Elsevier Editorial System(tm) for Fisheries Research
Manuscript Draft

Manuscript Number: FISH8891R1

Title: External damage to trawl-caught Northeast arctic cod (Gadus morhua): Effect of codend design

Article Type: Research Paper

Keywords: 4-panel construction; Bottom trawl; cod; Fish injuries; Knotless codend

Corresponding Author: Miss Guro Møen Tveit, MSc

Corresponding Author's Institution: SINTEF Ocean

First Author: Guro Møen Tveit, MSc

Order of Authors: Guro Møen Tveit, MSc; Manu Sistiaga; Bent Herrmann; Jesse Brinkhof

Manuscript Region of Origin: NORWAY

Abstract: The purpose of this study was to investigate the extent of external damage (gear marks, pressure injuries, ecchymosis and skin abrasion) present on trawl-caught cod (Gadus morhua) and to examine whether the extent of damage could be reduced by introducing changes in the gear. We tested whether changing the 2-panel knotted codend used by the Norwegian trawler fleet operating in the Barents Sea today to a 2-panel knotless codend or a 4-panel knotless codend could decrease the extent of external damage to the fish in the catch. We evaluated 720 fish over 12 hauls carried out with a twin trawl setup and found that the probability for cod to be without any external damage was 9.4% (4.7% - 15.8%) with the codend used in the fishery today. Thus, most fish in these catches are likely to have slight or moderate damage. Gear marks were the most frequent type of damage, with only 11.5% (6.0% - 18.9%) of the cod being free of this type of injury. When gear marks were not considered in the analysis, 68.4% (58.8% - 78.3%) of the fish was estimated to be flawless. Replacing the knotted netting in the codend increased the probability of obtaining fish without gear marks to 15.5% (6.2% - 28.0%). However, the confidence intervals were wide, and this effect was not statistically significant. For the other three damage types, the estimated effects of changing the design of the codend were small and not statistically significant. Changing from a 2- to 4-panel codend was estimated to reduce the probability for gear marks by a further 1.7% (-13.4% - 16.8%). However, this increase was not significant. Overall, the two codend design changes tested in this study did not significantly decrease the external damage present on trawl-caught cod.

Highlights

- Trawlers fishing cod in the Barents Sea often use knotted netting in the codend.
- The effect of codend designs was investigated for external damages on cod.
- Only 9.4% of the cod caught with the knotted codend was flawless.
- Gear marks were the most frequent type of damage.
- The new codend designs didn't decrease external damages on cod significantly.

External damage to trawl-caught Northeast arctic cod (*Gadus morhua*): Effect of codend design

Guro Møen Tveit [a,&,*], Manu Sistiaga [a,&], Bent Herrmann[b,&] Jesse Brinkhof[c,&]

[a] SINTEF Ocean, Seafood technology, Brattørkaia 17C, 7010 Trondheim, Norway

[b] SINTEF Ocean, Seafood technology, Willemoesvej 2, 9850 Hirtshals, Denmark

[c] The Arctic University of Norway UIT, Hansine Hansens veg 18, 9019 Tromsø, Norway

[*] Corresponding author, Tel. +47 93002709, Email: Guro.Tveit@sintef.no (G. M. Tveit)

[&] Equal authorship

Abstract

The purpose of this study was to investigate the extent of external damage (gear marks, pressure injuries, ecchymosis and skin abrasion) present on trawl-caught cod (*Gadus morhua*) and to examine whether the extent of damage could be reduced by introducing changes in the gear. We tested whether changing the 2-panel knotted codend used by the Norwegian trawler fleet operating in the Barents Sea today to a 2-panel knotless codend or a 4-panel knotless codend could decrease the extent of external damage to the fish in the catch. We evaluated 720 fish over 12 hauls carried out with a twin trawl setup and found that the probability for cod to be without any external damage was 9.4% (4.7% – 15.8%) with the codend used in the fishery today. Thus, most fish in these catches are likely to have slight or moderate damage. Gear marks were the most frequent type of damage, with only 11.5% (6.0% – 18.9%) of the cod being free of this type of injury. When gear marks were not considered in the analysis, 68.4% (58.8% – 78.3%) of the fish was estimated to be flawless. Replacing the knotted netting in the codend increased the probability of obtaining fish without gear marks to 15.5% (6.2% – 28.0%). However, the confidence intervals were wide, and this effect was not statistically significant. For the other three damage types, the estimated effects of changing the design of the codend were small and not statistically significant. Changing from a 2- to 4-panel codend was estimated to reduce the probability for gear marks by a further 1.7% (-

13.4% – 16.8%). However, this increase was not significant. Overall, the two codend design changes tested in this study did not significantly decrease the external damage present on trawl-caught cod.

Keywords: 4-panel construction; Bottom trawl; cod; Fish injuries; Knotless codend

1. Introduction

Cod (*Gadus morhua*) fisheries are the most important fisheries in the Barents Sea (Yaragina et al., 2011), and approximately 30% of the Norwegian Total Allowable Catch for this species (412,000 tons in 2017) is caught with trawls (Norwegian Directorate of fisheries, 2018a). Thus, improvements in the quality of the fish caught with trawls would have considerable impact on the quality of the overall national fish production. Fish and fishing quotas are a limited resource, and due to the technical advances implemented in the last two decades, fishermen rarely struggle to meet their cod quotas. Today, the focus is more on improving the quality of the raw material produced (Brinkhof et al., 2018a,b), as this often will result in increased revenue. The quality of fish is determined by factors such as levels of stress, internal and external damage, and processing and storage conditions (Huss, 1995). The appearance of fish provides no certainty of quality, but it is more likely that fish with good external appearance will be of good quality than fish with poor external appearance. Thus, even though fish with the same level of external damage can be of different quality, external damage to a fish is generally considered to be a good indicator of the overall quality of fish (Olsen et al., 2013).

Trawlers fishing cod in the Norwegian Exclusive Economic Zone are required to use a sorting system composed of a 55 mm bar spacing sorting grid and a codend with a minimum mesh size of 130 mm (Herrmann et al., 2013; Sistiaga et al., 2016). However, fishermen are free to decide the overall dimensions as well as the construction materials they want to use for the codend (Norwegian Directorate of Fisheries, 2018b). A typical codend used in this fishery would be constructed as a 2-panel codend 100–140 meshes in length and 70–100 meshes around made of 8–10 mm single polyethylene (PE) twine with meshes of 130–140 mm. Most vessels use knotted twine in the lower panel of the codend and knotless twine in the top panel. Fishermen use this construction because they believe that knotless materials can reduce damage to the captured fish and escaping juveniles, but knotted materials are substantially cheaper, more resistant, and easier to repair if gear damage occurs. Considering that the lower panel in the codend often is in contact with the seabed while towing, this construction seems adequate. However, trawlers in general, but especially those that deliver headed and gutted fresh cod, often see a substantial reduction in price for the fish they deliver compared to those that deliver frozen fish. For some vessels this reduction affected ca. 10% of the catch during 2017, which represented a considerable loss of income for fishermen and vessel owners (Ronny Vågsholm, personal communication). According to fishermen, the reason for this phenomenon is that some of the damage to the fish is only visible over time and is not noticeable if the fish is frozen right after capture.

Despite the risk for reduced price and its importance for a large number of vessels in the Norwegian fishing sector, to our knowledge no one has systematically evaluated the source and extent of the external damage to trawl-caught cod that result in this price reduction. Furthermore, fishermen do not know if the damage to the fish occurs during the capture process or during processing in the vessel factory. Therefore, it is important to first establish the level of damage and what types of external damage are most frequent in trawl-caught cod.

The trawl haul-back process is an important phase because the forces to which the fish are exposed can increase dramatically during the transition from water to air, particularly for large catches. This is especially true for the fish in the outer layers of the catch, as they are in direct contact with the netting in the codend (Fig. 1). In this respect, one could speculate that knots in the netting are the cause of much of the external damage found on fish. Although this hypothesis has never been scientifically proved, fishermen believe that knotless nettings do less external damage to fish than knotted materials. Therefore, testing whether reducing the area of knotted netting in the codend could potentially reduce external damage to trawl-caught fish would be relevant.

Fish can also be damaged during the towing phase. In codends that oscillate greatly during towing due to their shape/construction, the movements inside the codend could potentially lead to fish being more frequently in contact with the netting than in codends that oscillate less, and this process could increase the frequency of external damage to the fish. O'Neill et al. (2003) reported that some codend constructions oscillate more than others during the towing phase, and Sistiaga et al. (2016) indicated that a 4-panel grid + codend construction oscillated less under towing than an identical 2-panel grid + codend construction. Thus, testing whether a 4-panel codend could contribute to decreased external damage to the fish caught relative to a 2-panel codend also would be relevant.

The purpose of this study was to investigate external damage present on trawl-caught cod and to examine whether the frequency of this damage could be reduced by introducing simple changes in the gear. Specifically, we aimed to answer the following research questions:

- What is the level of external damage to the fish harvested in the fishery today? What is the probability that a trawl-caught cod does not have any external damage at all?
- Which are the most frequent types of external damage and what types of damage are responsible for compromising the overall quality of cod?
- Can we decrease the extent of external damage to trawl-caught cod by replacing the knotted netting in the codend with knotless netting?
- Can we decrease the extent of external damage further by changing the codend construction from a 2-panel codend to a 4-panel codend?

2. Materials and methods

2.1 Study area and gear configuration

Sea trials were carried out onboard the commercial trawler F/Tr Havtind (overall length 59.75 m, width 13 m, horse power 6130 hp, gross tonnage 1860 tons) between the 28 June and 11 July 2016 off Hopen in the Barents Sea (76°18'–76°58' N / 32°05'–34°24' E).

