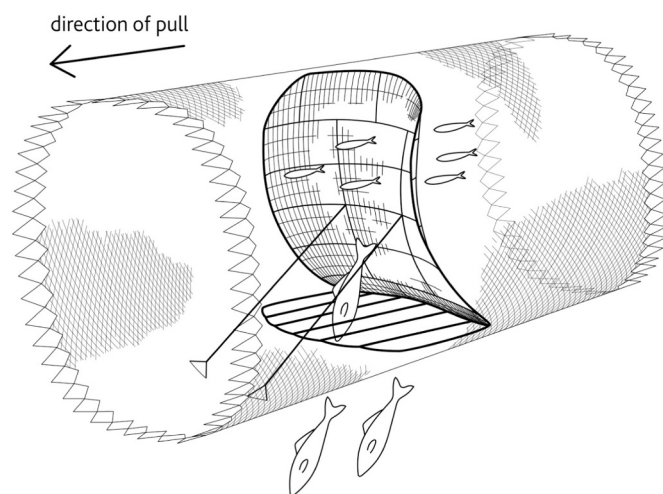

Fig. 2. Sketch of the trawl section with the final design of the grid and exit hole. In order to avoid large fish stacking up or being forced through the grid, the lower part of the grid was released backwards creating an arched semi-cylindrical structure.

at a speed over the ground of 3–4 knots.

3.1. Grid modifications during sea trials

The initial setup of the grid consisted of 24 sections, resulting in a total grid area of 300 cm in length and 480 cm in height. The opening for the exit hole equalled the full length of the grid's bottom (300 cm) and was designed to open about 30 cm at its widest point. In order to maintain the symmetry of the trawl tunnel, one single Dyneema® rope was mounted in the centre crossing the exit hole. This initial setup was only used during the first 3 hauls, since after review of the video recordings, it was evident that due to the material's flexibility and the pressure from the water flowing over the grid the net section collapsed to some extent and forced the grid into a bulging concave shape. Due to this deformation of the grid and the net section, the exit hole was also much wider (> 2 m) than the designers had anticipated (Fig. 3). To resolve this problem, a kite (10 m^2) was mounted on the outside of the net section (similar to the solution described by Van Rijn et al. [12]) and the size of the grid area was reduced to 300 cm in width and 360 cm in height. Supporting ropes were attached from the centre of the grid to the bottom of the net section in front of the grid and four additional reinforcement ropes were attached across the exit hole. Although this modification would likely make the exit hole smaller, the crew of the vessel also wanted to add "curtains" of loose netting over the exit hole to prevent catch losses of target species (Fig. 3). Haul 4–6 showed that the kite and the additional reinforcements reduced the collapsing effect but did not fully resolve the issue with the concave shape of the grid. A review of the recorded video also showed that the curtains covering the exit hole substantially reduced the escape of bycatch as large fish were no longer escaping though the exit hole and were instead forcing their way through the grid head first or stacking up on the grid, thereby increasing the concave shape even further (Fig. 3). The amount of this unintended bycatch was only recorded on camera as the grid was partially cleaned during haul-back. For the remaining hauls during the first set of sea trials, the curtains were removed, only minor modifications to the length of the reinforcement ropes crossing the exit hole were made and the camera was placed at the bottom of the grid to record video that could be used to estimate escape of both bycatch and the target species. During the second set of sea trials the following year, the polyurethane mixture in the grid-sections had been modified to create a stiffer material (less flexible, shore 98 A hardness). The reinforcement ropes crossing the exit hole were elongated and additional net was added to the bottom of the net section in front of the exit hole, thus reducing the pulling force from the reinforcement ropes and allowing the bottom of the grid to fall backwards from the pressure of the flowing water. Video observations showed that these additional modifications reduced the concave shape of the grid to a more semi-cylindrical structure (Fig. 2). Large predatory fish that did not pass through the grid were no longer stacking up on the grid (or being forced through the grid) but were instead guided towards the exit hole (which at this point had an approximate depth of 1.4 m at its widest point) and were able to escape from the trawl. After these final modifications, the crew of the vessel was satisfied with the grid's performance and the camera was again placed at the bottom of the grid to collect video that could be used to estimate escape of bycatch and the target species.

