



# Quantification of gear inflicted damages on trawl-caught haddock in the Northeast Atlantic fishery

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## ARTICLE INFO

### Keywords:

Grid  
Codend design  
Bottom trawl  
Fish quality

## ABSTRACT

External damages are indicators of the overall quality of fish and fish welfare. Haddock is an important commercial species widespread in the North Atlantic, but few studies related to quality have been carried out on this species. We studied the levels of external damages on haddock captured with a demersal trawl in the Northeast Atlantic. Further, we investigated to what extent the compulsory sorting grid and diamond mesh codend gear configuration employed in this trawl fishery is responsible for the external damages observed during the capture process. We evaluated external damages on 563 haddock captured over 22 hauls. In general, the results showed that catching haddock without any gear inflicted damages using demersal trawls is challenging. However, the results also showed that the severity of most damages is low and the probability to catch haddock with no external damage can be significantly increased removing the grid and changing codend design.

## 1. Introduction

Reducing external damages on fish can increase fishermen's revenue and make their limited fishing quotas more valuable. On top of the purely economic benefit, increased general awareness on issues like fish quality and fish welfare add to the motivation of fishing as gently as possible and minimize damages inflicted on fish during the capture process. Thus, the research carried out globally in this respect has substantially increased in the last years (e.g. Huntingford et al., 2006; Davis, 2010; Diggles et al., 2011; Cheng et al., 2014; Veldhuizen et al., 2018).

Catch related damages are not the only factor affecting fish quality (Huss, 1995; Dowlati et al., 2013). However, the extent of external damages is generally considered a good indicator of the overall quality of the fish caught (Olsen et al., 2013). Several of the studies carried out to evaluate the quality of gadoid fish caught with different types of trawls, have been carried out by evaluation of the external damages inflicted during the capture process (e.g. Digre et al., 2010; Brinkhof et al., 2018a, 2018b; Tveit et al., 2019). In these studies, the overall condition of fish was evaluated based on external damages such as gear marks, bruises and blood marks, improper bleeding, loss of scales and/

or abrasion on the skin, and pressure damage on the flesh of the fish.

There are several commercially important haddock fisheries in the North Atlantic (Fryer et al., 2016), which makes research on this species of broad interest. One of these fisheries is the Northeast Atlantic demersal trawl fishery, where cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) are the two most important species. In this fishery, the landings of haddock have varied between 35,681 and 77,710 tons per year in the last decade (Norwegian directorate of Fisheries, 2019). Through large periods of the year, these two species are harvested mixed using demersal trawls. However, most studies carried out on the extent of external damages and fish quality of trawl-caught fish in this area have only considered cod (e.g. Olsen et al., 2013; Brinkhof et al., 2018a, 2018b; Tveit et al., 2019). To our knowledge, only Digre et al. (2010, 2017) and Karlsson-Drangsholt et al. (2018) have evaluated the quality of trawl-caught haddock in the last decade, and contrary to cod, no work has quantified the degree of damage with trawls. In addition, haddock are reportedly more vulnerable to gear damage than cod (Soldal et al., 1993; Ingolfsson et al., 2007; Digre et al., 2010; Karlsson-Drangsholt et al., 2018), meaning that this species is important to consider when quantifying the extent to which a gear can inflict damage to fish.

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The compulsory selectivity gear used in the Northeast Atlantic demersal trawl fishery is composed by a sorting grid with a minimum bar spacing of 55 mm and a codend with a minimum mesh size of 130 mm (Sistiaga et al., 2016). Fishermen can freely choose between three different types of grids (Herrmann et al., 2013), but the use of these grids has long been under dispute (e.g. Jørgensen et al., 2006) because fishermen mean that they are impractical, can damage fish and reduce waterflow in the extension piece of the trawl and the codend (Sistiaga et al., 2016). The latter can create problems to monitor (by acoustic catch sensors) the filling rate and catch volume in the codend. Further, for some years now there have been considerations to change the ordinary knotted codends used in the fishery for more gentle alternatives that would preserve the initial quality of the fish in the trawl better. Digre et al., 2010 tested the effect of turning the codend netting meshes 90 degrees (i.e. T90), Brinkhof et al. (2018b) tested the potential reduction in external damages by substituting an ordinary knotted codend by a knotless codend and a subsequent gentle codend, while Tveit et al., 2019 studied potential differences on the extent of external damages on cod with different knotted and knotless codend constructions. Despite the improvements reported in all three studies, none of the gear configurations tested the removal of the grid or substitution of the codends used in the fishery, which are normally a combination of knotted and knotless nettings (Tveit et al., 2019).

The aim of the present study was to quantify the extent of external damages on haddock captured with the compulsory grid and codend system used in the Northeast Atlantic demersal fisheries, and further, to investigate potential reduction of those damages by removing the grid and using a more gentle codend.

## 2. Materials and methods

### 2.1. Vessel, area, time and gear setup

Sea trials were carried out onboard the R/V “Helmer Hanssen” (63.8 m length overall and 4080 HP engine) between the 1 to 5 March 2019. The fishing area was off the coast of Finnmark (North of Norway) between 71°31.33–71°54.76 N and 24°40.65–25°57.53 E. Depths varied between 263 and 291 m. During the fishing trials we used two identical two-panel trawls (type Alfredo nr. 3) built entirely of 150 mm polyethylene (PE) meshes and rigged the same.

In one of the trawls we installed a 2-panel Sort-V grid section (Herrmann et al., 2013; Fig. 1), a 2- to 4-panel transition section and a

4-panel diamond mesh codend. The bar spacing in the grid was measured to be  $55.88 \pm 2.38$  mm (mean  $\pm$  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 diamond mesh codend was 11 m long, 64 free meshes around, and was constructed of 8 mm PE knotted twine. The meshes were measured to be  $131.1 \pm 2.73$  mm. Measurements were made following the protocol described in Wileman et al. (1996) (Fig. 1a).

In the other trawl, we installed a codend with a quality preserving segment identical to the one used by Brinkhof et al. (2018b) and we term it a “gentle codend”. This quality preserving segment was 10 m long and comprised four panels. It was built of 6 mm nominal mesh size knotless “tobis netting” (nr. 15), had a circumference of 1440 meshes (360-meshes wide in each panel) and was strengthened by four 36 mm lastridge ropes (5% shorter than the codend netting). Unlike in the trials carried out by Brinkhof et al. (2018b), the catch accumulated in this segment during the whole towing period, and due to the small-meshed knotless netting used and the potential reduction in waterflow, this segment was meant to be gentle to the catch. In front of the quality preserving segment, we installed a 4-panel netting section built of  $150.2 \pm 3.4$  mm (9 mm PE twine) mesh size knotless netting (Ultra cross) to ensure sufficient size selection. This section was 49 meshes long and had 60 open meshes around. To ensure mesh opening the four lastridges in this selective netting section were 30% shorter than the codend netting. 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 selection section (Fig. 1b).

The gear setup employed in the trials allowed a comparison between the levels of external damages observed on haddock with both configurations. By comparing the damage levels observed with the gentle codend design and the grid and codend design used by the fleet, would enable us quantifying to what extent the damages observed with the grid and codend system could be related to the grid and standard knotted codend themselves.