The vessel employs a twin trawl gear consisting of a system composed of Injector Sparrow trawl doors (each with an area of 9 m^2 and weight of 4200 kg), a mid-clump (5700 kg), 90 m sweeps, and two Alfredo 5 standard trawls (155 mm nominal mesh size, 37.7 m headline, and 21.30 m fishing line), which provides the possibility of collecting data for two different gears simultaneously. The ground gear used in the trawls was 101.6 m long with two 40.40 m side sections and a mid-rockhopper section of 20.8 m constructed with 52 cm rubber discs. The two trawls used during the trials were identical in the front and belly sections, and a flexigrid (Sistiaga et al., 2016) sorting system installed in front of each of the codends was used in every haul. In the cases where we tested a 2-panel codend, we used a 2-panel flexigrid system, whereas when we used a 4-panel codend we used a 4-panel flexigrid system (Sistiaga et al., 2016).

During the trials we tested three different codend configurations of identical dimensions. In all three cases the codends were 99.5 meshes long and had 80 free meshes around. To avoid excessive pressure on the codend, netting lastridge ropes (5%–10% shorter than the codend length) were installed in all cases (two ropes in the 2-panel codends and four ropes in the 4-panels codends). The codend configurations tested were as follows:

- 2P_Knotted: 2-panel codend with the lower panel constructed of 8 mm PE twine (ordinary knotted meshes) and the upper panel constructed knotless of 9 mm PE twine. Both codend panels had a nominal mesh size (nms) of 135 mm. This codend served as the baseline for the tests carried out in these trials, as it is the configuration the vessel normally uses (Fig. 1).
- 2P_Knotless: 2-panel codend constructed entirely of 135 mm nms knotless netting (Ultracross) with 9 mm twine.
- 4P_Knotless: 4-panel codend constructed entirely of 135 mm nms knotless netting (Ultracross) with 9 mm twine.

FIG. 1

2.2 Data sampling and categorization of damage on fish

The sea trials were carried out following commercial practices. Depth (average between start and end depths), trawling time and total catch were registered for each haul. For all hauls, 30 cod were manually selected at random from each codend and killed with a sharp blow to the head. This process was carried out on deck. Subsequently, the fish were tagged and visually examined for the level of external damage (gear marks, pressure injuries, ecchymosis, and skin abrasion). Each of the fish selected from the codends were tagged and examined for the level of external damage incurred during the capture process (Table 1) (Rotabakk et al., 2011; Essaiassen et al., 2013; Olsen et al., 2013; Brinkhof et al., 2018a).

TABLE 1

Each fish was given a score for each damage type according to the severity of the damage it showed. A fish that scored 0 was considered flawless, whereas a fish that scored 3 was severely damaged (i.e., low fish quality) regarding that damage type (Fig. 2). For all fish included in the study, both body sides were considered in the evaluation. The head region of the fish was not included in the evaluation because: i) the fish was killed with a sharp blow to the head and it would not be possible to distinguish between damage that occurred during the capture process and damage that was consequence of the killing method applied; and ii) the fish produced from this fishery are integrally sold as headed and gutted fish (independent on whether they are sold fresh or frozen) or filet. All fish were evaluated by the same person to avoid potential criteria differences among evaluators.

FIG. 2

2.3 Data analysis

Knowing the probability of obtaining a cod without any external damage at all (i.e., a fish scored as flawless for all damage types simultaneously) is important, as it quantifies the probability of obtaining the best possible catch quality. In addition, knowing the probability of obtaining fish with different severity (category) of specific damage types in the catch will help identify where we have the highest potential for improving catch quality. Furthermore, knowing the probability of obtaining a given combination of catch damage types that do not exceed a given score (severity) on any of them is relevant, as it provides an estimate for the fraction of the catch that can be expected to be within a certain minimum quality. The catch data were collected and categorized according to Table 1 for the samples of cod taken from each of the fishing hauls. To perform this analysis, we used the method and analysis tool described by Brinkhof et al. (2018a). The catch damage data first were analysed for each of the three codend designs separately to obtain information about how they individually performed regarding fish quality in terms of external damage. Thereafter, the potential effect of changing from the traditional codend design to the 2-panel knotless design and further to the 4-panel knotless design was inferred by utilizing the method described in Brinkhof et al. (2018a) for quantifying the difference in probability between designs.

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

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

$$with$$

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

where m is the number of hauls conducted, n_j is the number of cod given a score in haul j, and k_{ajt} is the score given on catch damage type a to cod number t evaluated in haul j.

The probability $\widehat{pm_{as}}$ of obtaining a score that does not exceed s on catch damage type a (i.e. the probability of obtaining a given score or lower), was quantified using Equation 2:

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

Equations 1 and 2 provide an evaluation of each catch damage type separately. However, it is also of interest to investigate the probability for a fish scoring s or maximum s on 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:

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

And

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

Equations 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 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% confidence intervals by applying a double bootstrap methodology. By providing bootstrap-based estimates with uncertainties for the difference in the estimated quality scores, this method allows direct comparison of catch quality between cod caught with the different codends and thereby the effect of changing codend design. The bootstrapping method is thoroughly described in Brinkhof et al. (2018a).

3. Results

During the cruise we collected data for a total of eight hauls for each of the configurations tested. The total catch varied between approximately 8 and 51 tons, tow duration between 35 and 235 min, and the depth range was 160–256 m (Table 2). In total we examined 720 fish for external damage (Figs. 3–5).

TABLE 2

FIG. 3

FIG. 4

FIG. 5

3.1. Quantifying the quality level in the fishery today

The results obtained with the 2P_Knotted codend (Table 3; Fig. 6), which is the codend used by the fishing fleet today, showed that gear marks were the most frequent type of injury for this codend. Only 11.5% (6.0% – 18.9%) of the fish were free of gear marks, and 42.3% (31.2% – 55.1%) of the fish had either moderate or severe gear marks. More than 90% of the fish had no pressure injuries or ecchymosis, and 77.8% (66.7% – 88.5%) of the fish had no skin abrasion.

TABLE 3

FIG. 6

The probability for cod to be completely flawless, meaning no external damage (combination of all four damage types), was only 9.4% (4.7% – 15.8%). However, 55.6% (42.9% – 66.7%)

of the fish that showed some level of damage had only slight damage, and only 2.6% (0.0% – 6.1%) of the fish exhibited severe damage (Gear&Press&Ecchy&Skin in Table 3; Fig. 7). The importance of gear marks is clear from the results. When gear marks was included, on average at most 10.7% (5.6% – 17.5%) of the fish were damage free or flawless, but when gear marks was not included in the analysis the average percentage of flawless fish increased to 68.4% (58.8% – 78.3%), and over 90% of the fish had either no or only slight damage (Table 3; Fig. 8).

FIG. 7

FIG. 8

3.2. Effect of changing to a completely knotless 2-panel codend

When the 2P_Knotless codend was used, gear marks were again the most frequent type of external injury. Only 15.5% (6.2% – 28.0%) of the fish investigated exhibited no gear marks, and 98.7% (96.5% – 100.0%), 90.1% (85.0% – 94.4%), and 79.0% (66.4% – 90.1%) of the fish had no pressure injuries, ecchymosis, or skin abrasion, respectively. Furthermore, the existing pressure injuries and ecchymosis were scored as slight, and only 3% (0.0% – 7.5%) of the fish had skin abrasion that was scored more severe than slight. In contrast, the severity of gear marks of almost half the fish evaluated was scored as more than slight (Table 4a).

Changing from a 2P_Knotted codend to a 2P_Knotless codend increased the frequency of flawless fish from 9.4% (4.7% – 15.8%) to 11.6% (5.9% – 18.6%). However, the frequency of fish with only slight damage decreased from 55.6% (42.9% – 66.7%) to 51.1% (39.7 – 64.1%) (Tables 3, 4a). Neither the difference in frequency of flawless fish nor the difference in frequency of fish with slight damage was statistically significant. Overall, the fish quality differences between these two codends were small and non-significant (the confidence intervals for the difference values between the codends (2P_Knotless - 2P_Knotted) include 0 as value) (Table 4b).

TABLE 4

3.3. Effect of changing to a completely knotless 4-panel construction

Gear marks were also the most common type of injury to fish captured with the 4P_Knotless codend. Only 17.2% (8.4% – 28.9%) of the fish had no gear marks, whereas 95.0% (90.5% – 98.3%), 90.0% (83.1% – 95.8%), and 82.9% (71.7% – 92.0%) of the fish had no pressure injuries, ecchymosis, or skin abrasion, respectively. When gear marks were removed from the analysis, the frequency of flawless fish was on average 72.0% (58.9% – 82.8%), whereas the frequency of flawless fish did not exceed 13.0% (7.6% – 20.0%) when gear marks were included (Table 5a; Fig. 8).

Detailed analysis of the differences in fish quality between fish captured with the 4P_Knotless and the 2P_Knotted codends (4P_Knotless - 2P_Knotted) showed that while the frequency of fish without gear marks or skin abrasion was 5.6% (-5.7% – 18.1%) higher for the former, the frequencies of fish without pressure injuries and ecchymosis were 2.5% (-2.2% – 7.5%) and 1.5% (-5.4% – 9.3%) higher for the latter (Table 5b). Overall, the 4P_Knotless codend had 1.9% (-6.1% – 9.9%) higher frequency of flawless fish and 8.0% (-7.5% – 25.2%) higher frequency of fish with slight damage than the 2P_Knotted codend, but the differences were not statistically significant.

In summary, changing the gear from a 2P_Knotted codend to a 4P_Knotless did not result in a major improvement in fish quality, and the slight improvements observed were non-significant in any case.