3.2. Biological data collection

The catch from the trawl was pumped on-board the vessel through a hose inserted in the codend according to the vessel's normal method of emptying the codend. Once onboard the vessel, the catch was flushed over a metal sorting grid that separated large individuals (minimum length of about 30 cm) from smaller individuals. For the purpose of this study, all catch separated out by the sorting grid was considered bycatch and all catch that went through to the holding tanks was considered wanted catch (and was subsequently landed). The total weight of the
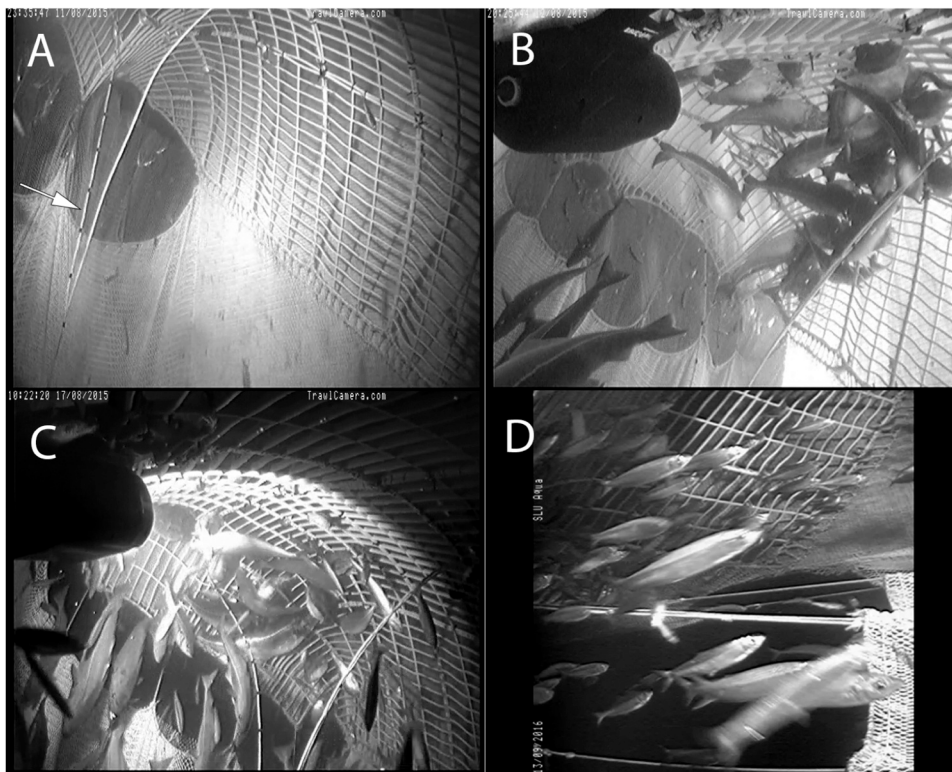
Fig. 3. Selected video screenshots. Picture A shows the concave geometry of the grid and the large exit hole during the initial setup in 2015 before the kite and reinforcement ropes were added. Picture B shows the curtains of loose netting covering the exit hole during haul 4 and 5 in 2015 and the resulting accumulation of saithe on the grid. Picture C shows the final setup of the grid and exit hole used during the last 10 hauls in 2015. Picture D shows the new geometry of the bottom of the grid after the 2016 modifications and represents the camera view used during escapee estimates. The rope with black markers seen in pictures A, B, and C (marked with an arrow in picture A) is a size reference that was used in 2015 (there is 20 cm between each marker).

wanted catch (by volume measurement of the holding tanks), mean weight of herring (by counting the number of individuals in a 10 kg subsample) and total weight of bycatch (by measurement on a scale) were recorded for all hauls. From the hauls used to estimate the number of escapees, a minimum of 20 individuals of each species of the bycatch was measured for length to the nearest cm.