### 2.2. Data sampling and categorization of damage on fish

The two trawls were fished one at the time and alternated during the trials. As the experiments were carried out on a research vessel and the vessel would have capacity problems with catches exceeding 2–3 tons, towing time was set based on the echosounder fish registration levels and the signal from the catch sensor. Once the catch came

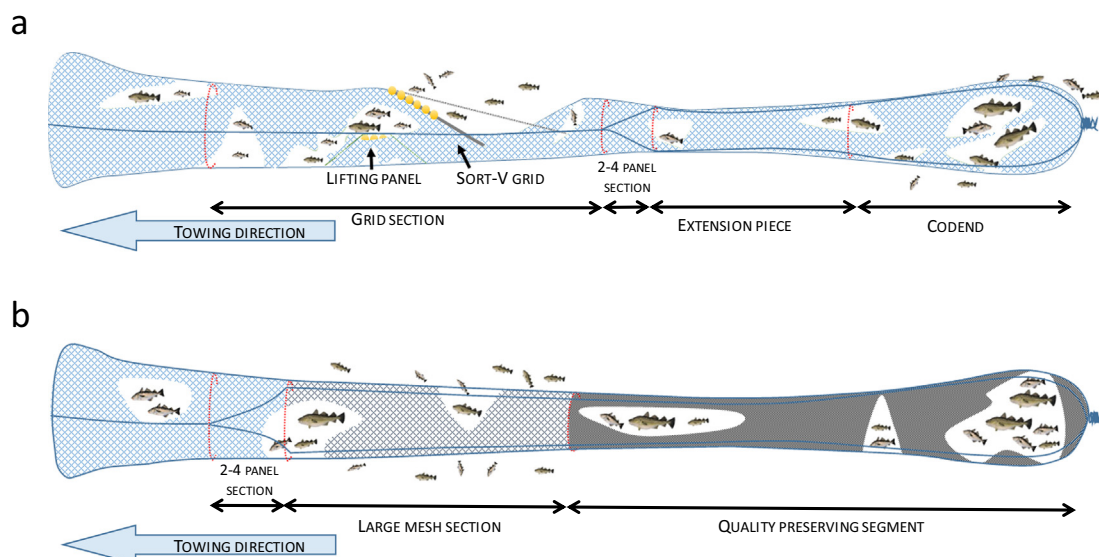


Fig. 1. Grid and codend configuration (a) and gentle codend (b) used during the sea trials.

**Table 1**

Catch damage index used to evaluate external damages on the fish included in the study. Names in brackets are the short names for each damage type.

Catch damage	Score				Description
	No damage	Slight	Moderate	Severe	
Type					
Gear marks (Gear)	0	1	2	3	Marks caused by gear contact
Ecchymosis (Ecchy)	0	1	2	3	Discoloration on the skin, bruises.
Exsanguination (Exsan)	0	1	2	3	Improper bleeding, blood in veins.
Skin abrasion (Skin)	0	1	2	3	Loss of scales
Pressure (Press)	0	1	2	3	Noticeable pressure damages

onboard, 30 haddock were randomly selected from the catch for analysis of external damage. The density of haddock in the fishing ground was variable, and in the hauls that did not contain 30 individuals of this species, all haddock available were evaluated. The fish was 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. Since, factory trawlers mostly deliver headed and gutted fish (i.e. HG product); all haddock were headed and gutted prior to the assessment of catch damages. For each haddock, the level of damage incurred during the capture process was evaluated following the scale presented in Table 1 (Rotabakk et al., 2011; Essaiassen et al., 2013; Brinkhof et al., 2018a, 2018b). The assessment was performed as a blinded experiment where the fish from both gears was evaluated by the two same trained scientists through the whole data collection period. Prior to the data collection period and for various hauls, both scientists assessed the same fish in order to standardize the assessment criteria.

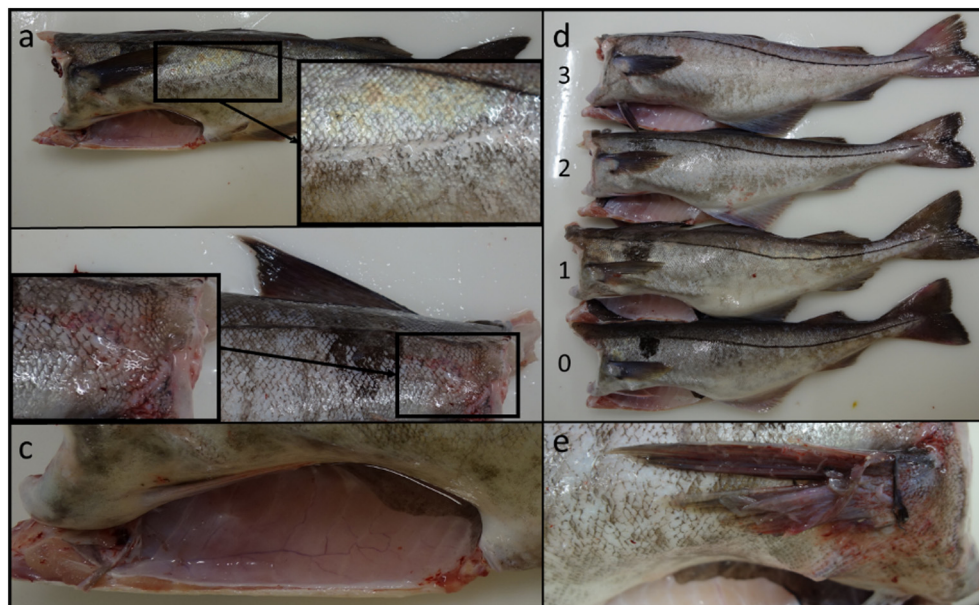
We assessed five different external damage types on each fish: a) marks caused by contact with the gear (gear marks); b) bruises and blood marks in the skin and flesh (ecchymosis); c) blood in the veins due to improper bleeding (exsanguination); d) loss of scales and/or abrasion on the skin (skin abrasion); and e) noticeable pressure damage on the flesh of the fish (pressure) (Table 1; Fig. 2). Each fish was given a score for each damage type according to the severity of the damage. A fish that scored 0 was considered to have no damage, whereas a fish that scored 3 was severely damaged for that damage type (Table 1; Fig. 2d). For all fish included in the study, both body sides were considered in the evaluation.

### 2.3. Data analysis

The data analysis method used 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) (Brinkhof et al., 2018a). Quantifying the probability of obtaining haddock without any external damage at all (i.e., a fish with no damage in any of the damage types simultaneously) is relevant. In addition, quantifying the probability of obtaining fish with different severity (score) of specific damage types in the catch will help identify the potential measures needed to reduce these damages. 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 (Brinkhof et al., 2018a). This is important to consider because the combination of multiple damages have implications for the overall fish quality and welfare.

The catch data were derived according to Table 1 for the samples of haddock taken from each of the hauls. The catch damage data were first analysed for each gear separately. Thereafter, the potential difference between gears was inferred using the method described in Brinkhof et al. (2018a) for quantifying the difference in probability.

The expected average value  $\widehat{p}_{as}$  for the probability for a score  $s$  on catch damage type  $a$  was determined using Eq. (1):



**Fig. 2.** Illustration of the five damage types evaluated during the study: gear marks (a), ecchymosis (b), exsanguination (c), skin abrasion (d) and pressure (e).

$$\widehat{p}_{as} = \frac{\sum_{j=1}^m \left\{ \frac{1}{n_j} \sum_{t=1}^{n_j} \text{equal}(s, k_{ajt}) \right\}}{m}$$

with

$$\text{equal}(s, k) = \begin{cases} 1 & \forall k = s \\ 0 & \forall k \neq s \end{cases} \quad (1)$$

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  $\widehat{p}_{as}$  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 Eq. (2):

$$\widehat{p}_{as} = \frac{\sum_{j=1}^m \left\{ \frac{1}{n_j} \sum_{t=1}^{n_j} \text{lequal}(s, k_{ajt}) \right\}}{m}$$

with

$$\text{lequal}(s, k) = \begin{cases} 1 & \forall k \leq s \\ 0 & \forall k > s \end{cases} \quad (2)$$

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

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

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

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

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

and

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

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

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

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

Eqs. (3) and (4) were applied for all possible combinations of catch damage types.

