Food Control 120 (2021) 107562

Contents lists available at ScienceDirect

Food Control

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

Effect of gear design on catch damage on cod (*Gadus morhua*) in the Barents Sea demersal trawl fishery

Jesse Brinkhof[a,*,1], Bent Herrmann[a,b,1], Manu Sistiaga[b,c,1], Roger B. Larsen[a,1], Nadine Jacques[a], Svein Helge Gjøsund[b]

[a] The Arctic University of Norway, UiT, Breivika, N-9037, Tromsø, Norway
[b] SINTEF Ocean, Brattørkaia 17C, N-7010, Trondheim, Norway
[c] Institute of Marine Research, Postbox 1870, Nordnes, N-5817, Bergen, Norway

ARTICLE INFO

Keywords:
Demersal trawl
Cod
Codend
Catch damage
Gentle codend
Sorting grid

ABSTRACT

Damage incurred during the catch process is an indicator of the overall quality of fish and fish welfare. Because catch quality is difficult to improve once it has deteriorated, it is important to preserve quality during the catch process. Atlantic cod (*Gadus morhua*) is the most important species in the Barents Sea bottom trawl fishery. Bottom trawling is a non-benign fishing method, and it is therefore considered important to reduce damage imparted to fish during capture, and subsequently improve catch quality and fish welfare. In the present study, the levels of damage on cod captured with a new gear design were assessed in the Barents Sea bottom trawl fishery. Furthermore, this study investigated to what extent the compulsory sorting grid and diamond mesh codend configuration employed in the fishery is responsible for the damage incurred by cod during the capture process. In total, 750 cod captured over 25 hauls were evaluated for catch damage (marks, ecchymosis, exsanguination, and scale loss). The results showed that substituting the grid and codend configuration with a four-panel selective knotless section followed by a gentle codend increased the probability of cod having no catch damage by 6.00% (CI: 0.6%–11.41%). Moreover, the gentle codend led to a significant reduction in the severity of all catch damage categories.

1. Introduction

The high densities of gadoid fish in the Barents Sea (Norwegian Directorate of Fisheries, 2018; Yaragina et al., 2011) have led to an increased focus on two main areas in the demersal trawl fishery: i) improving catch quality, and ii) improving size selectivity. Improved catch quality results in increased revenue and improved fish welfare. The latter is a factor that is also subject to increasing attention by NGOs and consumers (Veldhuizen et al., 2018). One method for investigating the overall catch quality is to assess the extent and severity of catch damage (Dowlati et al., 2013). Catch damage on fish has been used in the past as an indicator of fish welfare (Madsen et al., 2008; Veldhuizen et al., 2018) and to determine the survival probability of fish (Soldal et al., 1993; Davis, 2010).

Tveit et al. (2019), recently tested the effect of codend construction (2- and 4-panel codend constructions) and the potential advantage of using knotless netting in the codend on catch damage in the Barents Sea demersal trawl fishery. The design changes tested in the study did not significantly decrease the catch damage present on trawl-caught cod (*Gadus morhua*). Brinkhof, Larsen et al., 2018 presented a new codend design, termed a sequential codend, which significantly improved the catch quality of cod without compromising size selectivity (Brinkhof et al., 2019). In the sequential codend, the quality preserving codend segment was adhered behind an ordinary selective diamond mesh codend. The passage between the two codend segments was closed during towing by a hydrostatic catch releaser that enabled fish to pass into the quality preserving codend segment during haul-back. Using a sequential codend makes this part of the gear twice as long as the ordinary configuration, and makes the codend difficult to handle, beside that the passage between the codend segments needs to be tied up after each haul, which is time-consuming. Moreover, the fish are kept in the quality preserving codend segment only during haul-back and can still be subject to severe damage during towing.

The compulsory gear in the Barents Sea demersal trawl fishery

* Corresponding author.
E-mail address: jesse.brinkhof@uit.no (J. Brinkhof).
[1] equal authorship.

https://doi.org/10.1016/j.foodcont.2020.107562
Received 20 April 2020; Received in revised form 11 August 2020; Accepted 12 August 2020
Available online 18 August 2020

includes a 55 mm bar spacing sorting grid followed by a codend with a minimum mesh size of 130 mm (Grimaldo et al., 2015; Norwegian directorate of Fisheries, 2018b; Brinkhof et al., 2020). This system ensures the effective release of undersized fish, which are mainly cod (50–100%) and haddock (0–50%) (*Melanogrammus eaglefinus*). Catches usually also contain a small percentage of redfish (*Sebastes* spp.), Greenland halibut (*Reinhardtius hippoglossoides*), and wolfish (*Anarhichas* spp.). Fishers complain that sorting grids damage fish, and thus reduce the catch quality. Therefore, it is relevant to investigate if the existing grid and codend can be replaced with a design that would preserve catch quality while maintaining the efficiency of sorting out undersized fish. The current study builds on the work of Brinkhof, Larsen et al., 2018 by testing a gear configuration where the compulsory sorting grid and diamond mesh codend configuration were substituted with a knotless large meshed section with short lastridges (Isaksen & Valdemarsen, 1990, p. 46) followed by a gentle codend. The short lastridges ensured that the meshes in the large mesh section stay open during the fishing process to enable the release of undersized fish through this section of the gear. The rationale for testing this gear configuration was the hypothesis that the small meshed gentle codend in the aft would cause a "bucket effect", pushing the water sideways in front of its entry. Thus, the water would mostly flow out of the anterior section with large meshes increasing the possibility of undersized fish utilizing these meshes to escape. If working as intended, such a configuration could simultaneously improve catch quality by reducing the levels of stress and mechanical strain on the catch, and simultaneously provide a size selective method that does not require a size selective grid.

However, before testing the release efficiency of undersized fish it was necessary to investigate if the new gear configuration reduces catch damage to cod. The study aimed to answer the following research questions:

- What level of catch damage is observed for cod with the compulsory grid and codend configuration used in the Barents Sea demersal trawl fishery targeting cod?
- Does removing the sorting grid and substituting the ordinary codend with a gentle codend reduce catch damage to cod?

2. Materials and methods

2.1. Vessel, area, time and gear set-up

Sea trials were carried out onboard the R/V "Helmer Hanssen" (63.8 m length overall and 4080 HP engine) from the 1st to the March 5, 2019. The fishing area was off the northern coast of Norway between 71°31.33–71°54.76 N and 24°40.65–25°57.53 E, with depths ranging between 263 and 291 m.

During the fishing trials two identically rigged two-panel Alfredo 3 trawls built entirely of 150-mm polyethylene (PE) meshes were used. The trawls were kept open by a set of Injector Scorpion otter boards (each weighing 3100 kg and measuring 8 m^2) that were linked to 60 m sweeps by 7 m long chains. The sweeps were equipped with a Ø 53 cm steel bobbin at the center, to protect them from excessive abrasion. The ground gears were 46.9 m in length and consisted of 18.9 m long rockhopper gears with Ø 53 cm discs in the center and 14 m chains (Ø 19 mm) on each side equipped with three steel bobbins (Ø 53 cm).