3.3. Manual video analysis and escapee estimates

During the hauls used to estimate escapee numbers, the camera was placed at the bottom of the grid in a horizontal position facing sideways (Fig. 3). The recorded video was reviewed in VLC media player (https ://www.videolan.org) with a high-resolution monitor. Each session started with a review of the video at high speed from the moment recording commenced until the first fish started to appear in the view of the camera. The moment the first fish were visible was set to T_0 and was used as the starting point for analysis. From T_0, a detailed, slow-motion review of the video was performed in sequences, which was evenly distributed throughout the haul, with 20 min intervals in 2015 and 10 min intervals in 2016, until the trawl started collapsing at haul back (T_1). The sequences for review were set to 20 s for hauls conducted in 2015 and 40 s for hauls conducted in 2016. During each reviewed sequence, the number of herring (and all similar sized species) escapees (E) and bycatch of large fish were estimated by counting all individuals escaping trough the exit hole between the camera and the centre reinforcement rope (i.e. ½ the area of the exit hole). Sequences with large numbers of herring escapees (> 50) were counted 3 times, and the maximum number was used. The total number of escapees per trawling hour and haul (N_E) was calculated by raising the number of escapees counted to the total exit hole area and multiplying by 60 such that $N_E = (E/t) * 2 * 60$ where t was the total number of minutes of reviewed video. From N_E, the total weight (W) of escapees per haul was calculated by using the mean individual weight (W_m) that was retrieved in the

catch subsample such that $W = N_E * W_m * T$, where T was the total trawling effort in hours with an active selection process at the exit hole ($T_1–T_0$). For the calculation of the total weight of bycatch of saithe, cod, whiting and haddock during 2016, (when no or little bycatch were caught in the codend), mean individual weights from hauls in 2015 were used. During the third and final two hauls conducted in 2016, the camera position shifted unintentionally such that only the front end of the exit hole was visible, therefore, sequences from these hauls were not used to estimate escapees of the landed catch only for estimate escapees of bycatch that were large enough that they did not pass through the grid (saithe and cod with an estimated minimum length of 60 cm).

4. Results

In the first set of sea trials, a total of 673 tonnes of catch was sorted into wanted catch and 3.73 tonnes into bycatch (Table 1). The landed catch consisted of approximately 98% herring (*Clupea harengus*), 1.5% blue whiting (*Micromesistius poutassou*) and 0.5% horse mackerel (*Trachurus trachurus*). The bycatch consisted of 99% saithe (*Pollachius virens*) and 1% cod (*Gadus morhua*). Length measurements collected from the fish caught in the codend showed that the size range of the saithe passing through the grid was 43–102 cm. However, visual observations of saithe in the trawl, positioned next to the length reference line, indicated that the maximum length of saithe entering the trawl was > 110 cm (Fig. 4). The manual video analyses and escapee estimates revealed that 2–13% of the target species (and similar sized species) and 93–96% of the bycatch entering the trawl escaped through the exit hole (Table 2). Based on these estimates, the grid reduced the bycatch proportion from 7.9% to 0.5% of the total catch during the 5 hauls that were used for the manual video analysis.

In the second set of sea trials, a total of 241 tonnes of catch was sorted into wanted catch and 0.129 tonnes into bycatch (Table 1). The landed catch consisted of approximately 98% herring (*Clupea harengus*), 0.6%

Table 1

Presentation of all hauls conducted during the sea trials. Catch and bycatch is given in tonnes, duration represents the total time in hours and minutes that the crew of the vessel determined the trawl to be fully open.