The method described above incorporates the effect of potential between-haul variation in the external damages observed on fish 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% confidence intervals (CI) by applying a double bootstrap methodology. By providing bootstrap-based estimates with uncertainties for the difference in the estimated external damage scores, this method allowed direct comparison of external damage levels between the haddock captured with the different gears. When the uncertainty for the differences in the estimated external damage scores does not include 0%, the result means that the difference between the gears for that specific damage type (or types) is significant. The bootstrapping method used is thoroughly described in Brinkhof et al. (2018a).

All analyses in the study were carried out using the computer software SELNET (Herrmann et al., 2012).

### 3. Results

#### 3.1. Data collection

During the sea trials 25 hauls were carried out (Table 2). Haul one, six, and thirteen did not contain any haddock and therefore were not included in this study. Thus, the study comprised of 11 hauls with each of the gears tested and evaluated external damages on 563 haddock (Table 2). The catches with the gentle codend configuration varied between 636 and 2945 kg, whereas the catches with the grid and codend configuration varied between 524 and 3421 kg (Table 2). An unpaired  $t$ -test showed that the catches between the gears did not differ significantly ( $p = .384$ ), which means that the potential differences in damage between the gears tested do not originate from differences in catch size.

#### 3.2. External damages on haddock captured with the grid and 130 mm diamond mesh codend configuration

For haddock captured with the grid and 130 mm diamond mesh codend configuration, the probability to obtain fish with no damage was 0.00% (0.00%–0.00%). Further, 53.05% (43.92–63.37) and 11.45% (5.99–18.11) of the fish were inflicted some type of slight damage or moderate damage, respectively (Fig. 3; Table 3), when captured with the grid and 130 mm diamond mesh codend configuration. Skin abrasion was the most frequent type of damage observed on



**Table 2**

Overview of the hauls conducted, and the numbers of haddock measured during the data collection period. \*: Missing values.

Haul #	Gear	Date	Time	Tow time (min)	Lat.	Long.	Depth (m)	n Haddock	Catch (kg)
2	Gentle codend	1.03.2019	02:46:23	90	7149.58 N	02446.53 E	267.63	30	854
3	Gentle codend	1.03.2019	05:09:55	91	7154.01 N	02449.99 E	263.35	30	636
4	Grid + codend	1.03.2019	07:46:12	90	7154.76 N	02440.65 E	276.94	30	524
5	Grid + codend	1.03.2019	20:24:56	60	7136.96 N	02540.52 E	280.38	30	3421
7	Gentle codend	2.03.2019	07:01:42	43	7136.10 N	02548.26 E	282.57	30	1660
8	Grid + codend	2.03.2019	11:20:45	90	7134.91 N	02542.77 E	282.62	30	2275
9	Grid + codend	2.03.2019	16:02:01	60	7135.04 N	02554.40E	285.33	23	563
10	Gentle codend	2.03.2019	18:00:05	50	7135.12 N	02543.03 E	279.4	30	1589
11	Gentle codend	2.03.2019	22:17:11	19	7133.59 N	02544.88 E	280.48	30	948
12	Grid + codend	3.03.2019	00:41:59	43	7131.33 N	02548.15 E	275.99	15	1468
14	Gentle codend	3.03.2019	06:47:57	60	7129.95 N	02546.59 E	284.85	18	1074
15	Gentle codend	3.03.2019	10:09:03	59	7137.49 N	02545.90 E	288.25	30	824
16	Grid + codend	3.03.2019	12:12:32	120	7134.93 N	02546.25 E	284.01	30	1344
17	Grid + codend	3.03.2019	15:01:58	118	7138.04 N	02540.20 E	281.74	29	1469
18	Gentle codend	3.03.2019	17:54:47	68	7132.66 N	02529.15 E	287.47	14	1783
19	Gentle codend	3.03.2019	22:51:55	54	7135.18 N	02532.81 E	280.98	30	1868
20	Grid + codend	4.03.2019	03:06:06	61	7135.78 N	02535.72 E	*	19	1893
21	Grid + codend	5.03.2019	02:08:01	75	7134.32 N	02530.93 E	286.35	6	2332
22	Gentle codend	5.03.2019	05:43:05	78	7132.93 N	02531.58 E	289.13	30	2945
23	Gentle codend	5.03.2019	12:31:24	75	7135.00 N	02554.64 E	290.1	29	2825
24	Grid + codend	5.03.2019	18:28:02	24	7136.67 N	02557.30 E	290.48	30	1257
25	Grid + codend	5.03.2019	20:10:49	38	7136.82 N	02557.53 E	290.85	20	*

haddock captured with the grid and 130 mm diamond mesh codend configuration. Only 4.20% (1.21%–8.18%) of the individuals were exempt from this type of damage and more than half of the haddock evaluated showed moderate or severe skin damage (Fig. 3; Table 3). Damage in the form of poor exsanguination and gear marks were also frequently observed on haddock captured with the grid and 130 mm diamond mesh codend configuration with probabilities to have slight damages of 64.12% (54.13%–74.67%) and 61.45% (51.15%–72.45%), respectively. The probability to obtain fish with just slight or no ecchymosis was over 97% and pressure damages were seldom observed on haddock captured with this gear (Table 3).

### 3.3. External damages on haddock captured with the gentle codend

As for the haddock captured with the grid and 130 mm diamond mesh codend configuration, skin abrasion was the most frequent damage type (Fig. 4) for haddock captured with the gentle codend, and the probabilities to get fish with no damage or slight damage of this type were respectively 17.61% (9.81%–24.82%) and 45.18% (36.28%–52.87%) (Table 4). Exsanguination and gear marks were the two next most frequent damages observed as the probabilities to capture fish without these types of damages were respectively 41.86% (32.81%–51.27%) and 46.51% (33.55%–60.22%). Ecchymosis and pressure damages were the two least frequent damages observed on haddock captured with this gear as the probabilities to capture fish without these damage types were respectively 77.41% (70.49%–83.68%) and 96.35% (92.88%–98.67%). Except for skin abrasion, where moderate and severe damages accounted for almost 40% of the damages observed, the levels of damages observed were slight (Table 4). The probability to capture haddock with no damage at all with this codend was estimated to be at only 2.66% (0.39%–5.45%), however, the probability to capture fish with just slight damages of any type was 56.48% (44.94%–66.34%).

Table 4.

### 3.4. Differences on external damages on haddock captured with the grid and 130 mm diamond mesh codend configuration and the gentle codend

The probability to capture haddock without any type of damage was significantly higher with the gentle codend than with the grid and 130 mm diamond mesh codend configuration (2.66% (0.39%–5.45%)) (Table 5; Fig. 5). This was also reflected in the estimations for each

damage type individually as the probability to capture haddock without ecchymosis or skin abrasion was significantly higher with the gentle codend than with the grid and 130 mm diamond mesh codend configuration. The difference in probability to capture fish without these specific damage types separately were respectively 17.10% (5.31%–29.47%) and 13.41% (5.22%–20.86%). These differences meant an increase in probability to obtain fish without ecchymosis or skin damage of 28.36% (7.28%–59.52%) and 319.39% (87.30%–1645.03%) respectively, when using the gentle codend instead of the grid and 130 mm diamond mesh codend configuration. Further, the probability to capture haddock with slight ecchymosis or moderate skin abrasion was significantly lower for the gentle codend than for the grid and 130 mm diamond mesh codend configuration (Table 5; Fig. 5). More haddock exhibited gear marks (12.92% (–2.19%–30.65%)) or poor exsanguination (5.98% (–8.50%–20.58%)) when captured with the grid and 130 mm diamond mesh codend configuration than when captured with the gentle codend. Also, changing from the grid and 130 mm diamond mesh codend configuration to the gentle codend meant an increase in the probability to capture fish without any gear marks or poor exsanguination of 38.48% (–11.24–118.24) and 16.67% (–18.45–78.56), respectively. However, these differences were not significant (Table 5; Fig. 5). The differences in pressure damages between the gears were negligible. Finally, when all five external damage types were considered combined, the probability to obtain fish with only slight damage of some kind or no damage at all was almost 10% higher when the gentle codend was used than when the grid and codend gear configuration was used. However, this difference was not significant. Due to that the probabilities to find fish with moderate or severe damages with any of the two gears were in general low, most of the significant differences between the gears were found for the lower and not higher degrees of damages. There were no differences between the probabilities to find fish with severe damages of any type between the gears, and significant differences for moderate damages were only found for skin abrasion.