TABLE 5

3.4. Effect of changing from a 2-panel knotless to a 4-panel knotless construction

To elucidate the potential effect on fish quality of changing from a 2-panel to a 4-panel codend, we estimated the difference in fish quality obtained with the 4P_Knotless and 2P_Knotless codends (4P_Knotless - 2P_Knotless) (Table 6). The results showed no clear improvements for any of the four damage types examined, and the overall difference in quality between the codends differed by only 0.3% (-7.7% – 8.2%). None of the small differences observed were statistically significant in any case.

TABLE 6

4. Discussion

In the present study we investigated the extent of external damage to trawl-caught cod caused by the codend used in the Barents Sea fishery today. The results showed that cod caught with the codend used in the fishery today frequently exhibited gear marks (88.5% (81.1% – 94.0%) showed gear marks at varying levels of severity), and the probability of obtaining completely flawless cod without any type of external damage was only 9.4% (4.7% – 15.8%). When we investigated whether introducing changes in the codend could reduce the level of external damage to cod, replacing the knotted netting in the 2P_Knotted codend to knotless netting in the 2P_Knotless codend increased the probability of obtaining completely flawless fish to 11.6% (5.9% – 18.6%) and an additional 1.9% (-6.1% – 9.9%) when changing from a 2- to a 4-panel knotless construction. However, none of these improvements were statistically significant, thus these changes to codend design did not effectively reduce external damage to cod.

In an experiment carried out to evaluate the effect of buffer towing on the quality of trawl-caught cod, Brinkhof et al. (2018a) reported the probability of obtaining flawless fish with a 4-panel codend to be 21% (9% – 33%). Although the authors do not specify whether this result was achieved with a knotted or knotless codend, the percentage reported is higher than that of any of the three codends tested in the present investigation, which were 9.4% (4.7% – 15.8%) for the 2P_Knotted codend, 11.6% (5.9% – 18.6%) for the 2P_Knotless codend, and 11.3% (6.7% – 17.4%) for the 4P_Knotless codend. The differences in results between the studies are not statistically significant, but there are several potential reasons that the estimated percentage of flawless fish was higher in the Brinkhof et al. (2018a) study. Catch size likely affects fish quality because the larger the catch, the greater the forces inside the codend, especially during the haul-back process, and the fish thus have greater possibility of experiencing external damage. Therefore, all gear marks in the form of stripes or lines on the skin of the fish, pressure damage, ecchymosis, and skin abrasion may be more likely on fish that have been part of a large haul (Fig. 1). The fishing trials in the present study followed commercial practice and the catches ranged between 8 and 51 tons, whereas the catches in the Brinkhof et al. (2018a) study never exceeded 2 tons. This may explain the higher gear mark frequency observed in the present study. Other parameters such as fishing depth and tow duration also have been found to have a negative influence on the frequency of gear damage (Bottari et al., 2003), but the effect of fish size on the presence of external damage of trawl-caught cod is disputed in the literature (Veldhuizen et al., 2018). Suuronen et al. (2005) reported that large trawl-caught cod had more scale and skin injuries than smaller cod caught by trawl, whereas no relation between fish size and frequency of external damage was identified in other studies (Suuronen et al., 1996; Ingólfsson and Jørgensen, 2006). In the present study, fish length was not registered during sampling because the study was not large enough to consider the potential effect of length-dependency in the results. Fish condition also can affect the extent of gear damage (Veldhuizen et al., 2018). However, these parameters are very difficult to compare among studies, especially when the experimental trials are carried out under commercial conditions and many of the potentially influential parameters (e.g., fish condition, fishing depth, size distribution in the fishing area, etc.) cannot be controlled.

In an earlier study that also recorded external damage on trawl-caught cod, Digre et al. (2010) reported that 72% of the cod captured in a trawl with a T90 codend and 79% of the fish captured with an ordinary knotted codend were flawless. Some years later, Olsen et al. (2013) reported that 48% of the trawl-caught cod examined in their study did not have catch related damage. The results from these two studies show substantially lower damage levels than those registered by Brinkhof et al. (2018a) or the present study. However, it should be noted that the damage score indexes used in Digre et al. 2010 (0 or 1) and Olsen et al. (2013) (0,1, or 2) did not have as many levels as those used in the present study and that of Brinkhof et al. (2018a), which could mean that a percentage of the fish that were considered to have slight damage (score = 1) in the present study would have been considered flawless by Digre et al. (2010) and/or Olsen et al. (2013).

In the present study, considerable external damages were indeed observed in the trawl-caught cod, which supports the fishermen's assumption that onboard fish quality may reduce fish price. The results also show that simple changes to the codend used by the fleet today are not enough to significantly reduce the damage levels. In the future, the effect of alternative changes to the gear (e.g., gentler codends) or changes in the operation of gear (e.g., smaller hauls, shorter towing times, etc.) should be investigated to elucidate whether these types of changes could significantly reduce the external damage frequency in trawl-caught Barents Sea cod. Further, as fish can also be damaged during processing in the vessel factory, detailed examination of fish at different stages onboard is recommended for future studies.

Acknowledgments

We would like to thank Havfisk AS and the Crew of F/Tr Havtind for their help during the fishing trials. Thanks also to Ulf G. Erikson and Hanne Digre for their valuable help and comments during the preparation of the manuscript. We are grateful to the Norwegian

Seafood Research Fund (FHF, project number 901232), the Norwegian Directorate of Fisheries in Norway, and the Norwegian Research Council (NRC, project number 268388/E40) for their financial support. Finally, we would like to thank the two anonymous reviewers assigned by the journal, who contributed greatly to improve this manuscript.

References

Bottari, T., Greco, S., Panebianco, A., 2003. Trawling lesions: incidence in some fish species and preliminary statistical evaluations. Vet. Res. Commun. 27, 285–288.

Brinkhof, J., Larsen, R.B., Herrmann, B., Olsen, S.H., 2018a. Assessing the impact of buffer towing on the quality of Northeast Atlantic cod (*Gadus morhua*) caught with a bottom trawl. Fish. Res. 206, 209–219.

Brinkhof, J., Olsen, S.H., Ingólfsson, O.A., Herrmann, B., Larsen, R.B., 2018b. Sequential codend improves quality of trawl-caught cod. PLoS ONE 13: e0204328.

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.

Essaiassen, M., Akse, L. and Joensen, S., 2013. Development of a catch-damage-index to assess the quality of cod at landing. Food Control, 29(1), pp.231-235.0254-2.

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*). Fish. Res. 146, 59–73.

Huss, H.H., 1995. Quality and Quality Changes in Fresh Fish. FAO Fisheries Technical Paper, No. 348, 195p., FAO, Rome, Italy.

Ingólfsson, O.A., Jørgensen, T., 2006. Escapement of gadoid fish beneath a commercial bottom trawl: relevance to the overall trawl selectivity. Fish. Res. 79, 303–312.

Norwegian directorate of Fisheries, 2018a. https://www.fiskeridir.no/Yrkesfiske/Dokumenter/Reguleringsmoetet/Sakspapirer-innspill-og-referat-fra-reguleringsmoetene/Reguleringsmoetet (In Norwegian).

Norwegian Directorate of Fisheries, Strandgaten 229, Pb. 185, Sentrum, 5804 Bergen, Norway.

Norwegian directorate of Fisheries, 2018b. J-119-2018, Utøvelsesforskriften. 61 pp. (In Norwegian). Norwegian Directorate of Fisheries, Strandgaten 229, Pb. 185, Sentrum, 5804 Bergen, Norway.

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. Fish. Res. 147, 446–453.

O'Neill, F.G., McKay, S.J., Ward, J.N., Strickland, A., Kynoch, R.J., Zuur, A.F., 2003. An investigation of the relationship between sea state induced vessel motion and cod-end selection. Fish. Res. 60, 107–130.

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. Fish. Res. 112, 44–51.

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. Fish. Res. 183, 340–351.

Suuronen, P., Lehtonen, E., Tschernij, V., Larsson, P.O., 1996b. Skin injury and mortality of Baltic cod escaping from trawl codends equipped with exit windows. Arch. Fish. Mar. Res. 44, 165–178.

Suuronen, P., Lehtonen, E., Jounela, P., 2005. Escape mortality of trawl-caught Baltic cod (*Gadus morhua*) - the effect of water temperature, fish size and codend catch. Fish. Res. 71, 151–163.

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. Fish. Res. 204, 41–48.

Yaragina, N. A., Aglen, A., Sokolov, K. M., 2011. 5.4 Cod, in: Jakobsen, T., Ožigin, V. K., (Eds.). The Barents Sea: ecosystem, resources, management: half a century of Russian-Norwegian cooperation. Trondheim: Tapir Academic Press, pp. 225-270.

TABLES

Table 1: Catch damage types and categories/scores used to examine external damages on trawl-caught cod.

Table 2: Haul overview for the data collected during the cruise.

Table 3: Probability (with 95% confidence intervals in brackets) of score for the different damage types (Gear = Gear marks; Press = Pressure injuries; Ecchy = Ecchymosis; Skin = Skin injuries) and damage type combinations examined during the cruise for the 2P_Knotted codend.

Table 4: a) Probability (with 95% confidence intervals in brackets) of score for the different damage types (Gear = Gear marks; Press = Pressure injuries; Ecchy = Ecchymosis; Skin = Skin injuries) and damage type combinations examined during the cruise for the 2P_Knotless codend. b) Differences in catch damage probabilities (with 95% confidence intervals in brackets) between the 2P_Knotless and the 2P_Knotted codends.

Table 5: a) Probability (with 95% confidence intervals in brackets) of score for the different damage types (Gear = Gear marks; Press = Pressure injuries; Ecchy = Ecchymosis; Skin = Skin injuries) and damage type combinations examined during the cruise for the 4P_Knotless codend. b) Differences in catch damage probabilities (with 95% confidence intervals in brackets) between the 4P_Knotless and the 2P_Knotted codends.