Year	Haul	Start time	Duration	Catch	Bycatch	Note
2015	1	17:10	01:58	17	0.45	Camera in middle of grid, grid broke
2015	2	20:45	05:00	50	0.03	Camera in middle of grid
2015	3	22:50	00:55	0	0	Open codend, camera at top of grid
2015	4	08:20	04:10	25	0.23	Camera used at top of grid, "curtains"
2015	5	14:50	05:23	45	0.65	Camera light not working, "curtains"
2015	6	08:25	04:25	45	0.30	Camera used in middle of grid
2015	7	15:15	04:50	65	0.37	Evaluation of all escapees
2015	8	22:40	03:30	60	0.25	Camera not used
2015	9	17:17	02:38	65	0.18	Camera used in middle of grid
2015	10	23:40	04:30	35	0.25	Camera not covering exit hole
2015	11	08:20	04:20	70	0.24	Evaluation of all escapees
2015	12	15:40	04:17	36	0.22	Evaluation of all escapees
2015	13	09:00	04:30	40	0.20	Evaluation of all escapees
2015	14	14:30	06:55	30	0.16	Evaluation of all escapees
2015	15	08:30	04:30	90	0.20	No observers onboard
2016	1	21:00	03:20	35	0	Camera not covering exit hole
2016	2	10:30	03:30	5	0.002	Camera not covering exit hole
2016	3	16:35	02:55	5	0	Evaluation of bycatch escapees
2016	4	10:10	02:45	10	0.002	Evaluation of all escapees
2016	5	18:05	03:05	50	0.025	Evaluation of all escapees
2016	6	22:40	05:40	30	0	Camera not working
2016	7	10:10	03:15	90	0.01	Evaluation of bycatch escapees
2016	8	16:15	01:30	16	0.003	Evaluation of bycatch escapees

Fig. 4. Screenshot of saithe with a length estimated to be > 110 cm next to the length reference used during the sea trials 2015. To illustrate how measurements were collected, a measurement of 40 cm is shown in this picture.

shooting or retrieving the trawl.

5. Discussion

This project has shown that a flexible sorting grid can be used in large pelagic herring trawls to reduce the bycatch of large fish in this fishery by more than 90%. In the aspect of being an industry-science collaboration project, where the fishery took the initiative to solve an expected problem under the LO with the help of scientists, the development of the pelagic sorting grid was largely a success. By giving the crew of the contracted vessel full responsibility for alteration of the grid design and trawl modifications, they independently determined whether the gear performed well during shooting, operation and retrieval. This resulted in a high level of industry involvement and a product that the fisherman themselves regarded as optimised for their fishery. Involving fishers in all aspects of the work have also been shown as a key factor for the adoption of new methods in the fishing industry [13].

The use of the underwater camera system made it possible to conduct a scientific evaluation of the grid's selectivity under conventional commercial fishing conditions, without using the paired gear method or a grid cover to collect escapees, i.e. the standard methods most often chosen to study gear selectivity. In addition, the review of video during the sea trials facilitated communication between the fishermen and scientists by providing visual observations rather than statistics and numbers and also made it possible to quickly assess the effect of different alterations to the grid and gear. Manual video analysis of recordings from underwater camera systems is not a standard method for generating loss of catch estimates and bycatch in trawl selectivity experiments. This may be partly due to the fact that, to date, the equipment has been expensive and inaccessible. The method may also have limited use in demersal fisheries, which are often limited by poor visibility when trawling on the bottom (personal observation). Compared to conventional methods using catch-comparison or cover design methods [14], video recording also provided less data on escapees. Since the fish that escaped from the gear were released back into the water alive, it was not possible to determine the exact length (methods using stereo cameras could potentially solve this issue), number or weight of escapees. Therefore, this study used the mean weight of the fish that passed through the grid for to estimate the total weight of escapees. The flexibility of the polyurethane mixture used in 2015 allowed the bars in the