In one of the trawls, a 2-panel Sort-V grid section (Herrmann et al., 2013), a 2- to 4-panel transition section and a 4-panel diamond mesh codend were installed (Fig. 1a). The grid section (1234 × 1750 mm) was made of steel and installed so that it maintained an angle of approximately 25–26° while fishing, which is considered optimal for selectivity (Brinkhof et al., 2020; Herrmann et al., 2019; Sistiaga et al., 2010). The bar spacing of the grid was 55.88 ± 2.38 mm (mean ± SD). The 2- to 4-panel transition section between the grid section and the codend was 5.9 m long and built of 130 mm meshes (8 mm PE twine). The 4-panel codend was 11 m long, 64 meshes in circumference, and was

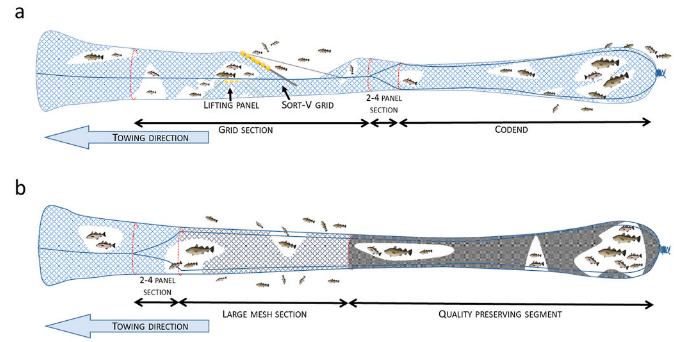

Fig. 1. Grid and codend configuration (a) and configuration with gentle codend (b) used during the sea trials.

constructed of 8 mm PE knotted twine. The meshes were 131.1 ± 2.73 mm (mean ± SD). Measurements were made according to the protocol described in (Wileman, Ferro, Fonteyne, & Millar, 1996).

In the other trawl, a gentle codend identical to the quality preserving codend segment used by Brinkhof, Larsen et al., 2018 was installed. This codend was 10 m long and comprised four panels. It was built of 6 mm nominal mesh size and had a circumference of 1440 meshes (360-meshes wide in each panel). To strengthen the codend, the small mesh netting was reinforced with an outer codend of knotless Ultra cross with a nominal mesh size of 112 mm (90 meshes in circumference), and four 36 mm lastridge ropes (5% shorter than the codend netting). The large mesh section in front of the gentle codend, consisted of four panels built of 150.2 ± 3.4 mm (mean ± SD) mesh size knotless Ultra cross netting with 9 mm PE twine. This section was 49 meshes long and had 60 open meshes around. The lastridges in the section were 30% shorter than the stretched meshes, with the purpose of keeping the meshes constantly open. A 2- to 4-panel transition section identical to the one described for the first trawl was installed between the trawl and the Ultra cross selective section (Fig. 1b).

Both trawls were monitored by Scanmar acoustic sensors measuring the door spread and trawl height, a catch sensor, and a trawl eye. A grid sensor was installed at the grid for a couple of hauls before and after the trials to ensure that the grid angle was approximately 25°.

2.2. Data collection and assessment of damage on fish

The two trawls were deployed alternately during the trials. Towing time was set based on fish registration on the echo-sounder and the signal from the catch sensor. Due to capacity limits onboard the research vessel the catches were limited to 2–3 tons. To ensure random sampling, once the catch came onboard, approximately ten fish were collected at the end of the codend, ten from the middle, and ten from the beginning of the codend, while emptying the catch into the holding bin. This resulted in 30 cod from each haul for the damage analysis. These fish were killed immediately and exsanguinated in a tank containing 1000 L of running seawater. The exsanguination time was 30 min, as practised in the commercial fishery. As factory trawlers mostly deliver headed and gutted fish (i.e. HG product), all cod were headed and gutted prior to catch damage assessment. For each cod, the level of damage incurred during the capture process was evaluated on both body sites following the scaling scheme presented in Table 1 (Rotabakk et al., 2011; Essaiassen et al., 2013; Brinkhof, Larsen et al., 2018).

Four different types of catch damage were assessed: marks, ecchymosis, exsanguination, and scale loss (Table 1; Fig. 2). These damages are commonly assessed when evaluating headed and gutted fished (Rotabakk et al., 2011; Essaiassen et al., 2013; Brinkhof, Larsen et al., 2018,b). Absence of a given category is scored as 0 (no damage). If a damage was present it was scored from 1 (slight) to 3 (severe) depending on its severity (Table 1). Marks are seen as marks or imprint on the fish, ranging from minor marks/imprint on the skin (without scale loss) that

Table 1
Scoring scheme used to evaluate damage on the fish included in the study. Terms in brackets are the abbreviations for each damage type.

Damage type	Description		Score
Marks (Marks)	No damage:	No marks or imprint on the fish	0
	Slight:	Minor marks or imprint on the fish	1
	Moderate:	Major marks or imprint on a defined area on the fish	2
	Severe:	Severe and major marks or imprint on large areas of the fish	3
Ecchymosis (Ecchy)	No damage:	No red discoloration on the skin	0
	Slight:	Slight red discoloration around the base of the fins	1
	Moderate:	Red discoloration on the belly and around the base of the fins	2
	Severe:	Severe red discoloration on the belly and around the base of the fins, as well as the on the loin or tail	3
Exsanguination (Exsan)	No damage:	No blood in the blood vessels in the belly, white neck and belly	0
	Slight:	Some of the blood vessels in the belly are partly filled with blood	1
	Moderate:	Blood vessels are only partly emptied for blood	2
	Severe:	Blood vessels in the belly are filled with blood, red belly and neck	3
Scale loss (Scale)	No damage:	No loss of scales	0
	Slight:	Minor loss of scales	1
	Moderate:	Major loss of scales on a defined part of the fish	2
	Severe:	Major loss of scales on large areas of the fish	3

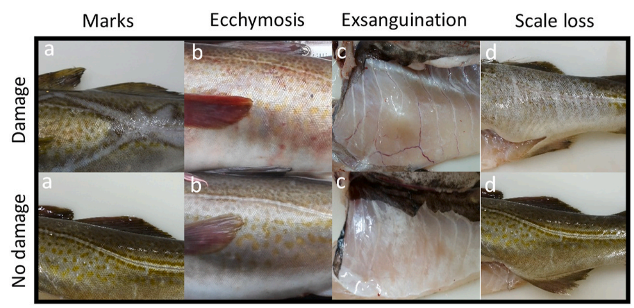

Fig. 2. Illustration of the four damage types evaluated during this study: marks, exsanguination, ecchymosis, and skin abrasion.

have little effect on the quality to major marks and/or impress through the skin and into the muscle causing severe degradation of the quality (Table 1; Fig. 2a). Ecchymosis was detected as red discoloration on the skin, ranging from slight discoloration at the base of the fins to severe red discoloration on the belly, loin part and/or tail (Table 1; Fig. 2b). The degree of exsanguination of a fish was seen in the belly, ranging from fully exsanguinated, were all blood vessels in the belly are emptied for blood, to poor exsanguinated were the blood vessels in the belly are not drained for blood and the belly and neck was coloured red (Table 1; Fig. 2c). Scale loss was seen as descaling on the skin, ranging from minor scale loss, often seen at the tail, to major scale loss covering a large area of the fish (Table 1; Fig. 2d).

2.3. Data analysis

Quantifying the probability of obtaining a cod without any catch damage at all (i.e., a fish with no evidence of any of the damage types) is relevant knowledge for especially the industry (Brinkhof, Larsen et al., 2018). In addition, quantifying the probability of obtaining fish with different severities (score) of specific damage types in the catch will help identify the potential to improve catch quality and fish welfare. Furthermore, knowing the probability of obtaining a given combination of catch damage types that does not exceed a given level (severity) will provide an estimate for the fraction of the catch that can be expected to be within a certain minimum quality level.