Table 6: Differences in catch damage probabilities (with 95% confidence intervals in brackets) between the 4P_Knotless and the 2P_Knotless codends.

TABLE 1

Damage type	Category / Score				Description
	Flawless	Slight	Moderate	Severe	
Gear marks	0	1	2	3	Marks on the skin caused by the gear (etc. netting wall).
Pressure injuries	0	1	2	3	The fish is squeezed/crushed in gear.
Ecchymosis	0	1	2	3	Bruising and discoloration of the skin due to squeezing.
Skin abrasion	0	1	2	3	Loss of scales / abrasion due to rubbing on the fishing gear.

TABLE 2

Date	Haul no.	Trawl		Total catch (kg)	Trawling time (min)	Depth (m)
		Codend port	Codend starboard			
30.06.2016	1	1_4P_Knotless	1_2P_Knotless	7940	235	222
01.07.2016	2	2_4P_Knotless	2_2P_Knotless	17624	101	181
01.07.2016	3	3_4P_Knotless	3_2P_Knotless	26082	155	176
02.07.2016	4	4_4P_Knotless	1_2P_Knotted	40870	75	182
02.07.2016	5	5_4P_Knotless	2_2P_Knotted	22164	35	204
03.07.2016	6	6_4P_Knotless	3_2P_Knotted	27924	95	198
03.07.2016	7	4_2P_Knotless	4_2P_Knotted	18208	59	211
04.07.2016	8	5_2P_Knotless	5_2P_Knotted	15446	74	217
04.07.2016	9	6_2P_Knotless	6_2P_Knotted	51176	45	160
05.07.2016	10	7_2P_Knotless	7_2P_Knotted	19618	197	256
07.07.2016	11	8_2P_Knotless	7_4P_Knotless	13112	210	226
08.07.2016	12	8_2P_Knotted	8_4P_Knotless	25794	205	216

TABLE 3

	2P_Knotted Results					
	0	1	2	3	≤1	≤2
Gear	11.54% (5.98%–18.92%)	46.15% (34.68%–56.25%)	42.31% (31.20%–55.09%)	0.00% (0.00%–0.00%)	57.69% (44.91%–68.80%)	100.00% (100.00%–100.00%)
Press	97.44% (94.58%–99.56%)	2.56% (0.44%–5.42%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	100.00% (100.00%–100.00%)	100.00% (100.00%–100.00%)
Ecchy	91.45% (87.18%–95.30%)	7.69% (3.95%–11.71%)	0.85% (0.00%–2.56%)	0.00% (0.00%–0.00%)	99.15% (97.44%–100.00%)	100.00% (100.00%–100.00%)
Skin	77.78% (66.67%–88.46%)	15.38% (8.33%–23.08%)	4.27% (0.83%–8.55%)	2.56% (0.00%–6.25%)	93.16% (88.03%–97.92%)	97.44% (93.75%–100.00%)
Gear&Press	11.11% (5.56%–17.54%)	1.71% (0.00%–4.17%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	57.69% (45.05%–68.75%)	100.00% (100.00%–100.00%)
Gear&Ecchy	11.11% (5.70%–17.98%)	3.85% (1.25%–7.08%)	0.85% (0.00%–2.92%)	0.00% (0.00%–0.00%)	57.69% (45.50%–69.17%)	100.00% (100.00%–100.00%)
Press&Ecchy	89.32% (83.75%–94.30%)	0.43% (0.00%–2.08%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	99.15% (97.37%–100.00%)	100.00% (100.00%–100.00%)
Gear&Press&Ecchy	10.68% (5.56%–17.52%)	0.43% (0.00%–1.75%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	57.69% (44.44%–68.75%)	100.00% (100.00%–100.00%)
Gear&Skin	10.26% (5.00%–16.24%)	7.26% (2.92%–12.08%)	2.99% (0.00%–7.08%)	0.00% (0.00%–0.00%)	55.56% (42.74%–66.67%)	97.44% (93.69%–100.00%)
Press&Skin	75.64% (64.96%–85.09%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	93.16% (87.72%–97.92%)	97.44% (93.98%–100.00%)
Gear&Press&Skin	9.83% (4.82%–15.83%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	55.56% (42.34%–66.67%)	97.44% (94.30%–100.00%)
Ecchy&Skin	70.09% (59.58%–80.42%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	92.31% (86.25%–97.37%)	97.44% (94.17%–100.00%)
Gear&Ecchy&Skin	9.83% (4.70%–15.83%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	55.56% (41.88%–66.67%)	97.44% (93.69%–100.00%)
Press&Ecchy&Skin	68.38% (58.77%–78.33%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	92.31% (86.32%–97.81%)	97.44% (93.59%–100.00%)
Gear&Press&Ecchy&Skin	9.40% (4.70%–15.81%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	55.56% (42.92%–66.67%)	97.44% (93.86%–100.00%)

32 TABLE 4

a)

	2P_knotless Results					
	0	1	2	3	≤1	≤2
Gear	15.45% (6.22%–27.97%)	36.91% (29.18%–45.00%)	47.64% (32.62%–59.82%)	0.00% (0.00%–0.00%)	52.36% (40.18%–67.38%)	100.00% (100.00%–100.00%)
Press	98.71% (96.51%–100.00%)	1.29% (0.00%–3.49%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	100.00% (100.00%–100.00%)	100.00% (100.00%–100.00%)
Ecchy	90.13% (85.04%–94.42%)	9.87% (5.58%–14.96%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	100.00% (100.00%–100.00%)	100.00% (100.00%–100.00%)
Skin	78.97% (66.37%–90.13%)	18.03% (8.77%–29.18%)	2.15% (0.00%–6.01%)	0.86% (0.00%–2.58%)	97.00% (92.47%–100.00%)	99.14% (97.42%–100.00%)
Gear&Press	15.45% (6.84%–29.79%)	0.86% (0.00%–2.93%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	52.36% (40.77%–67.38%)	100.00% (100.00%–100.00%)
Gear&Ecchy	15.02% (6.25%–28.51%)	3.86% (1.32%–6.81%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	52.36% (40.59%–66.95%)	100.00% (100.00%–100.00%)
Press&Ecchy	89.27% (84.45%–93.67%)	0.43% (0.00%–1.74%)	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&Press&Ecchy	15.02% (6.25%–28.94%)	0.43% (0.00%–2.10%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	52.36% (40.79%–68.83%)	100.00% (100.00%–100.00%)
Gear&Skin	11.59% (5.78%–18.97%)	7.30% (1.68%–14.29%)	0.86% (0.00%–3.04%)	0.00% (0.00%–0.00%)	51.07% (39.33%–66.38%)	99.14% (97.37%–100.00%)
Press&Skin	78.11% (64.83%–89.04%)	0.43% (0.00%–2.14%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	97.00% (92.24%–100.00%)	99.14% (97.48%–100.00%)
Gear&Press&Skin	11.59% (5.94%–18.49%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	51.07% (39.74%–66.52%)	99.14% (97.42%–100.00%)
Ecchy&Skin	71.67% (59.39%–82.01%)	2.58% (0.45%–4.89%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	97.00% (92.70%–100.00%)	99.14% (97.44%–100.00%)
Gear&Ecchy&Skin	11.59% (6.01%–18.49%)	0.86% (0.00%–2.56%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	51.07% (38.40%–65.37%)	99.14% (97.33%–100.00%)
Press&Ecchy&Skin	71.24% (59.07%–82.22%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	97.00% (91.60%–100.00%)	99.14% (97.42%–100.00%)
Gear&Press&Ecchy&Skin	11.59% (5.91%–18.57%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	51.07% (39.66%–64.14%)	99.14% (97.44%–100.00%)

b)

	2P_knotless - 2P_Knotted Results					
	0	1	2	3	≤1	≤2
Gear	3.91% (-8.59%–17.94%)	-9.24% (-22.80%–4.98%)	5.33% (-14.05%–22.36%)	0.00% (0.00%–0.00%)	-5.33% (-22.36%–14.05%)	0.00% (0.00%–0.00%)
Press	1.28% (-1.75%–4.70%)	-1.28% (-4.70%–1.75%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)
Ecchy	-1.32% (-7.36%–4.55%)	2.18% (-3.85%–8.07%)	-0.85% (-2.56%–0.00%)	0.00% (0.00%–0.00%)	0.85% (0.00%–2.56%)	0.00% (0.00%–0.00%)
Skin	1.19% (-13.00%–17.71%)	2.64% (-10.46%–15.12%)	-2.13% (-7.47%–3.02%)	-1.71% (-5.56%–0.91%)	3.83% (-2.76%–10.34%)	1.71% (-0.91%–5.56%)