## 4. Discussion

In the present study, the results showed that the probability to obtain haddock with no external damage of any type was 0.00% (0.00%–0.00%) with the grid and 130 mm diamond mesh codend configuration and 2.66% (0.39%–5.45%) with the gentle codend. Further, in the only study that has earlier reported external damages in

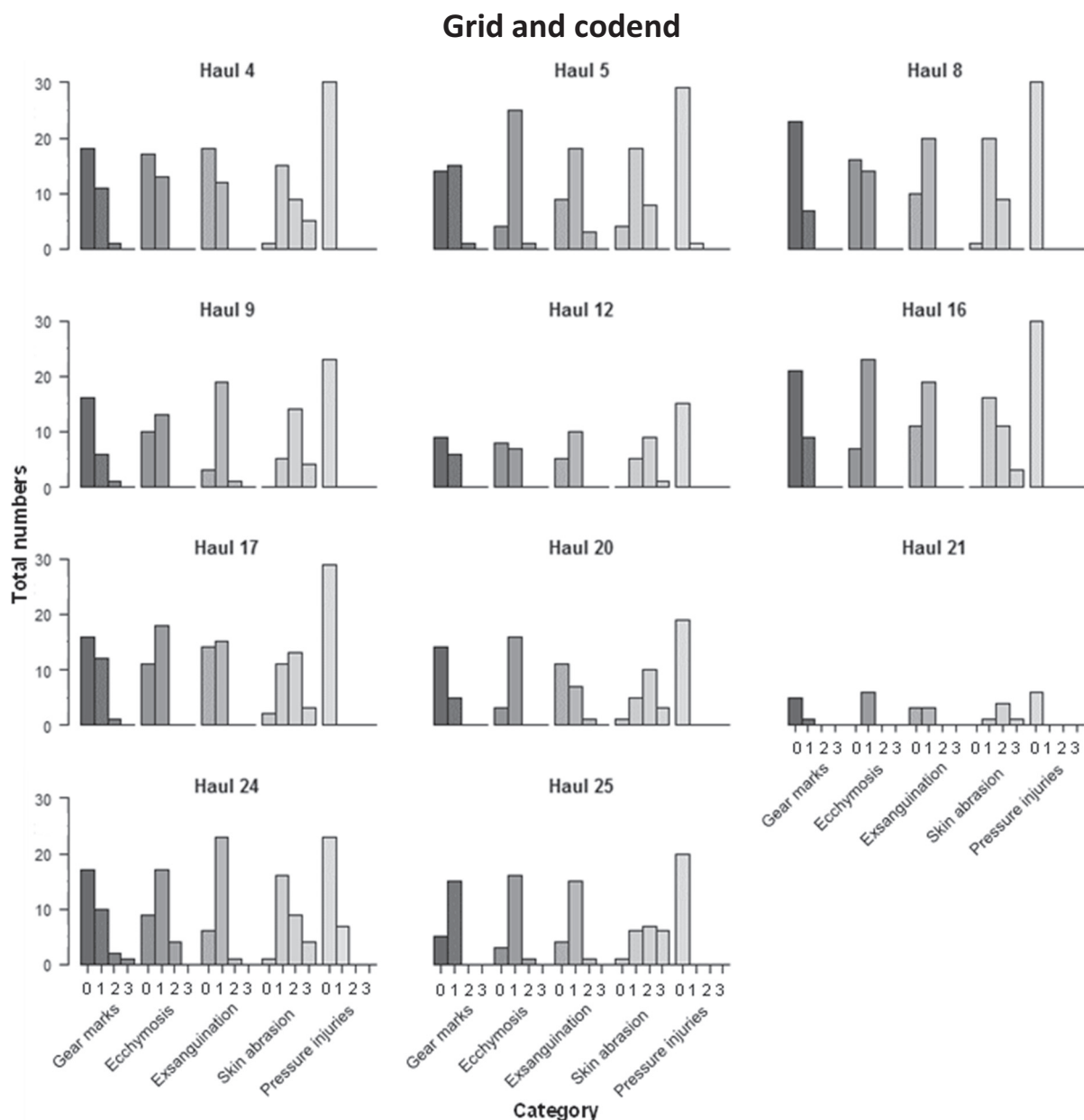


Fig. 3. Catch damage score histograms for haddock captured with the grid and 130 mm diamond mesh codend configuration in each haul.

trawl-caught haddock, Digre et al. (2010) showed that over 98% of the haddock had some degree of scale loss, over 21% of the haddock had some type of gear injury, and over 20% of the haddock had bruises. These results illustrate that catching haddock without external damages can be challenging when using trawl gear.

In general, the levels of damage observed on haddock captured with the grid and 130 mm diamond mesh codend configuration investigated in this study are higher than those observed for cod in previous studies. Both Brinkhof et al. (2018a) and Tveit et al. (2019) reported external damage levels of cod captured with a grid and codend configuration. In these two studies, the probabilities to catch cod without external damages of any kind were 21% (9%–33%) and 9% (5%–16%) respectively, whereas the probabilities to catch fish with none or just slight damages were 88% (82%–94%) and 56% (43%–67%), respectively. In both cases, the probability to catch fish with no damages was higher than that observed for haddock in the present study (0.00% (0.00%–0.00%)). Further, the probability to catch haddock with none or only slight damages of any type was also lower in both cases, but

only significant when the results from the present study (46.95% (36.63%–56.08%)) were compared to those by Brinkhof et al. (2018a).

The processes in the aft of the two gear configurations tested were different. In the compulsory gear, haddock have to pass a size sorting device and may actively contact the meshes of the codend in an attempt to escape. In the alternative configuration, we do not know if any of the retained haddock contacted the panels of the square mesh section before they entered the gentle codend. However, the results in this study show that at least part of the external damages observed on haddock captured with the grid and 130 mm diamond mesh codend configuration are consequence of the use of these two specific gear components, because these damages are significantly reduced when they are substituted by another codend. In particular, the results show that some specific external damages like skin abrasion and ecchymosis on trawl-caught haddock can be significantly reduced by removing the sorting grid and substituting the ordinary codend by a gentler codend. Due to the experimental setup used in the present experiment, it is not possible to conclude whether the reduction in damages observed is a sole effect

**Table 3**  
Probability of obtaining haddock with different types and levels of catch damage (scores) when captured with the grid and 130 mm diamond mesh codend configuration; values in brackets represent 95% confidence intervals.