mackerel (*Scomber scombrus*), 0.5% haddock (*Melanogrammus aeglefinus*), 0.5% horse mackerel (*Trachurus trachurus*), 0.2% blue whiting (*Micromesistius poutassou*) and 0.2% Norway pout (*Trisopterus esmarkii*). The bycatch consisted of 74% haddock (*Melanogrammus aeglefinus*), 24% whiting (*Merlangius merlangus*), 1% cod (*Gadus morhua*) and 1% mackerel (*Scomber scombrus*). Length measurements collected from the fish caught in the codend showed that the size range of the fish passing through the grid was 31–53 cm. The manual video analyses and escapee estimates revealed that 4–8% of the target species (and similar sized species) and 89–100% of the bycatch entering the trawl escaped through the exit hole (Table 2). Based on these estimates, the grid reduced the bycatch proportion from 1.4% to 0.1% of the total catch during the 5 hauls that were used for the manual video analysis.

With regard to gear performance and handling during operation, the polyurethane used proved to be a durable material; the panels in the grid were able to be fully compressed when retrieved on the net drum and then expanded to the designed shape during shooting. The fishermen considered the additional work needed in connection to the use of the grid to be minimal, and the grid never interrupted the process of

Table 2

Data collected during the manual video analyses and the factors used to estimate the total weight of escapees. T is the total time in hours with an active selection process at the exit hole, N_E is the raised number of counted escapees per hour and W_m is the mean weight in kg used for calculation of total weight in tonnes (W) per haul (* represents estimated mean weights). Loss of target species is the proportion of the potential catch of the target species (including other species of similar size) that are estimated to have escaped through the exit hole. Bycatch proportion is the proportion of large fish that entered the trawl relative to the total catch of the target species (including estimated lost catch). Bycatch CPUE (Catch Per Unit Effort) is the total amount (actual and estimated) of large fish entering the trawl in kg per hour. Loss of bycatch is the proportion of large fish estimated to have escaped through the exit hole.

Year	Haul	T	N_E target species	W_m target species	W target species	Loss of target species	N_E bycatch	W_m bycatch	W bycatch	Bycatch proportion	Bycatch CPUE	Loss of bycatch
2015	7	4:57	2570	0.122	1.74	3%	390	3.95	7.32	9%	1618	95%
2015	12	4:15	6720	0.127	3.68	5%	240	3.57	3.71	5%	912	94%
2015	13	4:06	10,380	0.127	5.39	13%	210	3.24	2.79	7%	734	93%
2015	14	4:31	5266	0.125	2.96	7%	166	3.41	2.55	6%	611	93%
2015	15	6:00	3604	0.133	2.88	9%	191	3.41	3.90	11%	676	96%
2016	3	2:41	N/A	N/A	N/A	N/A	8	3.50*	0.07	N/A	26	100%
2016	4	2:43	2817	0.117	0.89	8%	11	3.50*	0.10	1%	38	98%
2016	5	3:06	8439	0.089	2.27	4%	284	1.20*	1.03	2%	349	98%
2016	7	3:16	N/A	N/A	N/A	N/A	86	3.00*	0.84	N/A	287	89%
2016	8	1:42	N/A	N/A	N/A	N/A	63	3.00*	0.32	N/A	191	99%

grid to expand so that fish up to 102 cm could pass through if they hit the grid head first; this problem was reduced during 2016 when the grid was constructed with a harder polyurethane mixture. However, the assumption that the mean weight of the bycatch passing through the grid is equal to the mean weight of the bycatch escaping the gear is likely inaccurate. Smaller individuals are likely to pass through the grid to a higher degree than larger individuals. The results from the video review also support this by showing that the maximum length of the fish present in the gear was > 110 cm. Presumed underestimates of the mean weight of escaped bycatch means that the estimate of the total weight of escaped bycatch, and thereby the calculated proportion and CPUE of bycatch, is likely conservative and that we have likely underestimated the bycatch reduction effectiveness of the grid.