Gear&Press	4.34% (-6.44%–19.55%)	-0.85% (-3.52%–1.66%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	-5.33% (-20.97%–14.61%)	0.00% (0.00%–0.00%)
Gear&Ecchy	3.91% (-7.50%–17.41%)	0.02% (-4.19%–4.17%)	-0.85% (-2.92%–0.00%)	0.00% (0.00%–0.00%)	-5.33% (-21.52%–14.26%)	0.00% (0.00%–0.00%)
Press&Ecchy	-0.05% (-6.95%–7.24%)	0.00% (-1.67%–1.70%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.85% (0.00%–2.63%)	0.00% (0.00%–0.00%)
Gear&Press&Ecchy	4.34% (-7.63%–18.41%)	0.00% (-1.67%–1.72%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	-5.33% (-21.54%–15.50%)	0.00% (0.00%–0.00%)
Gear&Skin	1.33% (-7.44%–10.24%)	0.03% (-6.91%–8.41%)	-2.13% (-6.41%–1.68%)	0.00% (0.00%–0.00%)	-4.48% (-20.82%–16.23%)	1.71% (-1.31%–5.76%)
Press&Skin	2.47% (-12.39%–17.99%)	0.43% (0.00%–2.14%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	3.83% (-2.96%–10.78%)	1.71% (-1.26%–5.59%)
Gear&Press&Skin	1.76% (-6.33%–10.07%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	-4.48% (-21.12%–14.31%)	1.71% (-1.27%–5.16%)
Ecchy&Skin	1.59% (-13.25%–16.85%)	2.58% (0.45%–4.89%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	4.69% (-1.81%–11.88%)	1.71% (-1.26%–5.30%)
Gear&Ecchy&Skin	1.76% (-6.81%–10.13%)	0.86% (0.00%–2.56%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	-4.48% (-20.80%–15.77%)	1.71% (-1.65%–5.71%)
Press&Ecchy&Skin	2.87% (-13.68%–17.23%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	4.69% (-3.28%–11.84%)	1.71% (-1.36%–5.83%)
Gear&Press&Ecchy&Skin	2.19% (-6.45%–10.70%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	-4.48% (-20.98%–13.58%)	1.71% (-1.29%–5.29%)

TABLE 5

a)

	4P_knotless Results					
	0	1	2	3	≤1	≤2
Gear	17.15% (8.44%–28.93%)	48.95% (40.00%–57.74%)	33.89% (22.92%–45.53%)	0.00% (0.00%–0.00%)	66.11% (54.47%–77.08%)	100.00% (100.00%–100.00%)
Press	94.98% (90.50%–98.32%)	5.02% (1.68%–9.50%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	100.00% (100.00%–100.00%)	100.00% (100.00%–100.00%)
Ecchy	89.96% (83.12%–95.80%)	10.04% (4.20%–16.88%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	100.00% (100.00%–100.00%)	100.00% (100.00%–100.00%)
Skin	82.85% (71.73%–92.02%)	14.23% (6.28%–24.48%)	2.93% (0.00%–6.67%)	0.00% (0.00%–0.00%)	97.07% (93.33%–100.00%)	100.00% (100.00%–100.00%)
Gear&Press	15.06% (8.05%–24.58%)	2.51% (0.42%–5.39%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	66.11% (55.74%–76.45%)	100.00% (100.00%–100.00%)
Gear&Ecchy	14.64% (7.98%–24.07%)	3.77% (0.42%–8.40%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	66.11% (55.23%–77.18%)	100.00% (100.00%–100.00%)
Press&Ecchy	85.36% (77.08%–92.02%)	0.42% (0.00%–1.68%)	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&Press&Ecchy	12.97% (6.81%–20.58%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	66.11% (55.51%–77.69%)	100.00% (100.00%–100.00%)
Gear&Skin	14.23% (8.02%–22.22%)	7.53% (3.35%–14.23%)	0.42% (0.00%–2.07%)	0.00% (0.00%–0.00%)	63.60% (52.52%–74.27%)	100.00% (100.00%–100.00%)
Press&Skin	79.50% (68.75%–88.28%)	1.67% (0.00%–4.58%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	97.07% (93.31%–100.00%)	100.00% (100.00%–100.00%)
Gear&Press&Skin	12.55% (7.20%–18.26%)	1.26% (0.00%–3.75%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	63.60% (51.69%–74.58%)	100.00% (100.00%–100.00%)
Ecchy&Skin	75.31% (63.03%–86.67%)	1.67% (0.00%–4.18%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	97.07% (93.28%–100.00%)	100.00% (100.00%–100.00%)
Gear&Ecchy&Skin	12.97% (7.56%–20.00%)	0.42% (0.00%–2.09%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	63.60% (52.74%–75.10%)	100.00% (100.00%–100.00%)
Press&Ecchy&Skin	71.97% (58.85%–82.77%)	0.42% (0.00%–1.68%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	97.07% (93.70%–100.00%)	100.00% (100.00%–100.00%)
Gear&Press&Ecchy&Skin	11.30% (6.67%–17.43%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	63.60% (52.10%–75.62%)	100.00% (100.00%–100.00%)

b)

	4P_Knotless - 2P_Knotted Results					
	0	1	2	3	≤1	≤2
Gear	5.62% (-5.74%–18.12%)	2.80% (-11.25%–16.80%)	-8.42% (-26.00%–8.39%)	0.00% (0.00%–0.00%)	8.42% (-8.39%–26.00%)	0.00% (0.00%–0.00%)
Press	-2.46% (-7.51%–2.15%)	2.46% (-2.15%–7.51%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)
Ecchy	-1.49% (-9.25%–5.44%)	2.35% (-4.85%–10.00%)	-0.85% (-2.56%–0.00%)	0.00% (0.00%–0.00%)	0.85% (0.00%–2.56%)	0.00% (0.00%–0.00%)
Skin	5.07% (-10.47%–19.00%)	-1.16% (-12.36%–11.58%)	-1.34% (-6.60%–3.72%)	-2.56% (-6.25%–0.00%)	3.91% (-1.70%–10.11%)	2.56% (0.00%–6.25%)

Gear&Press	3.95% (-6.22%–14.58%)	0.80% (-2.18%–4.08%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	8.42% (-6.58%–23.79%)	0.00% (0.00%–0.00%)
Gear&Ecchy	3.53% (-6.48%–15.12%)	-0.08% (-4.58%–5.43%)	-0.85% (-2.92%–0.00%)	0.00% (0.00%–0.00%)	8.42% (-7.66%–26.09%)	0.00% (0.00%–0.00%)
Press&Ecchy	-3.96% (-13.70%–4.38%)	-0.01% (-1.71%–1.66%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.85% (0.00%–2.63%)	0.00% (0.00%–0.00%)
Gear&Press&Ecchy	2.29% (-5.98%–11.21%)	-0.43% (-1.75%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	8.42% (-6.68%–26.32%)	0.00% (0.00%–0.00%)
Gear&Skin	3.97% (-5.21%–13.85%)	0.27% (-5.56%–7.86%)	-2.57% (-6.67%–0.42%)	0.00% (0.00%–0.00%)	8.04% (-7.39%–23.99%)	2.56% (0.00%–6.31%)
Press&Skin	3.86% (-12.35%–16.95%)	1.67% (0.00%–4.58%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	3.91% (-2.06%–9.86%)	2.56% (0.00%–6.02%)
Gear&Press&Skin	2.72% (-5.42%–10.93%)	1.26% (0.00%–3.75%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	8.04% (-8.29%–26.85%)	2.56% (0.00%–5.70%)
Ecchy&Skin	5.23% (-11.52%–19.94%)	1.67% (0.00%–4.18%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	4.76% (-1.62%–11.54%)	2.56% (0.00%–5.83%)
Gear&Ecchy&Skin	3.14% (-5.31%–11.61%)	0.42% (0.00%–2.09%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	8.04% (-7.81%–26.31%)	2.56% (0.00%–6.31%)
Press&Ecchy&Skin	3.59% (-12.28%–18.27%)	0.42% (0.00%–1.68%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	4.76% (-1.28%–11.97%)	2.56% (0.00%–6.41%)
Gear&Press&Ecchy&Skin	1.90% (-6.09%–9.94%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	8.04% (-7.50%–25.21%)	2.56% (0.00%–6.14%)

TABLE 6

	4P_Knotless - 2P_Knotless Results					
	0	1	2	3	≤1	≤2
Gear	1.70% (-13.44%–16.75%)	12.04% (-0.44%–23.96%)	-13.75% (-29.14%–5.33%)	0.00% (0.00%–0.00%)	13.75% (-5.33%–29.14%)	0.00% (0.00%–0.00%)
Press	-3.73% (-8.63%–0.43%)	3.73% (-0.43%–8.63%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)
Ecchy	-0.17% (-8.58%–7.47%)	0.17% (-7.47%–8.58%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)
Skin	3.88% (-12.06%–18.61%)	-3.80% (-16.78%–9.80%)	0.78% (-3.95%–5.39%)	-0.86% (-2.58%–0.00%)	0.08% (-4.85%–5.46%)	0.86% (0.00%–2.58%)
Gear&Press	-0.39% (-16.53%–13.45%)	1.65% (-0.89%–4.64%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	13.75% (-3.89%–30.04%)	0.00% (0.00%–0.00%)
Gear&Ecchy	-0.38% (-14.23%–13.31%)	-0.10% (-4.58%–5.28%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	13.75% (-3.95%–31.36%)	0.00% (0.00%–0.00%)
Press&Ecchy	-3.91% (-13.75%–4.27%)	-0.01% (-1.72%–1.66%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)
Gear&Press&Ecchy	-2.05% (-16.88%–9.71%)	-0.43% (-2.10%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	13.75% (-5.14%–30.01%)	0.00% (0.00%–0.00%)
Gear&Skin	2.64% (-7.83%–12.79%)	0.24% (-7.56%–8.57%)	-0.44% (-2.94%–1.66%)	0.00% (0.00%–0.00%)	12.53% (-6.78%–28.68%)	0.86% (0.00%–2.63%)
Press&Skin	1.39% (-14.29%–16.78%)	1.24% (-0.93%–4.17%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.08% (-4.96%–5.91%)	0.86% (0.00%–2.52%)
Gear&Press&Skin	0.96% (-8.02%–9.39%)	1.26% (0.00%–3.75%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	12.53% (-6.30%–28.58%)	0.86% (0.00%–2.58%)
Ecchy&Skin	3.64% (-13.76%–19.20%)	-0.90% (-3.97%–2.46%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.08% (-5.31%–5.17%)	0.86% (0.00%–2.56%)
Gear&Ecchy&Skin	1.38% (-6.59%–10.33%)	-0.44% (-2.52%–1.64%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	12.53% (-5.62%–30.43%)	0.86% (0.00%–2.67%)
Press&Ecchy&Skin	0.72% (-16.73%–16.69%)	0.42% (0.00%–1.68%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.08% (-4.60%–6.08%)	0.86% (0.00%–2.58%)
Gear&Press&Ecchy&Skin	-0.29% (-8.15%–7.73%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	0.00% (0.00%–0.00%)	12.53% (-4.70%–29.04%)	0.86% (0.00%–2.56%)

FIGURES

Fig. 1: Codend images taken during the cruise. Picture (a) shows the 2P_Knotted codend normally used by the fleet, picture (b) shows detail of the 2P_Knotted codend, whereas picture (c) shows a detail of the compression of fish against a knotless netting panel.