Damage level	Grid and 130 mm codend configuration					
	0	1	2	3	≤1	≤2
All combined	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	46.95% (36.63%–56.08%)	88.55% (81.89%–94.01%)
Gear	33.59% (22.75%–43.82%)	64.12% (54.13%–74.67%)	2.29% (0.00%–6.38%)	0.00% (0.00%–0.00%)	97.71% (93.62%–100.00%)	100.00% (100.00%–100.00%)
Ecchy	60.31% (49.78%–70.37%)	37.02% (27.61%–47.74%)	2.29% (0.41%–5.10%)	0.38% (0.00%–1.73%)	97.33% (94.14%–99.58%)	99.62% (98.27%–100.00%)
Exsan	35.88% (24.04%–46.32%)	61.45% (51.15%–72.45%)	2.67% (0.37%–5.99%)	0.00% (0.00%–0.00%)	97.33% (94.01%–99.63%)	100.00% (100.00%–100.00%)
Skin	4.20% (1.21%–8.18%)	45.04% (33.19%–53.36%)	39.31% (31.60%–49.32%)	11.45% (6.19%–18.41%)	49.24% (36.59%–58.62%)	88.55% (81.59%–93.81%)
Press	96.95% (91.29%–100.00%)	3.05% (0.00%–8.71%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	100.00% (100.00%–100.00%)	100.00% (100.00%–100.00%)
Gear & Ecchy	19.08% (11.68%–26.86%)	21.37% (12.24%–34.07%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	95.04% (89.34%–99.19%)	99.62% (98.37%–100.00%)
Gear & Exsan	12.21% (5.45%–19.92%)	38.55% (29.33%–48.52%)	0.38% (0.00%–1.74%)	0.00% (0.00%–0.00%)	95.42% (90.60%–99.10%)	100.00% (100.00%–100.00%)
Ecchy & Exsan	24.05% (14.83%–32.63%)	23.66% (16.93%–33.92%)	0.38% (0.00%–1.68%)	0.00% (0.00%–0.00%)	95.04% (90.94%–98.42%)	99.62% (98.29%–100.00%)
Gear & Ecchy & Exsan	7.25% (2.53%–12.45%)	13.36% (7.33%–21.71%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	93.13% (87.42%–97.71%)	99.62% (98.32%–100.00%)
Gear & Skin	0.38% (0.00%–1.56%)	28.24% (20.28%–36.12%)	1.53% (0.00%–5.05%)	0.00% (0.00%–0.00%)	48.47% (36.73%–57.94%)	88.55% (81.39%–93.80%)
Ecchy and Skin	1.91% (0.00%–4.40%)	16.03% (8.90%–22.45%)	0.76% (0.00%–2.60%)	0.38% (0.00%–1.79%)	48.47% (35.93%–58.11%)	88.55% (81.13%–93.58%)
Gear & Ecchy & Skin	0.00% (0.00%–0.00%)	8.78% (3.36%–15.67%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	47.71% (36.73%–56.91%)	88.55% (81.53%–93.61%)
Exsan & Skin	1.15% (0.00%–3.14%)	27.86% (19.05%–35.92%)	1.53% (0.00%–4.07%)	0.00% (0.00%–0.00%)	48.09% (36.07%–57.28%)	88.55% (81.71%–93.96%)
Gear & Exsan & Skin	0.00% (0.00%–0.00%)	17.94% (11.74%–24.82%)	0.38% (0.00%–1.88%)	0.00% (0.00%–0.00%)	47.33% (36.36%–56.29%)	88.55% (81.56%–93.58%)
Ecchy & Exsan & Skin	1.15% (0.00%–3.15%)	9.92% (4.84%–14.39%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	47.71% (35.37%–57.39%)	88.55% (81.64%–93.94%)
Gear & Ecchy & Exsan & Skin	0.00% (0.00%–0.00%)	5.34% (1.48%–10.12%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	46.95% (35.56%–56.71%)	88.55% (81.41%–93.82%)
Gear & Press	32.82% (21.37%–44.44%)	2.29% (0.00%–6.77%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	97.71% (93.77%–100.00%)	100.00% (100.00%–100.00%)
Ecchy & Press	58.78% (48.50%–69.17%)	1.53% (0.00%–4.26%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	97.33% (94.01%–99.65%)	99.62% (98.31%–100.00%)
Gear & Ecchy & Press	18.70% (12.23%–26.20%)	1.15% (0.00%–3.36%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	95.04% (89.57%–99.14%)	99.62% (98.22%–100.00%)
Exsan & Press	35.11% (23.78%–45.49%)	2.29% (0.00%–6.62%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	97.33% (94.35%–99.63%)	100.00% (100.00%–100.00%)
Gear & Exsan & Press	12.21% (5.34%–19.46%)	1.53% (0.00%–4.46%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	95.42% (90.70%–99.13%)	100.00% (100.00%–100.00%)
Ecchy & Exsan & Press	23.66% (14.03%–32.31%)	1.15% (0.00%–3.52%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	95.04% (90.94%–98.38%)	99.62% (98.26%–100.00%)
Gear & Ecchy & Exsan & & Press	7.25% (2.38%–12.50%)	0.76% (0.00%–2.50%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	93.13% (86.90%–97.79%)	99.62% (98.25%–100.00%)
Skin & Press	4.20% (1.23%–7.90%)	1.15% (0.00%–4.25%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	49.24% (37.25%–58.76%)	88.55% (81.01%–93.83%)
Gear & Skin & Press	0.38% (0.00%–1.71%)	0.76% (0.00%–3.13%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	48.47% (35.55%–57.66%)	88.55% (81.58%–93.87%)
Ecchy & Skin & Press	1.91% (0.00%–4.44%)	0.38% (0.00%–1.64%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	48.47% (36.13%–57.88%)	88.55% (80.67%–93.71%)
Gear & Ecchy & Skin & Press	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	47.71% (36.74%–57.41%)	88.55% (81.57%–93.69%)
Exsan & Skin & Press	1.15% (0.00%–2.95%)	1.15% (0.00%–3.94%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	48.09% (36.16%–56.92%)	88.55% (81.00%–93.73%)
Gear & Exsan & Skin & Press	0.00% (0.00%–0.00%)	0.76% (0.00%–2.89%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	47.33% (35.47%–56.09%)	88.55% (81.78%–93.77%)
Ecchy & Exsan & Skin & Press	1.15% (0.00%–3.13%)	0.38% (0.00%–1.64%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	47.71% (36.29%–56.89%)	88.55% (80.95%–93.73%)