The method presented by Brinkhof, Larsen, et al. (2018) estimates the probability of obtaining a given catch damage score. It also quantifies the probability of obtaining a given score for a given combination of catch damage types, as well as the probability of not exceeding a given score (i.e. the probability of obtaining a given score or lower). The expected average value $\widehat{p_{as}}$ for the probability for a score s on catch damage type a was determined using Equation (1):

$$\widehat{p_{as}} = \frac{\sum_{j=1}^{m}\left\{\frac{1}{n_j}\sum_{t=1}^{n_j} equal\left(s, k_{ajt}\right)\right\}}{m}$$
$$with \tag{1}$$
$$equal(s,k) = \begin{cases} 1 \ \forall \ k = s \\ 0 \ \forall \ k \neq s \end{cases}$$

where m is the number of hauls conducted, n_j is the number of fish given a score in haul j, and k_{ajt} is the score given for catch damage type a to fish number t evaluated in haul j. The probability $\widehat{pm_{as}}$ of obtaining a score that does not exceed s for catch damage type a (i.e. the probability of obtaining a given score or lower) was quantified using Equation (2):

$$\widehat{pm_{as}} = \frac{\sum_{j=1}^{m}\left\{\frac{1}{n_j}\sum_{t=1}^{n_j} lequal\left(s, k_{ajt}\right)\right\}}{m}$$
$$with \tag{2}$$
$$lequal(s,k) = \begin{cases} 1 \ \forall \ k \leq s \\ 0 \ \forall \ k > s \end{cases}$$

Equations (1) and (2) provide an evaluation of each catch damage type separately. However, it is also relevant to assess the probability of a fish scoring s or maximum s for two or more of the catch damage types simultaneously. To estimate such probabilities, Equations (1) and (2) were extended to Equations (3) and (4), respectively:

$$\widehat{p_{as}p_{bs}} = \frac{\sum_{j=1}^{m}\left\{\frac{1}{n_j}\sum_{t=1}^{n_j} equal(s,k_{ajt}) \times equal(s,k_{bjt})\right\}}{m}$$

$$\widehat{p_{as}p_{bs}p_{cs}} = \frac{\sum_{j=1}^{m}\left\{\frac{1}{n_j}\sum_{t=1}^{n_j} equal(s,k_{ajt}) \times equal(s,k_{bjt}) \times equal(s,k_{cjt})\right\}}{m}$$

$$\widehat{p_{as}p_{bs}p_{cs}p_{ds}} = \frac{\sum_{j=1}^{m}\left\{\frac{1}{n_j}\sum_{t=1}^{n_j} equal(s,k_{ajt}) \times equal(s,k_{bjt}) \times equal(s,k_{cjt}) \times equal(s,k_{djt})\right\}}{m} \tag{3}$$

$$\widehat{p_{as}p_{bs}p_{cs}p_{ds}p_{es}} = \frac{\sum_{j=1}^{m}\left\{\frac{1}{n_j}\sum_{t=1}^{n_j} equal(s,k_{ajt}) \times equal(s,k_{bjt}) \times equal(s,k_{cjt}) \times equal(s,k_{djt}) \times equal(s,k_{ejt})\right\}}{m}$$

and

$$\widehat{pm_{as}pm_{bs}} = \frac{\sum_{j=1}^{m}\left\{\frac{1}{n_j}\sum_{t=1}^{n_j} lequal(s,k_{ajt}) \times lequal(s,k_{bjt})\right\}}{m}$$

$$\widehat{pm_{as}pm_{bs}pm_{cs}} = \frac{\sum_{j=1}^{m}\left\{\frac{1}{n_j}\sum_{t=1}^{n_j} lequal(s,k_{ajt}) \times lequal(s,k_{bjt}) \times lequal(s,k_{cjt})\right\}}{m}$$

$$\widehat{pm_{as}pm_{bs}pm_{cs}pm_{ds}} = \frac{\sum_{j=1}^{m}\left\{\frac{1}{n_j}\sum_{t=1}^{n_j} lequal(s,k_{ajt}) \times lequal(s,k_{bjt}) \times lequal(s,k_{cjt}) \times lequal(s,k_{djt})\right\}}{m} \tag{4}$$

$$\widehat{pm_{as}pm_{bs}pm_{cs}pm_{ds}pm_{es}} = \frac{\sum_{j=1}^{m}\left\{\frac{1}{n_j}\sum_{t=1}^{n_j} lequal(s,k_{ajt}) \times lequal(s,k_{bjt}) \times lequal(s,k_{cjt}) \times lequal(s,k_{djt}) \times lequal(s,k_{ejt})\right\}}{m}$$

Equations (3) and (4) were applied to all possible combinations of catch damage types.

The method described above incorporates the effect of potential between-haul variation in fish quality and the uncertainty resulting from only examining a limited number of fish from each haul. This is done by estimating uncertainties in the form of 95% percentile confidence intervals (CI) by applying a double bootstrap methodology. By providing bootstrap-based estimates with uncertainties for the differences in the estimated quality scores, this method allowed a direct comparison between the two trawl configurations. The bootstrapping method is thoroughly described in Brinkhof, Larsen, et al. (2018).

All analyses in the study were carried out using the computer software SELNET (Herrmann, Sistiaga, Nielsen, & Larsen, 2012).

3. Results

3.1. Data collection

During the sea trials a total of 25 hauls were carried out, 13 with the grid and codend configuration and 12 with the gentle codend (Table 2). Catch damage was evaluated for 750 cod. Examination of the CI's in Tables 3–5 indicate that this sample size was sufficient to provide conclusive results (i.e. narrow CI's). The catches contained 84.9 ± 13% (mean ± SD) cod, 13.04 ± 11.41% (mean ± SD) haddock, and 2.02 ± 2.7% (mean ± SD) redfish.

3.2. Damage on cod captured with the grid and 130 mm diamond mesh codend configuration

The data based on the scores derived from the catch damage assessment is presented in Fig. 3.

The results showed that the probability of catching cod with no damage was 5.38% (2.56%–8.72%) when the grid with the regular codend gear was used. Marks, exsanguination and scale loss were the most frequent types of damage observed, but in most cases, these were only slight (Table 3, Fig. 3). The probability of recording cod with moderate or severe damage for any of the four damage types investigated did not exceed 10%, and for ecchymosis. Further, the probability of obtaining cod that simultaneously showed only slight or moderate damage of any of the types investigated were 82.82% (75.13%–89.49%) and 98.21% (95.9%–100.00%), respectively (Table 3).

Table 2
Overview of the hauls conducted during the data collection period. *: missing values.

Haul #	Marks	Date	Time	Tow time (Min)	Lat.	Long.	Depth (m)	Catch (kg)
1	Grid + codend	March 01, 2019	00:41:15	60	7151.94 N	02444.80 E	269.86	*
2	Gentle codend	March 01, 2019	02:46:23	90	7149.58 N	02446.53 E	267.63	854.11
3	Gentle codend	March 01, 2019	05:09:55	91	7154.01 N	02449.99 E	263.35	636.38
4	Grid + codend	March 01, 2019	07:46:12	90	7154.76 N	02440.65 E	276.94	524.19
5	Grid + codend	March 01, 2019	20:24:56	60	7136.96 N	02540.52 E	280.38	3421.05
6	Gentle codend	March 02, 2019	02:40:34	30	7133.94 N	02540.77 E	281.03	2324.22
7	Gentle codend	March 02, 2019	07:01:42	43	7136.10 N	02548.26 E	282.57	1659.81
8	Grid + codend	March 02, 2019	11:20:45	90	7134.91 N	02542.77 E	282.62	2275.19
9	Grid + codend	March 02, 2019	16:02:01	60	7135.04 N	02554.40E	285.33	562.59
10	Gentle codend	March 02, 2019	18:00:05	50	7135.12 N	02543.03 E	279.40	1589.05
11	Gentle codend	March 02, 2019	22:17:11	19	7133.59 N	02544.88 E	280.48	948.18
12	Grid + codend	March 03, 2019	00:41:59	43	7131.33 N	02548.15 E	275.99	1467.88
13	Grid + codend	March 03, 2019	04:00:23	60	7132.49 N	02545.98 E	280.44	1374.52
14	Gentle codend	March 03, 2019	06:47:57	60	7129.95 N	02546.59 E	284.85	1073.62
15	Gentle codend	March 03, 2019	10:09:03	59	7137.49 N	02545.90 E	288.25	824.2
16	Grid + codend	March 03, 2019	12:12:32	120	7134.93 N	02546.25 E	284.01	1343.71
17	Grid + codend	March 03, 2019	15:01:58	118	7138.04 N	02540.20 E	281.74	1468.71
18	Gentle codend	March 03, 2019	17:54:47	68	7132.66 N	02529.15 E	287.47	1782.58
19	Gentle codend	March 03, 2019	22:51:55	54	7135.18 N	02532.81 E	280.98	1868.32
20	Grid + codend	March 04, 2019	03:06:06	61	7135.78 N	02535.72 E	*	1893.18
21	Grid + codend	March 05, 2019	02:08:01	75	7134.32 N	02530.93 E	286.35	2331.8
22	Gentle codend	March 05, 2019	05:43:05	78	7132.93 N	02531.58 E	289.13	2945.39
23	Gentle codend	March 05, 2019	12:31:24	75	7135.00 N	02554.64 E	290.10	2825.49
24	Grid + codend	March 05, 2019	18:28:02	24	7136.67 N	02557.30 E	290.48	1257.19
25	Grid + codend	March 05, 2019	20:10:49	38	7136.82 N	02557.53 E	290.85	*