Fig. 2: Examples of fish with different damage categories/scores on the four different damage types evaluated. Note that the blank cells result from the lack of fish with that particular score for a specific damage type.

Fig. 3: Damage frequency scores on cod harvested with the 2P_Knotted codend by hauls.

Fig. 4: Damage frequency scores on cod harvested with the 2P_Knotless codend by hauls.

Fig. 5: Damage frequency scores on cod harvested with the 4P_Knotless codend by hauls.

Fig. 6: Probability for cod to exhibit different scores for the four different damage types studied with the three different codends tested: 2P_Knotted (2PYK), 2P_Knotless (2PNK) and 4P_Knotless (4PNK).

Fig. 7: Probability for cod to exhibit different scores for all four different damage types studied combined with the three different codends tested: 2P_Knotted (2PYK), 2P_Knotless (2PNK) and 4P_Knotless (4PNK).

Fig. 8: Probability for cod to exhibit different scores for three of the damage types studied combined at the time with the three different codends tested: 2P_Knotted (2PYK), 2P_Knotless (2PNK) and 4P_Knotless (4PNK).

FIG. 1

FIG. 2

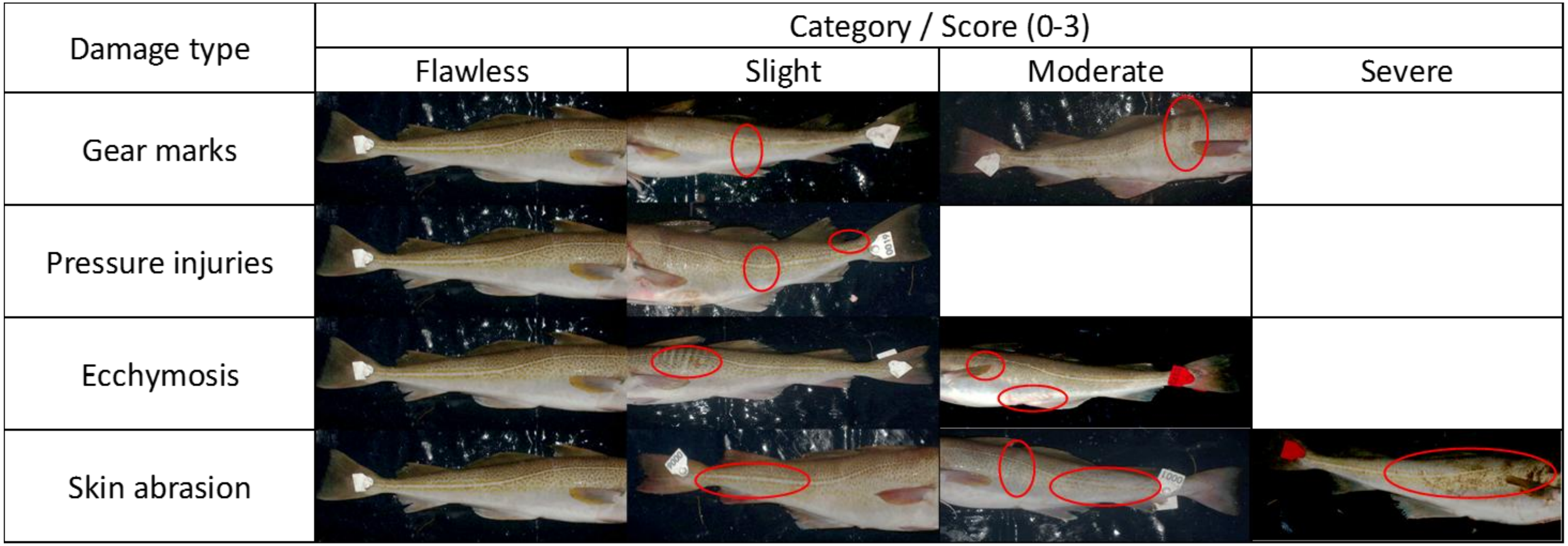

Damage type
Category / Score (0-3)
Flawless
Slight
Moderate
Severe
Gear marks
Pressure injuries
Ecchymosis
Skin abrasion

FIG. 3

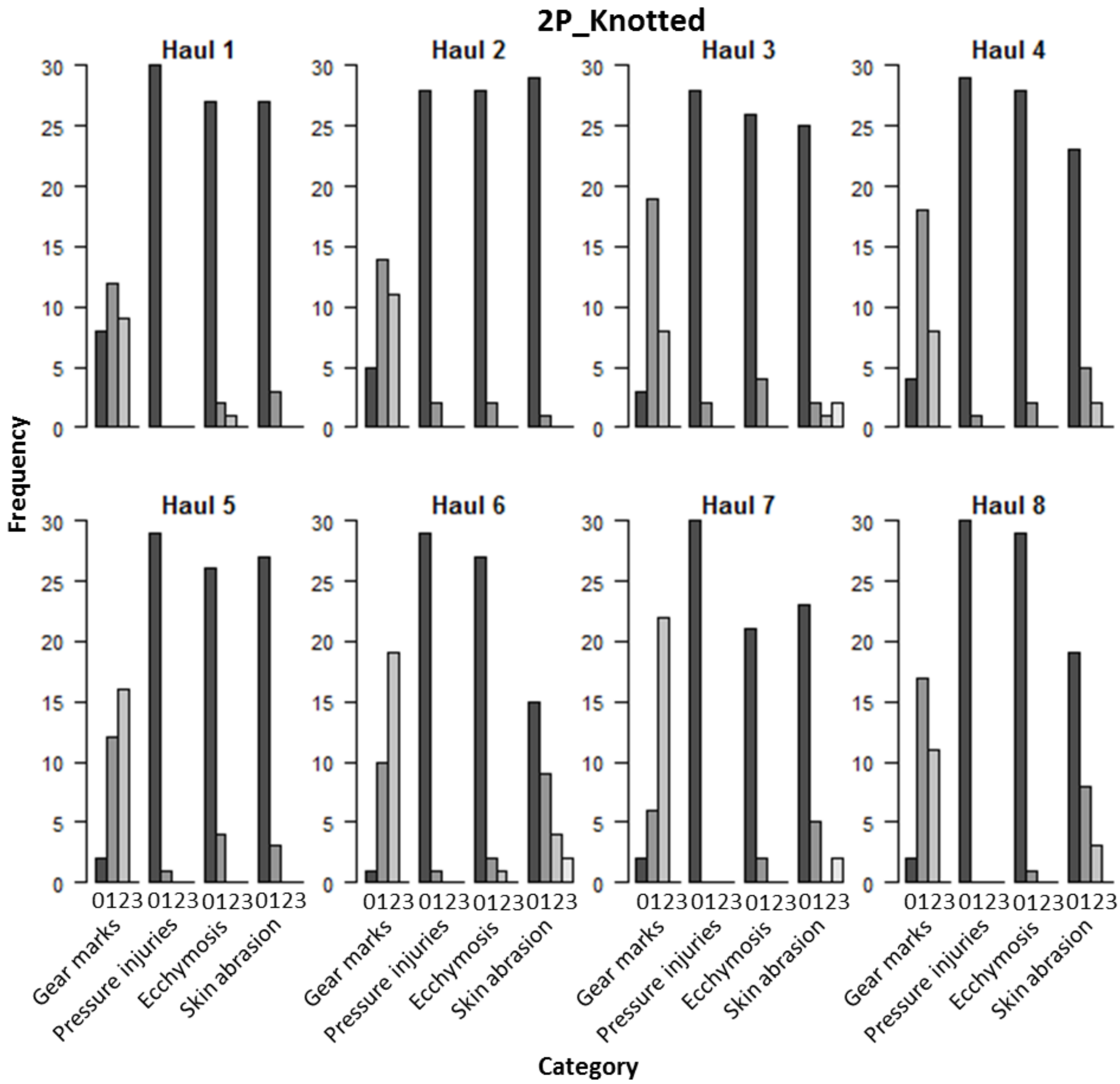

2P_Knotted
Haul 1
Haul 2
Haul 3
Haul 4
Haul 5
Haul 6
Haul 7
Haul 8
Frequency
Gear marks
Pressure injuries
Ecchymosis
Skin abrasion
Category