Considering the above uncertainties in the use of the video analysis method and the assumption in this case that the number of escapees was evenly distributed on both sides of the centre reinforcement rope of the exit hole (an assumption that had to be made due to the limitations of the camera and the large size of the grid and exit hole), the consistency of the escapee estimates shows that the method used was adequately robust for the purpose of this study. The variation between the estimated number of escapees for different hauls, in particular the "low" proportion of escaped bycatch in haul 7 of 2016, can be explained by a variation in the composition of the catch rather than bias in the method. During haul 7 of 2016, the catch consisted of comparatively large quantities of smaller sized haddock, i.e. individuals that could pass through the grid in the trawl but were too big to pass through the metal sorting grid on the boat, thereby contributing to an overall reduction in the loss of bycatch proportion.

Apart from showing that the pelagic sorting grid can significantly reduce the bycatch, the results presented here also highlight the potential scale of the saithe bycatch problem in the pelagic herring fishery in the Skagerrak. During the 2015 sea trials, the proportion of saithe entering the trawl of the total catch was between 5% and 11%, which corresponded to a CPUE of 600–1600 kg per trawling hour. Although this CPUE is calculated for hauls during daytime operation at greater depths and may not be representative of all fishing operations, the bycatch in just the 5 hauls used for selectivity estimates amounted to more than 4 times the total logbook recordings of saithe bycatch from all Swedish pelagic vessels participating in this fishery this year. During the 2016 sea trials, which were conducted in the same area and at the same time period as the previous year, the amount of saithe observed in the catch and on the recorded video was almost zero. There are different mechanisms to explain the migration of adult saithe [15], some years their presence in the Skagerrak will not coincide with the pelagic herring fishery, however, when it does coincide, it is evident that bycatches can be substantial and that they have historically been, and still are, under-reported.

The results of the industry-initiated collaborative scientific work presented here was communicated to Swedish industry and management representatives after each of the trials and was subsequently summarised in a Swedish popular science report [16] and as an English summary, including illustrative fact sheets [6]. The study was also presented to the responsible regional EU management body (Scheveningen group) and advisory councils (Pelagic Advisory Council and the Mid Atlantic Fishery Management Council) during 2016–2018. This work also drew interest in the annual negotiations between EU and Norway. In their agreement for 2018, the parties agreed to establish a working group on technical measures in the Skagerrak which among its tasks had one about reviewing selectivity of pelagic trawls as one of the terms of reference [17].

The EU/Norway working group on technical measures met three times during the first half of 2018 and reported back to the heads of the two delegations (EU and Norway) on 31 August 2018 [18]. The report contained a summary of the work presented here (as annex III) along with experiences from other countries. Among these, Norway informed that as a follow-up of their ban of pelagic trawling for herring in the Skagerrak since 2008, they had performed a trial fishery during 2016–2017 with and without a 55 mm sorting grid. They reported that saithe bycatch was 0.4% with a grid installed and 5% without a sorting grid (see also pp. 80–82 in Anon [19]), which indicates that bycatch levels of saithe and the sorting efficiency of a grid were similar to the findings in our study. Based on these results, Norway decided to reopen the herring trawl fishery for vessels using a grid as of 1 January 2018. The annexes to the working group report also contained comments from fishery organisations from the three countries concerned (Sweden, Norway and Denmark). Industry comments relating to pelagic trawl selectivity in the Skagerrak were limited.

One week later, in the agreed record of the delegations [20] and based on the working group report [18], the question of pelagic gear selectivity in the Skagerrak was summarised with "bycatch of saithe in the herring fishery in Skagerrak has previously been problematic", "sorting grids in pelagic trawls significantly reduce the bycatch of saithe" and "the Norwegian delegation informed that a sorting grid remains mandatory for Norwegian vessels in Skagerrak" [20]. Notably, there was no agreement or demands directed towards the EU in the agreed record regarding bycatches or selectivity for their pelagic trawlers in the Skagerrak in spite of the new information provided from this study or the obligation to use grids by Norwegian vessels.