3.3. *Damage on cod captured with the gentle codend configuration*

Like for the grid and 130 mm diamond mesh codend configuration the most frequent damage types observed on cod captured with the gentle codend were marks, poor exsanguination and to a lesser extent scale loss. The probability of observing ecchymosis and scale loss were observed less frequent. These latter damages were mostly slight (Fig. 4; Table 4) and the probability of moderate or severe damage was only over 10% for scale loss (38.21% CI: 26.49%–51.54%). The probability of capturing cod with no damage with this configuration was estimated to be 11.39% (7.22%–16.11%), and the probability of capturing cod with slight or no damage was 84.72% (77.22%–92.50%).

3.4. *Differences in damage on cod captured with the grid and codend configuration versus with the gentle codend*

The results demonstrated that the probability of capturing cod with no damage was significantly higher (6.00% CI: 0.60%–11.41%) for the

Table 3
Probability of obtaining cod with different types and levels of catch damage (scores) when captured with the grid and regular codend configuration. Values in brackets represent 95% confidence intervals.

Grid & Codend	0	1	2	3	≤1	≤2
Marks	42.31% (32.31%–51.54%)	56.41% (47.69%–65.64%)	1.03% (0.00%–2.82%)	0.26% (0.00%–1.28%)	98.72% (96.41%–100.00%)	99.74% (98.72%–100.00%)
Ecchy	85.38% (80.77%–89.74%)	14.62% (10.26%–19.23%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	100.00% (100.00%–100.00%)	100.00% (100.00%–100.00%)
Exsan	34.10% (26.67%–41.79%)	58.97% (52.56%–65.38%)	6.67% (3.08%–10.77%)	0.26% (0.00%–1.28%)	93.08% (88.97%–96.92%)	99.74% (98.72%–100.00%)
Scale	42.05% (33.85%–50.77%)	47.95% (38.97%–56.67%)	8.72% (4.62%–13.59%)	1.28% (0.00%–3.33%)	90.00% (84.10%–94.87%)	98.72% (96.67%–100.00%)
Marks & Ecchy	37.18% (27.69%–46.67%)	8.97% (5.90%–12.56%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	98.72% (96.41%–100.00%)	99.74% (98.72%–100.00%)
Marks & Exsan	14.36% (8.97%–20.51%)	34.10% (27.18%–41.54%)	0.26% (0.00%–1.28%)	0.00% (0.00%–0.00%)	92.05% (86.92%–96.67%)	99.49% (98.46%–100.00%)
Ecchy & Exsan	32.05% (24.62%–39.49%)	10.77% (6.92%–14.87%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	93.08% (88.97%–96.67%)	99.74% (98.97%–100.00%)
Marks & Ecchy & Exsan	13.33% (7.95%–20.26%)	7.18% (4.10%–10.77%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	92.05% (87.18%–96.67%)	99.49% (98.46%–100.00%)
Marks & Scale	20.26% (14.36%–26.92%)	27.18% (20.77%–33.59%)	0.51% (0.00%–1.79%)	0.00% (0.00%–0.00%)	89.49% (83.85%–94.10%)	98.46% (96.15%–100.00%)
Ecchy and Scale	37.95% (29.49%–46.92%)	7.95% (4.62%–11.54%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	90.00% (84.62%–94.87%)	98.72% (96.92%–100.00%)
Marks & Ecchy & Scale	18.21% (12.31%–24.36%)	5.38% (2.82%–8.46%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	89.49% (83.85%–94.87%)	98.46% (96.41%–100.00%)
Exsan & Scale	13.33% (8.21%–19.23%)	30.00% (23.59%–36.41%)	0.26% (0.00%–1.28%)	0.00% (0.00%–0.00%)	83.33% (75.90%–89.74%)	98.46% (96.41%–100.00%)
Marks & Exsan & Scale	5.38% (2.56%–8.46%)	18.21% (13.85%–23.33%)	0.26% (0.00%–1.28%)	0.00% (0.00%–0.00%)	82.82% (75.64%–89.49%)	98.21% (95.90%–100.00%)
Ecchy & Exsan & Scale	13.33% (8.72%–19.49%)	6.41% (3.33%–10.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	83.33% (75.90%–90.00%)	98.46% (96.15%–100.00%)
Marks & Ecchy & Exsan & Scale	5.38% (2.56%–8.72%)	4.62% (2.31%–7.44%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	82.82% (75.38%–89.74%)	98.21% (95.90%–100.00%)

Table 4
Probability of obtaining cod with different types and levels of catch damage (scores) when captured with the gentle codend configuration. Values in brackets represent 95% confidence intervals.

Gentle codend	0	1	2	3	≤1	≤2
Marks	51.11% (42.22%–60.83%)	46.11% (37.50%–54.44%)	2.50% (0.56%–5.00%)	0.28% (0.00%–1.11%)	97.22% (94.72%–99.17%)	99.72% (98.89%–100.00%)
Ecchy	87.22% (81.94%–92.22%)	11.94% (7.50%–16.67%)	0.83% (0.00%–2.22%)	0.00% (0.00%–0.00%)	99.17% (97.78%–100.00%)	100.00% (100.00%–100.00%)
Exsan	40.00% (32.50%–47.78%)	50.83% (44.17%–57.78%)	8.33% (3.61%–13.33%)	0.83% (0.00%–2.22%)	90.83% (85.83%–95.83%)	99.17% (97.78%–100.00%)
Scale	64.44% (56.39%–73.06%)	32.22% (23.61%–40.28%)	2.50% (0.28%–5.28%)	0.83% (0.00%–2.22%)	96.67% (93.33%–99.44%)	99.17% (97.78%–100.00%)
Marks & Ecchy	44.44% (35.56%–53.89%)	5.56% (2.50%–9.17%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	96.39% (93.33%–98.89%)	99.72% (98.61%–100.00%)
Marks & Exsan	20.00% (12.78%–27.22%)	22.22% (16.39%–28.89%)	0.28% (0.00%–1.11%)	0.00% (0.00%–0.00%)	88.33% (81.94%–94.44%)	98.89% (97.50%–100.00%)
Ecchy & Exsan	35.56% (27.50%–43.61%)	6.11% (3.33%–9.44%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	90.00% (84.44%–95.56%)	99.17% (97.78%–100.00%)
Marks & Ecchy & Exsan	18.06% (11.11%–25.28%)	2.78% (0.83%–5.28%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	87.50% (80.83%–93.89%)	98.89% (97.50%–100.00%)
Marks & Scale	31.67% (25.83%–38.06%)	12.22% (7.78%–17.22%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	94.17% (89.72%–98.06%)	98.89% (97.50%–100.00%)
Ecchy and Scale	56.67% (49.72%–63.61%)	3.33% (1.39%–5.83%)	0.28% (0.00%–1.11%)	0.00% (0.00%–0.00%)	96.11% (92.50%–98.89%)	99.17% (97.78%–100.00%)
Marks & Ecchy & Scale	27.78% (22.50%–33.89%)	0.83% (0.00%–2.50%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	93.61% (88.89%–97.78%)	98.89% (97.22%–100.00%)
Exsan & Scale	24.72% (17.78%–31.67%)	15.56% (10.83%–20.56%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	87.50% (80.56%–94.17%)	98.33% (96.67%–99.72%)
Marks & Exsan & Scale	12.78% (8.06%–17.50%)	4.72% (1.94%–8.33%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	85.28% (77.22%–92.50%)	98.06% (96.11%–99.44%)
Ecchy & Exsan & Scale	21.67% (15.83%–28.06%)	1.94% (0.28%–3.89%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	86.94% (80.00%–93.61%)	98.33% (96.67%–99.72%)
Marks & Ecchy & Exsan & Scale	11.39% (7.22%–16.11%)	0.28% (0.00%–1.11%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	84.72% (77.22%–92.50%)	98.06% (96.39%–99.44%)