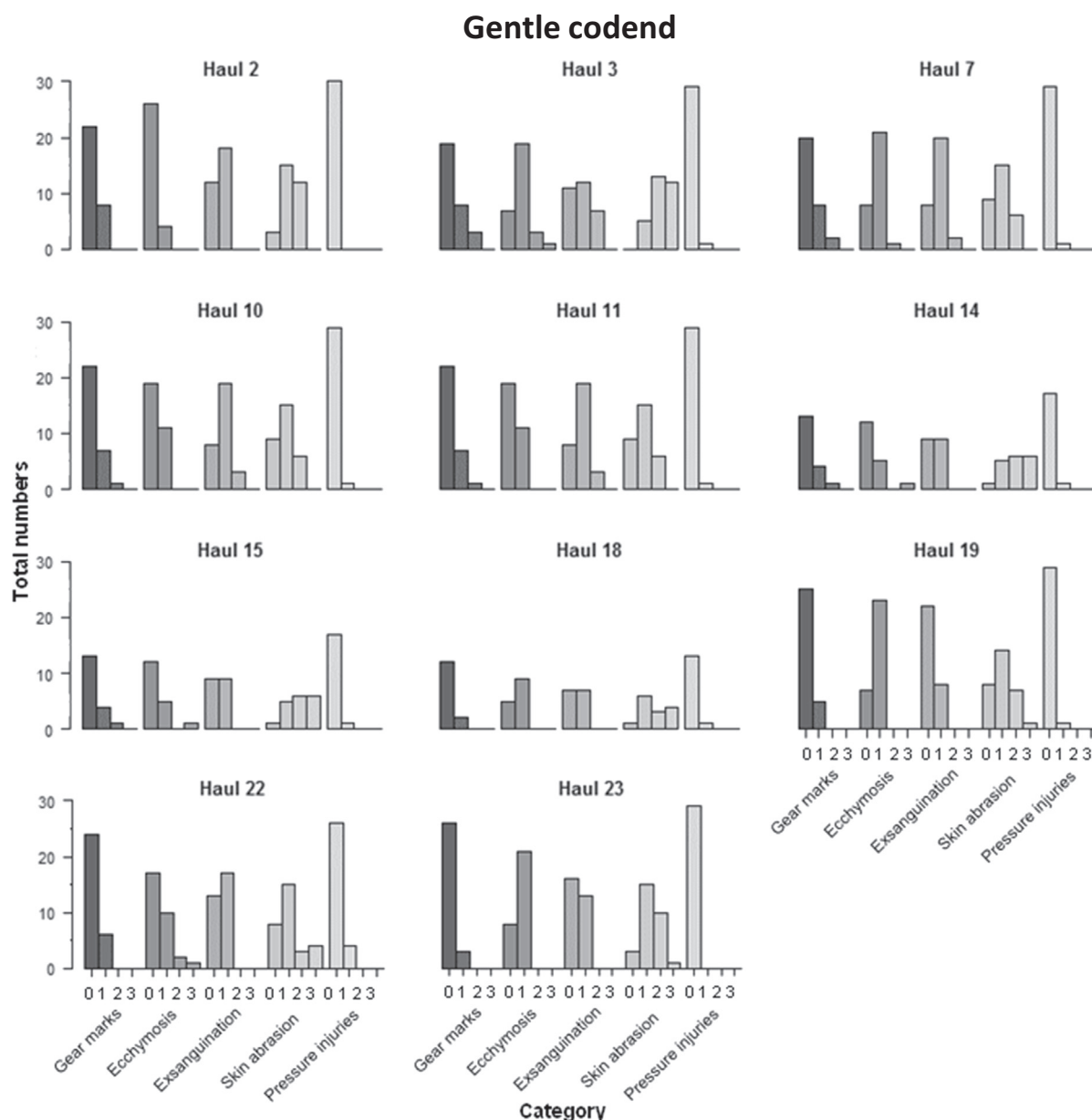


Fig. 4. Catch damage score histograms for haddock captured with the gentle codend configuration in each haul.

of the change in the codend configuration used or if removing the grid also contributed to the reduction on external damages observed. The passage below the sort-V grid is quite narrow and similar grids have earlier been documented to have clogging problems (Sistiaga et al., 2016), which one would expect to contribute to external damages like gear marks and skin abrasion on fish. Brinkhof et al. (2018b) carried out an experiment where they evaluated external damages on cod captured with a grid section followed by a sequential codend and a grid section followed by an ordinary trawl codend. Despite removing the potential impact of the grid, their results showed significant differences on the levels of external damages observed on cod with the different gears. Thus, even though we cannot separate the extent of the external damages infringed by the grid or the diamond mesh codend in the grid and 130 mm diamond mesh codend configuration, considering the similarity between the sequential codend used by Brinkhof et al. (2018b) and the gentle codend used in the present study, it is likely that at least part of the difference observed for haddock between the two configurations tested in this study is due to difference in the codends used, and not solely due to that the grid was not present in the configuration

with the gentle codend.

Most damages observed on haddock during the trials were just slight damages. Nearly 47% of the fish captured with the compulsory grid and codend gear and over 56% of the fish captured with the gentle codend showed none or only slight damages of any kind (Table 3; Table 4). Even though external damages are generally considered to be a good indicator for quality (Olsen et al., 2013), it can be difficult to assess the importance and impact of these damages on the overall fish quality of the fish delivered. Also, the type of damage exhibited can determine the type of product and market the fish will be allocated to. Fish quality and ultimately price in the market, are not solely determined by the level of external damages, and other factors such as freshness for example are at least as important (Cheng et al., 2014). Further, depending on how and how much the fish is processed before it is landed, the extent of external damages infringed to fish can be more or less relevant. For example, one could expect that slight gear marks or skin abrasion would have higher impact on the overall quality perception of haddock landed as whole or headed and gutted, than of haddock landed as filet. Therefore, in the future, it would be interesting to relate the impact of different

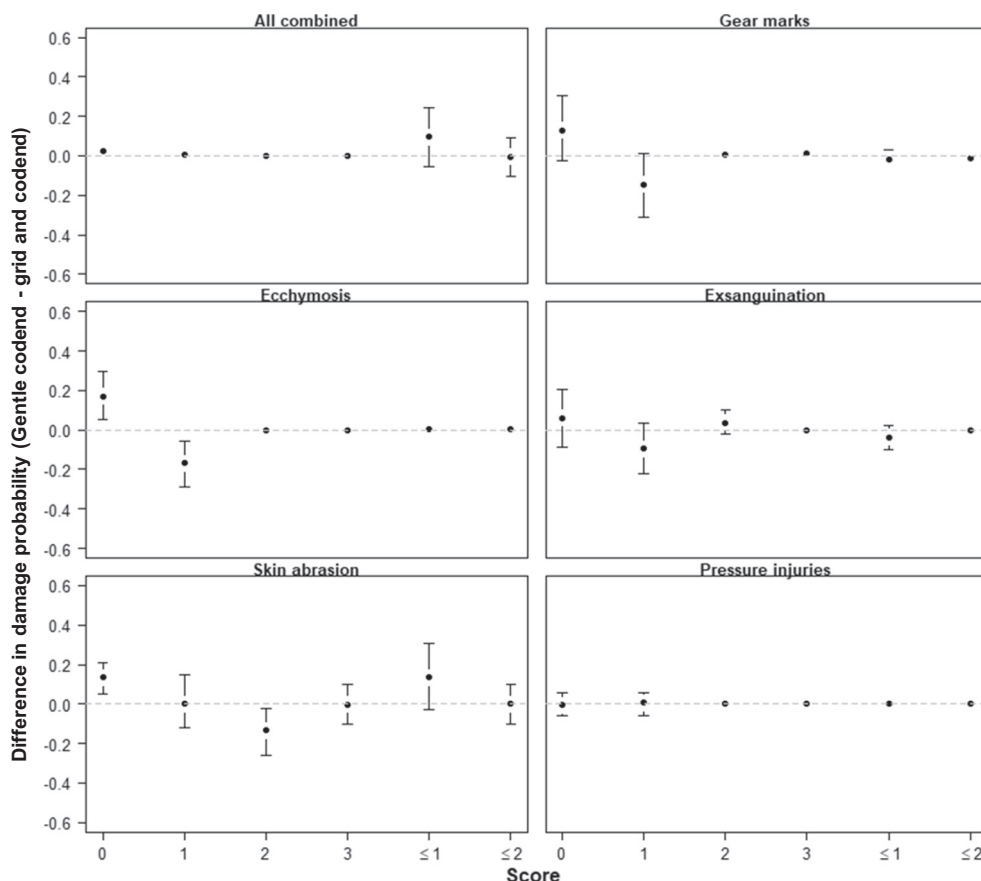


**Table 4**  
Probability of obtaining haddock with different types and levels of catch damage (scores) when captured with the gentle codend configuration; values in brackets represent 95% confidence intervals.