The events above can be seen as a missed opportunity for the EU to reduce unaccounted bycatches and secure better implementation of the landing obligation. The landings of herring in the Skagerrak have declined gradually due to reduced quotas from 30,000 tonnes in 2009 to 16,000 tonnes in 2018 [7], of which the fishery for consumption takes the vast majority (average = 89% for 2009–2018) according to ICES

estimates [21]. If a mid-range estimate at a 5% saithe bycatch rate, based on current numbers and the Norwegian trial [19], is assumed to be representative, this would indicate annual unreported saithe catches in the range of 800–1500 tonnes in the Skagerrak alone over the last decade. This number is relatively small when compared to the total saithe catches in the North Sea and Skagerrak (87.7 kilotonnes in 2018; [22]). However, considering that ICES noted that the 7.6 kilotonnes of estimated discards in 2018 (without the bycatches we discuss here) were "substantial", that saithe has been subject to the landing obligation since 2018 and the fishing mortality for saithe in pelagic trawls is undocumented, this number may well be significant and can certainly be considered unmanaged. It is also important to consider that this fishery and similar pelagic fisheries also extend into the greater North Sea region with potentially similar implications on bycatch mortality, compliance issues with the landing obligation, and most importantly, on the possibilities of catch limits to really control fishing mortality. Although this is potentially most important for saithe, this line of reasoning also applies to other often unreported or underreported yet regular bycatch species in pelagic trawls, such as haddock, whiting, cod, horse mackerel, and blue whiting as well as bluefin tuna, which has been regularly caught in low numbers in this fishery during autumn in recent years.

We believe that the initiative for the trials presented here emanated from a genuine concern among some industry representatives that the upcoming landing obligation could result in the risk that bycatches would choke up and thus prematurely close the herring fishery in the Skagerrak. However, due to the soft LO implementation and lack of management measures in response to identified issues, we noted a gradual trend of decreased interest from the industry during the project and afterwards. The grid developed within this project is now manufactured and sold as a bycatch reduction solution by COSMOS TRAWL, however the buyers of this product are mainly vessels outside the EU (Fredrik Gustavsson, personal comment). A similar drop in momentum for industry initiatives relating to new gear solutions to adapt to the landing obligation was also seen across most Swedish fisheries, where the number of industry proposals submitted to the Selective Fisheries Secretariat for novel selective gears dropped from 22 in 2015 to 7 in 2017 [16] and to 3 in 2018 (Nilsson, personal comment). Such a drop in momentum has also been noted in other similar initiatives and has been explained by the relaxed implementation and uncertainty surrounding the application of the landing obligation [5]. Furthermore, Nilsson et al. [6] highlighted that although many of the gear initiatives developed by the industry under the Swedish initiative actually were shown to be efficient in reducing unwanted catches and would help the industry to avoid choke situations under the LO, the voluntary uptake of these gears had been minimal. They concluded that legislation or stronger incentives (than the LO itself) are needed in order to increase uptake of such gears [6]. Thus, the elegant thought that the EU landing obligation would coax fisheries towards increased selectivity and better catch documentation certainly reads well but has clearly not worked. We see two compatible ways to move forward and avoid the implementation failure. These are stricter gear regulations to improve selectivity in key fisheries (an opportunity that was missed in the case presented here) and an increase in the degree of effective control of the landing obligation [23,24]. If the incentive and management structure is not shifted to move in this direction, we run the risk of seeing more much ado about nothing such as the case presented here, where costly projects and strong industry and science engagement simply fizzle out into oblivion.

CRediT authorship contribution statement

Mikael Ovegård: Methodology, Formal analysis, Investigation, Data curation, Writing - original draft. **Andreas Sundelöf**: Conceptualization, Methodology, Formal analysis, Investigation, Project administration, Writing - reviewing & editing. **Daniel Valentinsson**: Conceptualization, Investigation, Writing - original draft.

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