gentle codend than for the grid and codend configuration (Table 5). Scale loss was the damage type where the difference observed between the gear was largest. The probability of obtaining fish without scale loss was significantly higher for the cod captured with the gentle codend 22.39% (9.79%–34.70%). In addition, the probability of capturing fish with slight −15.73% (−28.29%–3.46%) or moderate −6.22% (−11.20%–1.26%) scale loss was significantly lower for this codend than for the grid and codend configuration (Table 5). The differences

Table 5
Differences in probability for different types and levels of catch damage (scores) between cod captured with the gentle configuration, and cod captured with the grid and codend configuration (gentle codend – grid & codend). Values in brackets represent 95% confidence interval. Significant differences are highlighted in bold.

Difference	0	1	2	3	≤1	≤2
Marks	8.80% (−3.61%–22.63%)	**−10.30% (-23.08%–1.07%)**	1.47% (−1.22%–4.19%)	0.02% (−1.03%–0.88%)	−1.50% (−4.49%–1.47%)	−0.02% (−0.88%–1.03%)
Ecchy	1.84% (−5.19%–8.48%)	**−2.67% (-9.12%–3.72%)**	0.83% (0.00%–2.22%)	0.00% (0.00%–0.00%)	−0.83% (−2.22%–0.00%)	0.00% (0.00%–0.00%)
Exsan	5.90% (−4.98%–17.22%)	**−8.14% (-16.94%–0.90%)**	1.67% (−4.36%–7.78%)	0.58% (−0.77%–1.97%)	−2.24% (−8.61%–4.10%)	−0.58% (−1.97%–0.77%)
Scale	**22.39% (9.79%–34.70%)**	**−15.73% (-28.29%–-3.46%)**	**−6.22% (-11.20%–-1.26%)**	−0.45% (−2.78%–1.67%)	**6.67% (0.71%–13.53%)**	0.45% (−1.67%–2.78%)
Marks & Ecchy	7.26% (−5.90%–20.06%)	**−3.42% (-8.29%–0.98%)**	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	−2.33% (−5.73%–0.96%)	−0.02% (−1.11%–1.03%)
Marks & Exsan	5.64% (−3.61%–14.89%)	**−11.88% (-21.86%–-2.93%)**	0.02% (−1.03%–1.11%)	0.00% (0.00%–0.00%)	−3.72% (−11.79%–3.68%)	−0.60% (−2.24%–1.00%)
Ecchy & Exsan	3.50% (−7.82%–14.42%)	−4.66% (−9.76%–0.58%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	−3.08% (−9.89%–3.48%)	−0.58% (−2.22%–0.75%)
Marks & Ecchy & Exsan	4.72% (−5.30%–13.57%)	**−4.40% (-8.80%–-0.17%)**	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	−4.55% (−12.78%–2.69%)	−0.60% (−2.24%–0.98%)
Marks & Scale	**11.41% (2.37%–20.24%)**	**−14.96% (-22.74%–-6.97%)**	−0.51% (−1.79%–0.00%)	0.00% (0.00%–0.00%)	4.68% (−1.97%–11.39%)	0.43% (−1.73%–2.80%)
Ecchy and Scale	**18.72% (6.82%–29.51%)**	**−4.62% (-8.76%–-0.64%)**	0.28% (0.00%–1.11%)	0.00% (0.00%–0.00%)	**6.11% (0.19%–12.37%)**	0.45% (−1.41%–2.29%)
Marks & Ecchy & Scale	**9.57% (1.41%–18.14%)**	**−4.55% (-7.67%–-1.65%)**	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	4.12% (−2.31%–11.18%)	0.43% (−1.97%–2.76%)
Exsan & Scale	**11.39% (2.76%–20.15%)**	**−14.44% (-22.01%–-6.24%)**	−0.26% (−1.28%–0.00%)	0.00% (0.00%–0.00%)	4.17% (−5.32%–14.32%)	−0.13% (−2.56%–2.50%)
Marks & Exsan & Scale	**7.39% (1.69%–13.03%)**	**−13.48% (-19.25%–-7.88%)**	−0.26% (−1.28%–0.00%)	0.00% (0.00%–0.00%)	2.46% (−8.01%–13.12%)	−0.15% (−2.84%–2.74%)
Ecchy & Exsan & Scale	8.33% (−0.06%–16.13%)	**−4.47% (-8.31%–-0.96%)**	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	3.61% (−6.79%–12.63%)	−0.13% (−2.56%–2.54%)
Marks & Ecchy & Exsan & Scale	**6.00% (0.60%–11.41%)**	**−4.34% (-6.92%–-1.77%)**	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	1.90% (−8.29%–12.48%)	−0.15% (−2.80%–2.74%)