FIG. 4

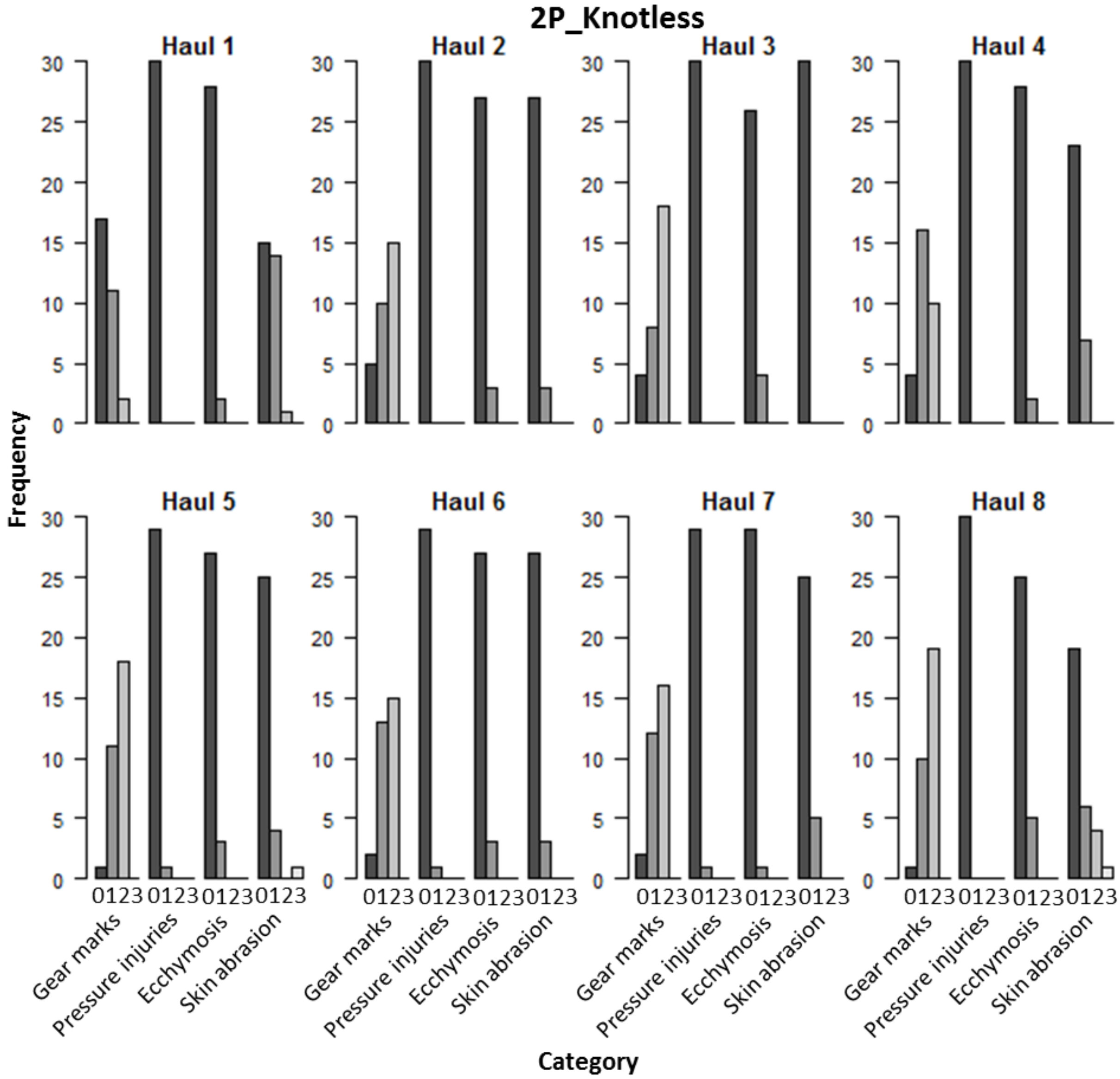
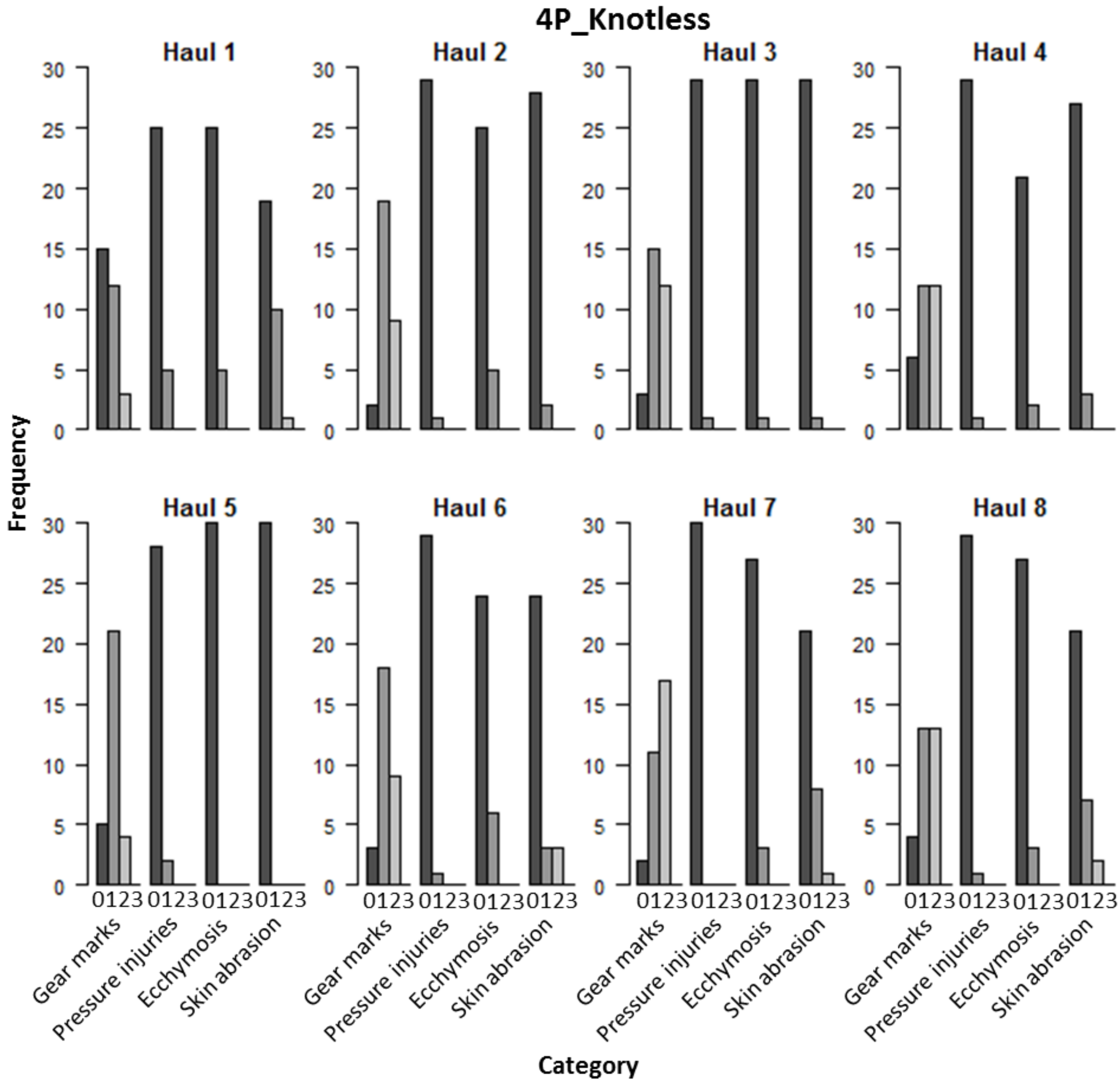
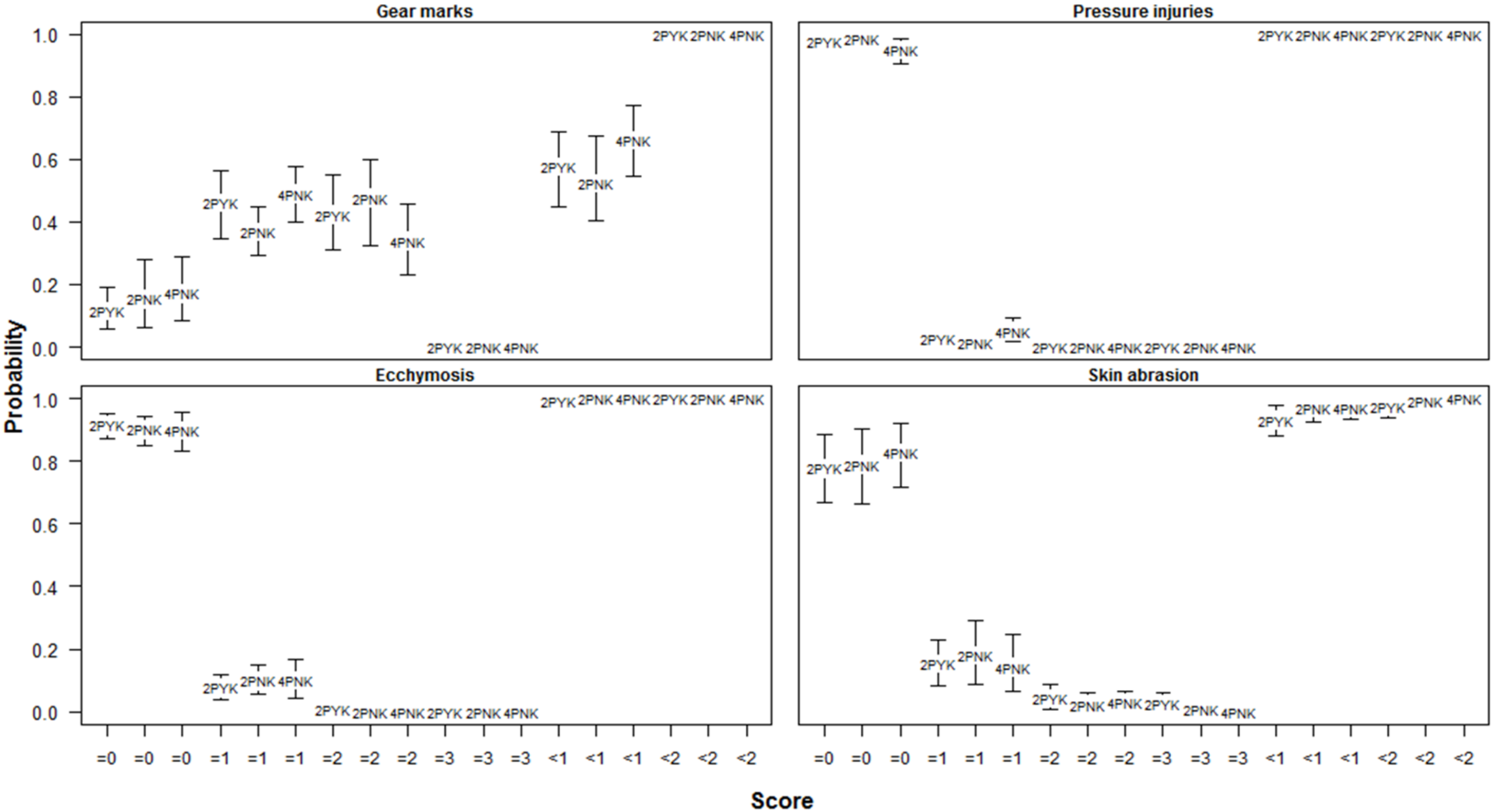