Damage level	Gentle codend					
	0	1	2	3	≤1	≤2
All combined						
Gear	2.66% (0.39%–5.45%)	0.33% (0.00%–1.64%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	56.48% (44.94%–66.34%)	88.04% (79.53%–95.03%)
Ecchy	46.51% (33.55%–60.22%)	49.50% (36.07%–62.03%)	2.66% (0.34%–5.43%)	1.33% (0.00%–3.28%)	96.01% (92.19%–99.01%)	98.67% (96.72%–100.00%)
Exsan	77.41% (70.49%–83.68%)	20.27% (14.92%–25.50%)	2.33% (0.34%–5.68%)	0.00% (0.00%–0.00%)	97.67% (94.32%–99.66%)	100.00% (100.00%–100.00%)
Skin	41.86% (32.81%–51.27%)	51.83% (43.79%–60.07%)	6.31% (1.67%–11.59%)	0.00% (0.00%–0.00%)	93.69% (88.41%–98.33%)	100.00% (100.00%–100.00%)
Press	17.61% (9.81%–24.82%)	45.18% (36.28%–52.87%)	25.91% (18.12%–33.44%)	11.30% (4.42%–20.14%)	62.79% (49.46%–73.51%)	88.70% (79.86%–95.58%)
Gear & Ecchy	96.35% (92.88%–98.67%)	3.65% (1.33%–7.12%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	100.00% (100.00%–100.00%)	100.00% (100.00%–100.00%)
Gear & Exsan	38.54% (28.90%–49.01%)	11.30% (6.33%–17.11%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	94.02% (89.47%–97.59%)	98.67% (96.85%–100.00%)
Ecchy & Exsan	18.94% (12.46%–25.59%)	24.25% (17.24%–32.32%)	0.33% (0.00%–1.40%)	0.00% (0.00%–0.00%)	90.37% (83.56%–95.99%)	98.67% (96.70%–100.00%)
Gear & Ecchy & Exsan	33.89% (24.46%–42.81%)	12.29% (7.67%–17.44%)	1.00% (0.00%–2.88%)	0.00% (0.00%–0.00%)	92.36% (86.60%–97.78%)	100.00% (100.00%–100.00%)
Gear & Skin	16.61% (10.00%–23.38%)	5.98% (1.97%–11.36%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	89.04% (82.21%–95.10%)	98.67% (96.75%–100.00%)
Ecchy and Skin	7.97% (4.32%–11.96%)	23.92% (16.50%–31.76%)	1.00% (0.00%–3.37%)	0.66% (0.00%–2.19%)	60.47% (48.26%–70.43%)	88.04% (79.05%–94.59%)
Gear & Ecchy & Skin	14.62% (8.20%–21.68%)	9.97% (6.01%–14.34%)	0.33% (0.00%–1.52%)	0.00% (0.00%–0.00%)	61.79% (49.52%–72.64%)	88.70% (79.46%–95.44%)
Exsan & Skin	6.98% (3.11%–11.18%)	5.65% (2.54%–9.27%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	59.47% (46.81%–68.87%)	88.04% (79.58%–95.09%)
Gear & Exsan & Skin	2.66% (0.61%–5.52%)	25.58% (18.33%–32.99%)	1.99% (0.00%–4.98%)	0.00% (0.00%–0.00%)	59.47% (46.13%–70.57%)	88.70% (79.24%–94.95%)
Ecchy & Exsan & Skin	5.65% (2.07%–9.82%)	13.62% (8.95%–18.84%)	0.33% (0.00%–1.65%)	0.00% (0.00%–0.00%)	57.14% (44.24%–67.17%)	88.04% (79.53%–94.90%)
Gear & Ecchy & Exsan & Skin	2.66% (0.66%–5.63%)	6.98% (3.49%–10.61%)	0.33% (0.00%–1.36%)	0.00% (0.00%–0.00%)	58.80% (47.02%–69.75%)	88.70% (79.86%–95.83%)
Gear & Press	46.51% (33.97%–60.41%)	3.99% (1.33%–7.33%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	56.48% (45.32%–66.88%)	88.04% (79.37%–94.81%)
Ecchy & Press	74.75% (68.18%–81.05%)	2.66% (0.67%–5.32%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	96.01% (92.42%–98.96%)	98.67% (96.72%–100.00%)
Gear & Ecchy & Press	38.54% (28.16%–49.18%)	1.00% (0.00%–2.85%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	97.67% (94.46%–99.68%)	100.00% (100.00%–100.00%)
Exsan & Press	40.20% (31.40%–49.51%)	1.99% (0.33%–4.50%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	94.02% (89.47%–97.56%)	98.67% (96.72%–100.00%)
Gear & Exsan & Press	18.94% (12.18%–26.35%)	1.00% (0.00%–2.76%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	93.69% (88.50%–98.22%)	100.00% (100.00%–100.00%)
Ecchy & Exsan & Press	32.89% (23.78%–41.40%)	0.33% (0.00%–1.58%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	90.37% (83.56%–95.90%)	98.67% (96.96%–100.00%)
Gear & Ecchy & Exsan & & Press	16.61% (10.67%–23.36%)	0.33% (0.00%–1.59%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	92.36% (85.94%–97.92%)	100.00% (100.00%–100.00%)
Skin & Press	17.28% (10.26%–24.32%)	2.66% (0.67%–5.78%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	62.79% (49.34%–73.31%)	88.70% (80.29%–95.19%)
Gear & Skin & Press	7.97% (4.15%–12.10%)	1.66% (0.32%–3.78%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	60.47% (47.95%–70.66%)	88.04% (78.97%–95.02%)
Ecchy & Skin & Press	14.29% (8.25%–20.77%)	0.66% (0.00%–2.24%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	61.79% (50.00%–72.20%)	88.70% (79.93%–95.68%)
Exsan & Skin & Press	6.98% (3.59%–11.15%)	0.66% (0.00%–2.41%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	59.47% (47.17%–69.60%)	88.04% (79.56%–95.14%)
Gear & Ecchy & Skin & Press	5.98% (2.19%–9.79%)	1.66% (0.00%–4.21%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	59.47% (47.08%–69.93%)	88.70% (79.81%–95.22%)
Gear & Exsan & Skin & Press	2.66% (0.63%–5.58%)	0.66% (0.00%–2.45%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	57.14% (45.45%–67.73%)	88.04% (79.18%–94.68%)
Ecchy & Exsan & Skin & Press	5.32% (1.99%–8.65%)	0.33% (0.00%–1.38%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	58.80% (46.50%–69.64%)	88.70% (79.94%–95.27%)

**Table 5**  
Differences in probability for different types and levels of catch damage (scores) between haddock captured with the grid and 130 mm diamond mesh codend configuration and haddock captured with the gentle codend configuration (gentle codend – grid & codend), values in brackets represent 95% confidence bands. Bold is for significant differences.