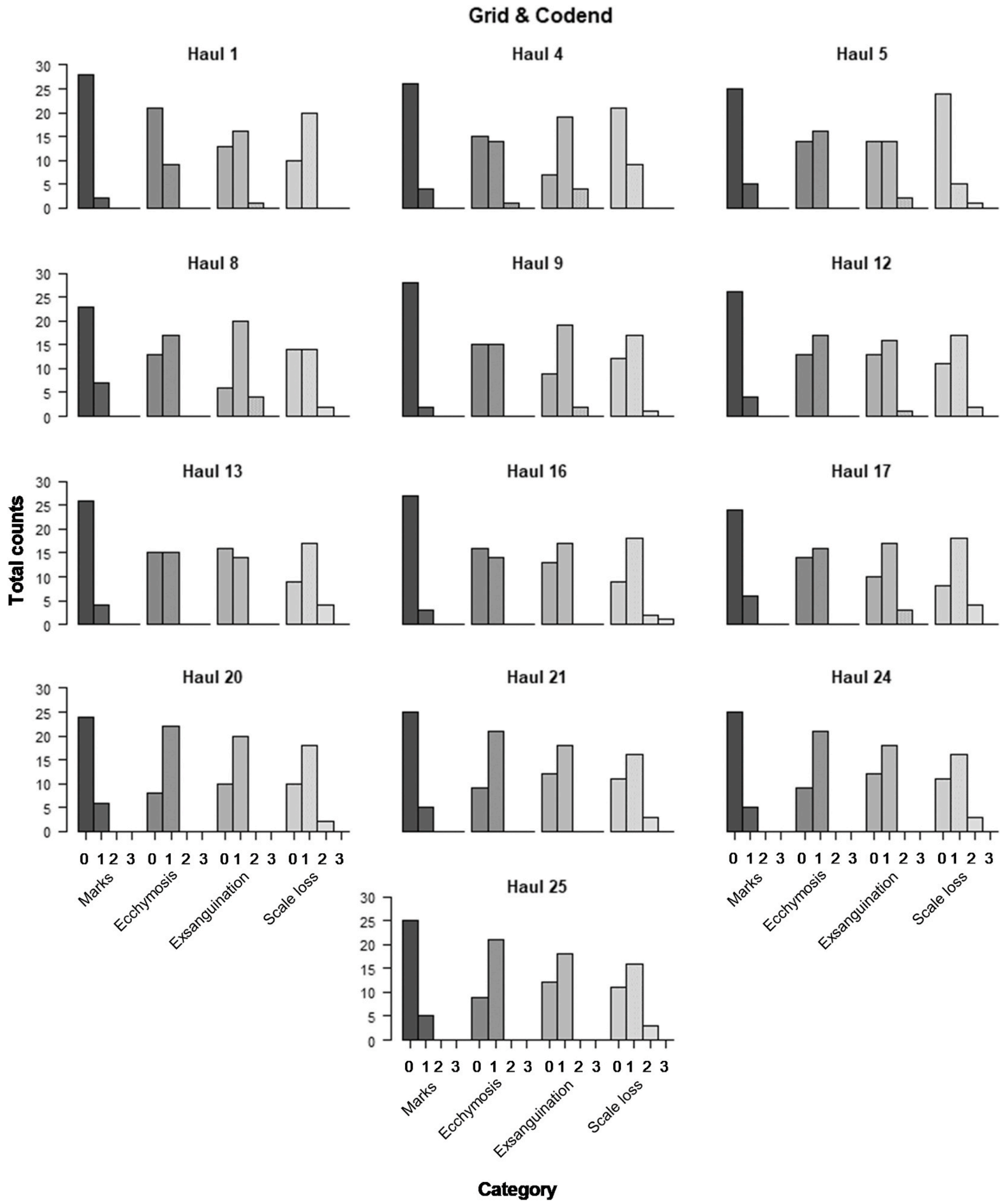

Fig. 3. Catch damage score histograms for cod captured with the grid and 130 mm regular codend configuration in each haul.

between the gears in the probability of capturing cod without marks or poor exsanguination were 8.80% (−3.61%–22.63%) and 5.90% (−4.98%–17.22%), respectively. However, these differences were not significant. The differences for ecchymosis was below 2% and non-significant (Table 5).

4. Discussion

In general fishers, retailers and scientist consider a catch to be of good quality, when it contains fish with negligible (score 0–1) physical injuries. Fish caught with bottom trawls often show marks, scale loss, internal and external ecchymosis, and poor exsanguination, all of which contribute to a reduction in overall quality (Esaiassen et al., 2004; Ingólfsson & Jørgensen, 2006; Digre et al., 2010; Rotabakk et al., 2011; Olsen et al., 2013, 2014). From a management perspective, poor catch quality increases the risk of illegal discards and high-grading (discarding of unwanted species, sizes or quality for the benefit of better payed catch) of fish, which contribute to unaccounted fishing mortality (Batsleer et al., 2015). From a fisheries perspective, poor catch quality limits how fish can be used for various products, and thus reduces revenue (Brinkhof, Larsen et al., 2018,b). In addition, catch quality can also influence shelf life (Bonilla et al., 2007; Cole et al., 2003). Hence, improving the quality of trawl caught fish could increase its value and contribute to a more sustainable fishery. Several studies have investigated the effect of post-catch handling onboard bottom trawlers (Borderías & SánchezAlonso, 2011; Botta et al., 1986; Erikson et al., 2016; Olsen et al., 2014, 2013). However, relatively few studies have investigated the effect of various trawling procedures and trawl components (including the codend) on catch quality. Karlsen et al. (2015) documented improved catch quality when separating crustaceans from fish, however, this is not an issue in the Barents Sea gadoid bottom trawl fishery. Redfish, which are caught as by-catch species in the Barents Sea fishery, can due to their spines have a negative effect on the catch quality. However, the levels of by-catch are usually low as demonstrated

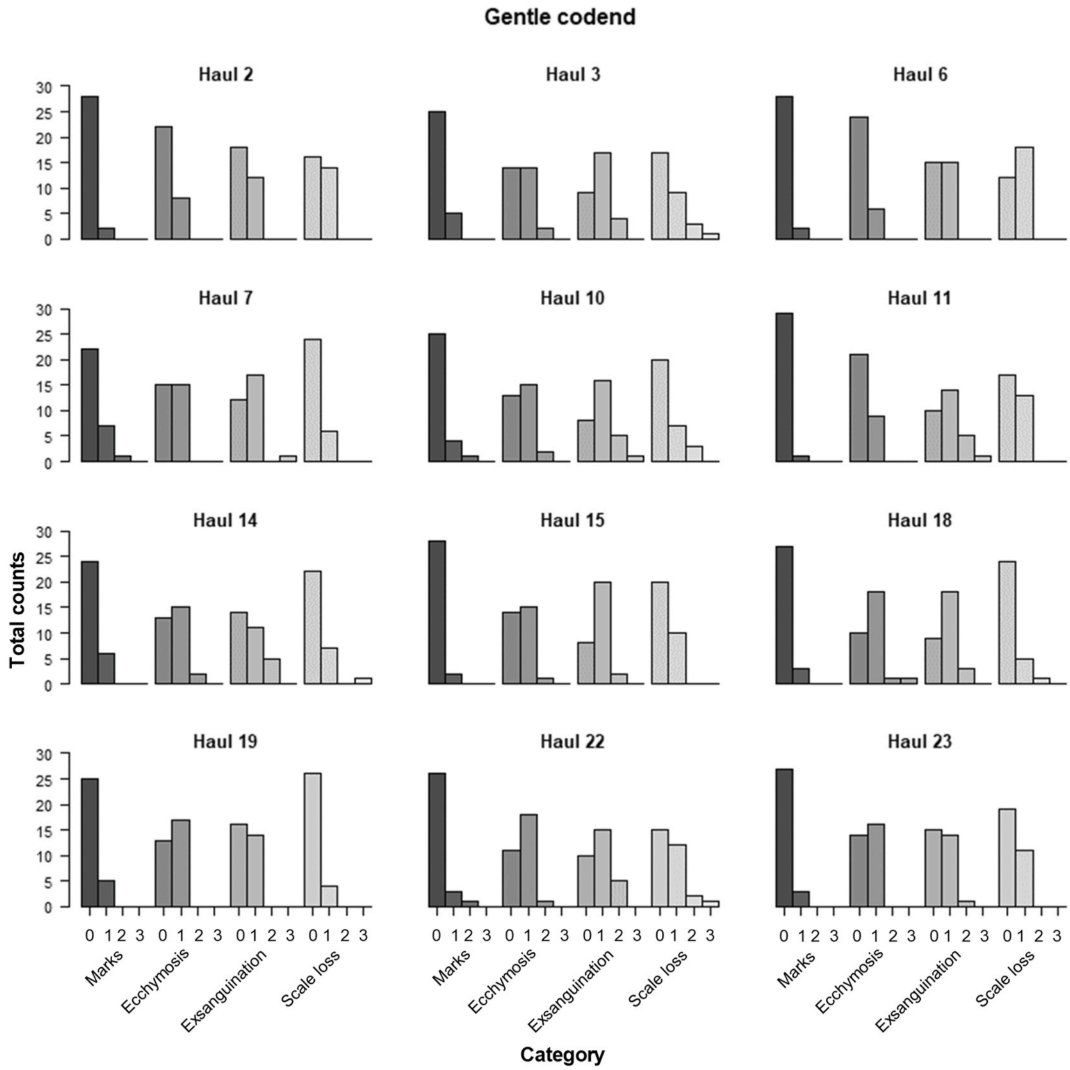

Fig. 4. Catch damage score histograms for cod captured with the gentle codend configuration in each haul.

in this study (catches contained 2.02 ± 2.7% (mean ± SD) redfish), and the negative effect is therefore believed to negligible. To our knowledge only the studies from Digre et al. (2010), Brinkhof, Larsen et al., 2018 and Tveit et al. (2019), all conducted in the same fishery, investigated the effect of substituting conventional codends with T90-codends, a sequential codend, and 4-panel codends, respectively. However, only the sequential codend resulted in a significantly improved catch quality. It is difficult, if not impossible, to improve catch quality based on existing processing methods once it has already deteriorated during the catch process. Hence, preventing the deterioration of the catch during the capture process is key to improving the quality of trawl caught cod.