2P_Knotless
Haul 1
Haul 2
Haul 3
Haul 4
Haul 5
Haul 6
Haul 7
Haul 8
Frequency
0
5
10
15
20
25
30
0123 0123 0123 0123
Gear marks
Pressure injuries
Ecchymosis
Skin abrasion
Category

FIG. 5



4P_Knotless
Haul 1
Haul 2
Haul 3
Haul 4
Haul 5
Haul 6
Haul 7
Haul 8
Frequency
0123
Gear marks
Pressure injuries
Ecchymosis
Skin abrasion
Category

FIG. 6



Gear marks
Pressure injuries
Ecchymosis
Skin abrasion
Probability
Score
1.0
0.8
0.6
0.4
0.2
0.0
2PYK
2PNK
4PNK
=0 =0 =0 =1 =1 =1 =2 =2 =2 =3 =3 =3 <1 <1 <1 <2 <2 <2

FIG. 7

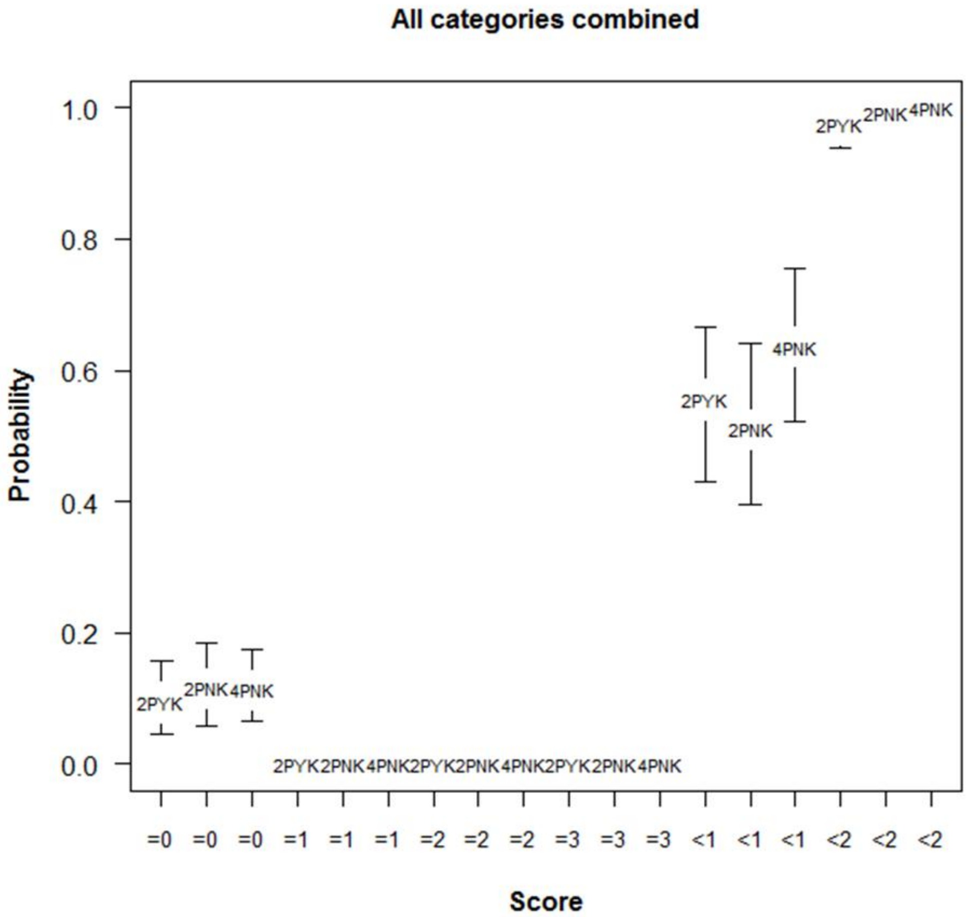
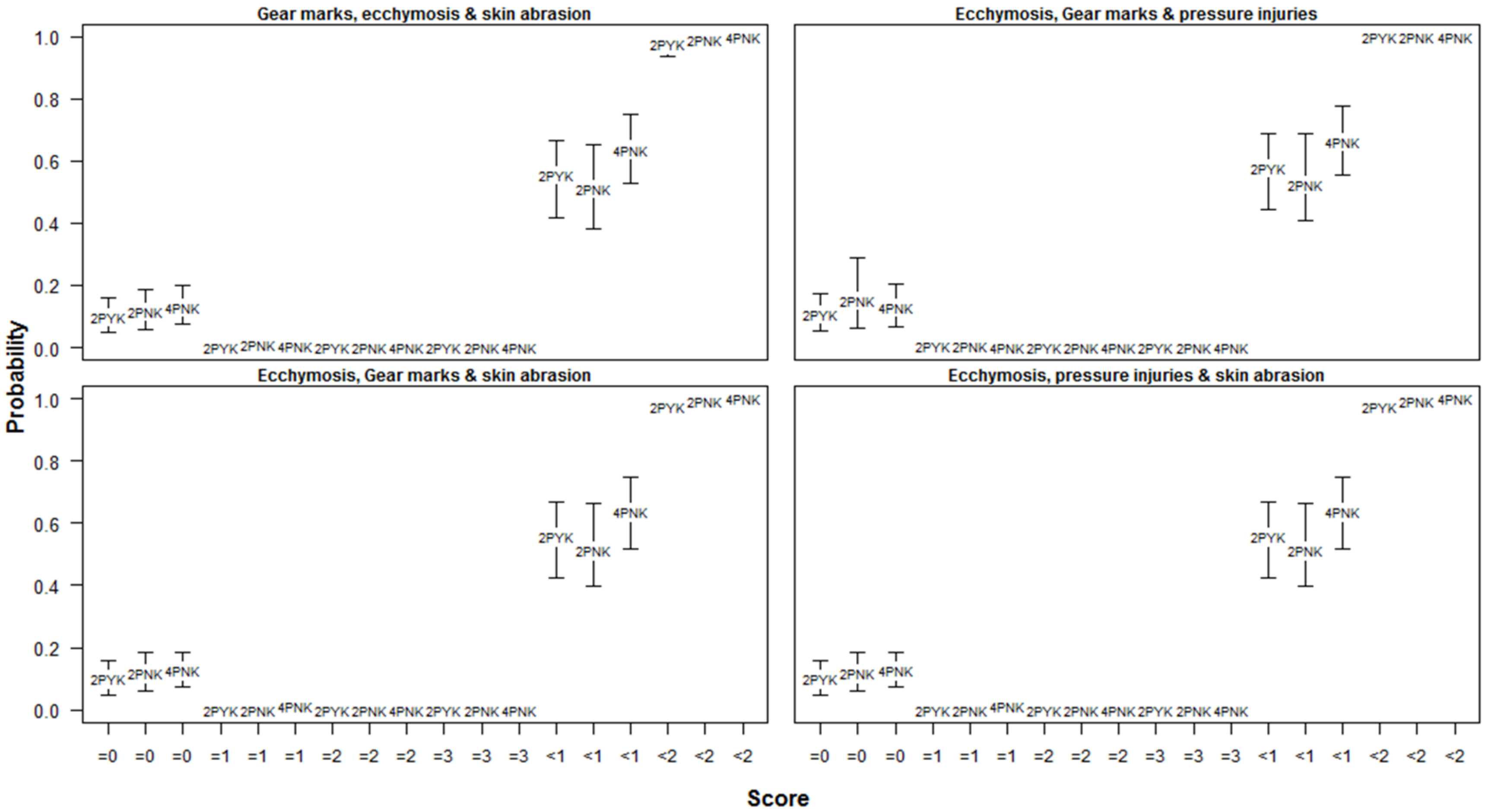

All categories combined
Probability
1.0
0.8
0.6
0.4
0.2
0.0
2PYK
2PNK
4PNK
2PYK2PNK4PNK2PYK2PNK4PNK2PYK2PNK4PNK
2PYK
2PNK
4PNK
2PYK
2PNK
4PNK
=0 =0 =0 =1 =1 =1 =2 =2 =2 =3 =3 =3 <1 <1 <1 <2 <2 <2
Score

FIG. 8


Gear marks, ecchymosis & skin abrasion
Ecchymosis, Gear marks & pressure injuries
Ecchymosis, Gear marks & skin abrasion
Ecchymosis, pressure injuries & skin abrasion
Probability
Score
2PYK
2PNK
4PNK
=0
=1
=2
=3
<1
<2
0.0
0.2
0.4
0.6
0.8
1.0