Damage level	Gentle codend Vs Grid and codend configuration				
	0	1	2	3	≤1 ≤2
All combined	<b>2.66%</b> (0.39%–5.45%)	0.33% (0.00%–1.64%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	9.53% (–4.46%–23.72%)
Gear	12.92% (–2.19%–30.65%)	<b>–14.62%</b> (–31.10%–1.48%)	0.37% (–4.19%–4.14%)	1.33% (0.00%–3.28%)	–1.70% (–6.13%–3.30%)
Ecchy	<b>17.10%</b> (5.31%–29.47%)	<b>–16.76%</b> (–28.99%–5.58%)	0.04% (–3.37%–4.02%)	–0.38% (–1.73%–0.00%)	0.35% (–3.81%–4.24%)
Exsan	5.98% (–8.50%–20.58%)	–9.62% (–22.30%–3.15%)	3.64% (–2.22%–10.12%)	0.00% (0.00%–0.00%)	–3.64% (–10.12%–2.22%)
Skin	<b>13.41%</b> (5.22%–20.86%)	0.14% (–11.92%–14.92%)	<b>–13.40%</b> (–25.97%–2.29%)	–0.15% (–9.93%–10.16%)	13.55% (–2.69%–30.79%)
Press	–0.60% (–5.96%–5.92%)	0.60% (–5.92%–5.96%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)
Gear & Ecchy	<b>19.45%</b> (7.33%–31.51%)	–10.08% (–23.01%–0.55%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	–1.02% (–7.50%–5.84%)
Gear & Exsan	6.72% (–3.18%–16.06%)	<b>–14.30%</b> (–25.94%–1.93%)	–0.05% (–1.50%–1.33%)	0.00% (0.00%–0.00%)	–0.95% (–2.99%–0.80%)
Ecchy & Exsan	9.84% (–2.62%–22.24%)	<b>–11.37%</b> (–22.70%–3.18%)	0.61% (–1.09%–2.52%)	0.00% (0.00%–0.00%)	–1.33% (–3.30%–0.00%)
Gear & Ecchy & Exsan	<b>9.36%</b> (0.94%–17.53%)	–7.38% (–17.10%–0.87%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.38% (0.00%–1.71%)
Gear & Skin	<b>7.59%</b> (3.76%–11.96%)	–4.32% (–14.74%–6.86%)	–0.53% (–4.38%–2.52%)	0.66% (0.00%–2.19%)	–0.95% (–3.07%–0.92%)
Ecchy and Skin	<b>12.71%</b> (5.91%–20.06%)	–6.06% (–13.41%–2.64%)	–0.43% (–2.39%–1.04%)	–0.38% (–1.79%–0.00%)	–0.51% (–11.09%–9.60%)
Gear & Ecchy & Skin	<b>6.98%</b> (3.11%–11.18%)	–3.13% (–10.88%–3.69%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.15% (–10.34%–10.21%)
Exsan & Skin	<b>5.17%</b> (0.78%–9.96%)	–2.28% (–12.20%–9.29%)	0.47% (–3.01%–3.95%)	0.00% (0.00%–0.00%)	–0.51% (–10.52%–9.15%)
Gear & Exsan & Skin	<b>2.66%</b> (0.61%–5.52%)	–4.32% (–13.08%–3.62%)	–0.05% (–1.59%–1.38%)	0.00% (0.00%–0.00%)	0.15% (–10.11%–10.07%)
Ecchy & Exsan & Skin	<b>4.50%</b> (0.28%–8.72%)	–2.95% (–8.60%–3.03%)	0.33% (0.00%–1.36%)	0.00% (0.00%–0.00%)	0.15% (–8.81%–10.39%)
Gear & Ecchy & Exsan & Skin	<b>2.66%</b> (0.66%–5.63%)	–1.36% (–6.60%–3.90%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	–0.51% (–9.68%–9.65%)
Gear & Press	<b>13.69%</b> (–4.15%–31.74%)	0.37% (–4.77%–4.11%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	–1.33% (–3.28%–0.00%)
Ecchy & Press	<b>15.97%</b> (3.66%–28.69%)	–0.53% (–3.63%–2.14%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.38% (0.00%–1.69%)
Gear & Ecchy & Press	<b>19.84%</b> (7.57%–32.26%)	–0.15% (–2.62%–2.13%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	–0.95% (–3.00%–0.79%)
Exsan & Press	5.08% (–8.30%–19.33%)	–0.30% (–4.75%–3.74%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)
Gear & Exsan & Press	6.72% (–2.57%–17.57%)	–0.53% (–3.69%–2.05%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	–1.33% (–3.04%–0.00%)
Ecchy & Exsan & Press	9.23% (–4.00%–22.48%)	–0.81% (–3.28%–1.03%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.38% (0.00%–1.74%)
Gear & Ecchy & Exsan & & Press	<b>9.36%</b> (1.76%–17.94%)	–0.43% (–2.30%–1.04%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	–0.95% (–2.99%–1.00%)
Skin & Press	<b>13.08%</b> (5.20%–21.01%)	1.51% (–2.19%–5.12%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.15% (–9.47%–9.19%)
Gear & Skin & Press	<b>7.59%</b> (3.72%–11.87%)	0.90% (–1.55%–3.45%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	–0.51% (–10.99%–9.78%)
Ecchy & Skin & Press	<b>12.38%</b> (5.86%–19.37%)	0.28% (–1.19%–2.07%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.15% (–9.52%–10.35%)
Gear & Ecchy & Skin & Press	<b>6.98%</b> (3.59%–11.15%)	0.66% (0.00%–2.41%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	–0.51% (–10.82%–9.77%)
Exsan & Skin & Press	<b>4.84%</b> (0.55%–9.15%)	0.52% (–2.67%–3.45%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.15% (–9.16%–9.69%)
Gear & Exsan & Skin & Press	<b>2.66%</b> (0.63%–5.58%)	–0.10% (–2.40%–2.30%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	–0.51% (–10.48%–9.33%)
Ecchy & Exsan & Skin & Press	<b>4.17%</b> (0.55%–7.89%)	–0.05% (–1.47%–1.31%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.15% (–9.70%–9.41%)



**Fig. 5.** Differences between haddock captured with the grid and 130 mm diamond mesh codend configuration and haddock captured with the gentle codend configuration (gentle codend – grid & codend) for the different score levels for the five external types of damage evaluated in the study, both individually and combined. The dashed line represents no difference in the probability between the gears, whereas the points above and below represent higher and lower probability for the gentle codend, respectively. The error bars represent the 95% confidence bands for each case.

levels of external damages and the overall market value of the fish landed with different processing levels.

The results from Brinkhof et al., 2018b and the present study show that by removing the compulsory sorting grid and substituting the knotted codend used by the fleet by a gentler codend, the trawl fleet operating in the Northeast Atlantic could benefit not only from not having to use a sorting grid, but also, from reduced damage levels on the catch. However, the grid and codend configuration has since its implementation in 1997 proved to be an effective size selective gear (Kvamme and Isaksen, 2004; Sistiaga et al., 2010), and substituting it by a codend with unknown selective properties can create additional challenges for the fishermen and the authorities. Earlier studies have shown that compared to other species commonly caught with bottom trawls (e.g. cod and saithe (*Pollachius virens*)), haddock is a more active species that often make multiple attempts to escape the gear. Thus, before a new device like the gentle codend tested in the present study is implemented in the fishery, it needs to be exhaustively tested regarding its size selective properties for several species with unequal behavioral patterns. If the two devices have different size-dependent catch efficiency, and if fish length influences the probability of damage, part of the differences observed in this study could originate from those two factors.

Fish welfare is another issue that encourages the design of gears that reduce external damages on fish. External damages and reflex impairment have in the past been used as indicators for fish welfare during the capture process (Metcalf, 2009; Davis, 2010; Veldhuizen et al., 2018). Based on the results obtained in the present study, we cannot provide any scientific answers on the impact of the observed external damages on fish welfare. However, assuming that external damages negatively impact fish welfare, and since the gentle codend infringed lower levels of external damages on the haddock captured, one could speculate whether this gear provides better fish welfare than the grid and codend

configuration.

#### CRediT authorship contribution statement

**Manu Sistiaga:**Conceptualization, Methodology, Validation, Formal analysis, 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.**Jesse Brinkhof:**Conceptualization, Methodology, Validation, Formal analysis, Resources, 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, Visualization.**Nadine Jacques:**Investigation, Data curation, Writing - original draft.**Juan Santos:**Investigation, Data curation, Writing - original draft.**Svein Helge Gjønsund:**Investigation, Writing - original draft, Project administration, Funding acquisition.

#### Declaration of competing interest

By this statement, the authors of this manuscript declare that there are no conflicts of interest.

This statement is to certify that all Authors have seen and approved the manuscript being submitted. We warrant that the article is the Authors' original work. We warrant that the article has not received prior publication and is not under consideration for publication elsewhere. On behalf of all Co-Authors, the corresponding Author shall bear full responsibility for the submission.

This research has not been submitted for publication nor has it been published in whole or in part elsewhere. We attest to the fact that all

Authors listed on the title page have contributed significantly to the work, have read the manuscript, attest to the validity and legitimacy of the data and its interpretation, and agree to its submission to Marine Pollution Bulletin.

## Acknowledgements

We thank the crew of the RV “Helmer Hanssen” and Elsa Cuende, Hermann Pettersen, Ivan Tatone, Kristine Cerbule, and John-Terje Eilertsen for their valuable help during the sea trials. We would also like to thank the Norwegian Research Council (NRC Grant number 268388/E40), the Norwegian Directorate of Fisheries (NDF Grant number 18/17046), and the Arctic University of Norway for providing the necessary financial support to carry out the experiments. Finally, we want to express our gratitude to the editor and the two anonymous reviewers, who helped improving the manuscript during the revision process.

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