The results of this study demonstrated that the gentle codend significantly improved the catch quality of cod by 6.00% (0.60%–11.41%) compared to the conventional configuration with the grid and codend. Brinkhof, Larsen et al., 2018 demonstrated a 14.00% (6.00%–24.00%) higher probability of catching cod without any catch damage by applying a quality preserving codend, similar to the gentle codend in the present study, in a sequential configuration, which was compared to a conventional trawl rigging similar to the one applied in this study. However, for scale loss, the current study demonstrated a larger improvement (22.39% CI: 9.79%–34.70%) than that reported by Brinkhof, Larsen et al., 2018 (16.00% CI: 6.00%–26.00%). Thus, the reduction in catch damage found in the current study was lower than that in Brinkhof, Larsen et al., 2018 for all damage types except for scale loss. This was somewhat unforeseen, especially considering that the gentle codend entry was open during the entire towing phase, and not closed as in the case of Brinkhof, Larsen et al., 2018.

The flow of fish in the aft of the two trawl configurations tested in the current study differed. In the compulsory trawl configuration, cod first pass through a sorting grid and may subsequently attempt to escape through the codend meshes. In the experimental trawl configuration, the cod could potentially escape through the meshes in the section with shortened lastridges before entering the gentle codend. The results of this study showed that some of the damage observed on cod captured with the grid and 130 mm diamond mesh codend configuration were caused by one or both of these gear components, because the damage was significantly reduced when they were substituted by another codend. In particular, the results showed that scale loss on trawl-caught cod could be significantly reduced by substituting the sorting grid and diamond mesh codend configuration by a gentler codend with a size selective section in front. The results also demonstrated that this configuration significantly reduced the probability of cod obtaining slight damage (score 1) for all categories. Due to the experimental design used in the current study, it was not possible to conclude whether the reduction in catch damage demonstrated a sole effect of the change in the codend configuration used, or if removing the size sorting grid also contributed to the observed reduction in catch damage. The passage below the sort-V grid was quite narrow and similar grids have previously been documented to have clogging problems (Sistiaga et al., 2016), which one would expect to contribute to damage like marks and scale loss on fish. However, considering the similarity between the sequential codend used by Brinkhof, Larsen et al., 2018 and the gentle codend used in the present study, it is likely that at least part of the difference observed for cod between the two designs tested in this study was due to difference in the codends used, and not solely due to the fact that the grid was not present in the configuration with the gentle codend.

Because the gentle codend configuration significantly improved catch quality, it could be applied to commercial fishing fleets. However, commercial implementation would require this new gear design to be as efficient at releasing undersized fish as the gear currently used in the fishery. Investigating the size selection of this new gear design and the release and retention efficiency of undersized and targeted sizes of fish were outside of the scope of the current study. It was hypothesized that the small meshed gentle codend in the aft of the gear would cause a “bucket effect”, pushing the water sideways in front of the gentle codend entry. If working efficiently, such a configuration could provide a size selection method that would not require a size selective grid, a rigid structure that complicates the gear. Avoiding the use of the grid would result in a gear configuration that is both easier to handle and less hazardous for fishermen to work with. Thus, before this new gear design can be considered for the commercial fleet, further research is required to investigate its efficiency in releasing undersized fish, and compare it to the current grid and codend configuration applied in the fishery.

CRediT authorship contribution statement

Jesse Brinkhof: Conceptualization, Methodology, Validation, Formal analysis, Resources, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Bent Herrmann:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Manu Sistiaga:** Conceptualization, Methodology, Validation, Formal analysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization. **Roger B. Larsen:** Conceptualization, Methodology, Validation, Formal analysis, Resources, Investigation, Data curation, Writing - original draft. **Nadine Jacques:** Investigation, Data curation, Writing - original draft. **Svein Helge Gjøsund:** Investigation, Writing - original draft, Project administration, Funding acquisition.

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.

Acknowledgements

Thanks to the crew of RV “Helmer Hanssen” and Juan Santos, Elsa Cuende, Hermann Pettersen, Ivan Tatone, Kristine Cerbule, John-Terje Eilertsen, for their valuable help during the sea trials. We would also like to thank the Norwegian Research Council (NRC Grant nr. 268388/E40), the Norwegian Directorate of Fisheries and the Arctic University of Norway for providing the necessary financial support to carry out the experiments. We thank the editor and the anonymous reviewer for the useful comments, which has helped to improve the final manuscript.

References

Batsleer, J., Hamon, K. G., van Overzee, H. M. J., Rijnsdorp, A. D., & Poos, J. J. (2015). Highgrading and over-quota discarding in mixed fisheries. *Reviews in Fish Biology and Fisheries, 25*, 715–736. https://doi.org/10.1007/s11160-015-9403-0.

Bonilla, A. C., Sveinsdottir, K., & Martinsdottir, E. (2007). Development of Quality Index Method (QIM) scheme for fresh cod (Gadus morhua) fillets and application in shelf life study. *Food Control, 18*(4), 352–358. https://doi.org/10.1016/j.foodcont.2005.10.019.

Borderías, A. J., & Sánchez Alonso, I. (2011). First processing steps and the quality of wild and farmed fish. *Journal of Food Science, 76*(1), R1–R5. http://dio.org/10.1111/j.1750-3841.2010.01900.x.

Botta, J. R., Squires, B. E., & Johnson, J. (1986). Effect of bleeding/gutting procedures on the sensory quality of fresh raw Atlantic cod (Gadus morhua). *Canadian Institute of Food Science and Technology Journal, 19*, 186–190. https://doi.org/10.1016/S0315-5463(86)71629-5.

Brinkhof, J., Herrmann, B., Larsen, R. B., & Veiga-Malta, T. (2019). Effect of a quality-improving cod end on size selectivity and catch patterns of cod in bottom trawl fishery. *Canadian Journal of Fisheries and Aquatic Sciences, 76*(11), 2110–2120. https://doi.org/10.1139/cjfas-2018-0402.

Brinkhof, J., Larsen, R. B., Herrmann, B., & Olsen, S. H. (2018b). Assessing the impact of buffer towing on the quality of Northeast Atlantic cod (*Gadus morhua*) caught with a bottom trawl. *Fisheries Research, 206*, 209–219. https://doi.org/10.1016/j.fishres.2018.05.021.

Brinkhof, J., Larsen, R. B., Herrmann, B., & Sistiaga, M. (2020). Size selectivity and catch efficiency of bottom trawl with a double sorting grid and diamond mesh codend in the North-east Atlantic gadoid fishery. *Fisheries Research, 231*, 105647. https://doi.org/10.1016/j.fishres.2020.105647.

Brinkhof, J., Olsen, S. H., Ingólfsson, O. A., Herrmann, B., & Larsen, R. B. (2018). Sequential codend improves quality of trawl-caught cod. *PloS One, 13*, Article e0204328. https://doi.org/10.1371/journal.pone.0204328.

Cole, R. G., Alcock, N. K., Handley, S. J., Grange, K. R., Black, S., Cairney, D., & Jerrett, A. R. (2003). Selective capture of blue cod Parapercis colias by potting: Behavioural observations and effects of capture method on peri-mortem fatigue. *Fisheries Research, 60*(2), 381–392. https://doi.org/10.1016/S0165-7836(02)00133-9.

Davis, M. W. (2010). Fish stress and mortality can be predicted using reflex impairment. *Fish and Fisheries, 11*(1), 1–11. https://doi.org/10.1111/j.1467-2979.2009.00331.x.

Digre, H., Hansen, U. J., & Erikson, U. (2010). Effect of trawling with traditional and ‘T90’ trawl codends on fish size and on different quality parameters of cod (Gadus morhua) and haddock (Melanogrammus aeglefinus). *Fish. Sci., 76*, 549–559. https://doi.org/10.1007/s12562-010-0254-2.

Dowlati, M., Mohtasebi, S. S., Omid, M., Razavi, S. H., Jamzad, M., & de la Guardia, M. (2013). Freshness assessment of gilthead sea bream (Sparus aurata) by machine vision based on gill and eye color changes. *Journal of Food Engineering, 119*, 277–287. https://doi.org/10.1016/j.jfoodeng.2013.05.023.

Erikson, U., Digre, H., & Grimsmo, L. (2016). Electrical immobilisation of saithe (Pollachius virens): Effects of pre-stunning stress, applied voltage, and stunner configuration. *Fisheries Research, 179*, 148–155. https://doi.org/10.1016/j.fishres.2016.02.017.

Esaiassen, M., Akse, L., & Joensen, S. (2013). Development of a catch-damage-index to assess the quality of cod at landing. *Food Control, 29*(1), 231–235. https://doi.org/10.1016/j.foodcont.2012.05.065.

Esaiassen, M., Nilsen, H., Joensen, S., Skjerdal, T., Carlehög, M., Eilertsen, G., … Evlevoll, E. (2004). *Effects of catching methods on quality changes during storage of cod (Gadus morhua). Lebensmittel-Wissenschaft und –Technologie, 37*, 643–648. https://doi.org/10.1016/j.lwt.2004.02.002.

Herrmann, B., Sistiaga, M., Grimaldo, E., Larsen, R. B., Olsen, L., Brinkhof, J., & Tatone, I. (2019). Size selectivity and length-dependent escape behaviour of haddock in a sorting device combining a grid and a square mesh panel. *Canadian Journal of Fisheries and Aquatic Sciences, 76*(8), 1350–1361. https://doi.org/10.1139/cjfas-2017-0461.

Herrmann, B., Sistiaga, M., Larsen, R. B., Nielsen, K. N., & Grimaldo, E. (2013). Understanding sorting grid and codend size selectivity of Greenland halibut (Reinhardtius hippoglossoides). *Fisheries Research, 146*, 59–73. https://doi.org/10.1016/j.fishres.2013.04.004.

Herrmann, B., Sistiaga, M. B., Nielsen, K. N., & Larsen, R. B. (2012). Understanding the size selectivity of redfish (Sebastes spp.) in North Atlantic trawl codends. *Journal of Northwest Atlantic Fishery Science, 44*, 1–13. https://doi.org/10.2960/J.v44.m680.

Ingólfsson, O. A., & Jørgensen, T. (2006). Escapement of gadoid fish beneath a commercial bottom trawl: Relevance to the overall trawl selectivity. *Fisheries Research, 79*, 303–312. https://doi.org/10.1016/j.fishres.2005.12.017.

Isaksen, B., & Valdemarsen, J. W. (1990). *Codend with short lastridge ropes to improve size selectivity in fish trawls*. ICES. CM 1990/B.

Karlsen, J. D., Krag, L. A., Albertsen, C. M., & Frandsen, R. P. (2015). From fishing to fish processing: Separation of fish from Crustaceans in the Norway lobster-directed multispecies trawl fishery improves seafood quality. *PloS One, 10*(11), Article e0140864. https://doi.org/10.1371/journal.pone.0140864.

Madsen, N., Skeide, R., Breen, M., Krag, L. A., Huse, I., & Soldal, A. V. (2008). Selectivity in trawl codend during haul-back operation – an overlooked phenomenon. *Fisheries Research, 91*, 168–174. https://doi.org/10.1016/j.fishres.2007.11.016.

Norwegian directorate of Fisheries. (2018a). *Norwegian directorate of fisheries*. Bergen, Norway: Norwegian Directorate of Fisheries (In Norwegian) https://www.fiskeridir.no/Yrkesfiske/Dokumenter/Reguleringsmoetet/Sakspapirer-innspill-og-referat-fraReguleringsmoetene/Reguleringsmoetet.

Norwegian directorate of Fisheries. (2018b). *J-119-2018, Utøvelsesforskriften.61*. Bergen, Norway: Norwegian Directorate of Fisheries (In Norwegian).

Olsen, S. H., Joensen, S., Tobiassen, T., Heia, K., Akse, L., & Nilsen, H. (2014). Quality consequences of bleeding fish after capture. *Fisheries Research, 153*, 103–107. https://doi.org/10.1016/j.fishres.2014.01.011.

Olsen, S. H., Tobiassen, T., Akse, L., Evensen, T. H., & Midling, K.Ø. (2013). Capture induced stress and live storage of atlantic cod (Gadus morhua) caught by trawl:

Consequences for the flesh quality. *Fisheries Research, 147*, 446–453. https://doi.org/10.1016/j.fishres.2013.03.009.
Rotabakk, B. T., Skipnes, D., Akse, L., & Birkeland, S. (2011). Quality assessment of Atlantic cod (Gadus morhua) caught by longlining and trawling at the same time and location. *Fisheries Research, 112*, 44–51. https://doi.org/10.1016/j.fishres.2011.08.009.
Sistiaga, M., Brinkhof, J., Herrmann, B., Grimaldo Langård, L., & Lilleng, D. (2016). Size selection performance of two flexible sorting grid section designs in the Northeast Arctic cod (Gadus morhua) and haddock (Melanogrammus aeglefinus) fishery. *Fisheries Research, 183*, 340–351. https://doi.org/10.1016/j.fishres.2016.06.022.
Sistiaga, M., Herrmann, B., Grimaldo, E., & Larsen, R. B. (2010). Assessment of dual selection in grid based selectivity systems. *Fisheries Research, 105*, 187–199. https://doi.org/10.1016/j.fishres.2010.05.006.
Soldal, A. V., Engås, A., & Isaksen, B. (1993). Survival of gadoids that escape from a demersal trawl. *ICES Marine Science Symposia, 196*, 122–127.
Tveit, G. M., Sistiaga, M., Herrmann, B., & Brinkhof, J. (2019). External damage to trawl-caught northeast arctic cod (Gadus morhua): Effect of codend design. *Fisheries Research, 214*, 136–147. https://doi.org/10.1016/j.fishres.2019.02.009.
Veldhuizen, L. J. L., Berentsen, P. B. M., de Boer, I. J. M., van de Vis, J. W., & Bokkers, E. A. M. (2018). Fish welfare in capture fisheries: A review of injuries and mortality. *Fisheries Research, 204*, 41–48. https://doi.org/10.1016/j.fishres.2018.02.001.
Yaragina, N. A., Aglen, A., & Sokolov, K. M. (2011). 5.4 cod. In T. Jakobsen, & V. K. Ožigin (Eds.), *The Barents Sea: Ecosystem, Resources, management: Half a century of Russian-Norwegian cooperation* (pp. 225–270). Trondheim: Tapir Academic Press.
Wileman, D. A., Ferro, R. S.T., Fonteyne, R., Millar, R. B. (Eds.) 1996. Manual of Methods of Measuring the Selectivity of Towed Fishing Gears. ICES Cooperative Research Report No. 215. 126 pp.