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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*

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Abstract The effect of trawling on fish size and on different quality parameters of cod (*Gadus morhua*) and haddock (*Melanogrammus aeglefinus*) was evaluated after conducting 16 valid hauls using two trawls in a double rig fitted with a traditional and a novel 'T90' codend, respectively. The total catch volume during the fishing period was 47.6 metric tons, with an average catch per codend of 1.5 (range 0.5–2.9) tons. The mean haul duration was 5 h. The catch was assessed according to fish size, mortality, external damage, initial white muscle pH and development of rigor mortis. Fillet quality (colour, blood spots, gaping) was assessed after 1 week of freeze-storage. Our results showed there was no difference between the two types of nets in terms of catch volume, but significantly slightly bigger fish were caught with T90 than with the traditional trawl net ($p < 0.05$). Haddock caught with the traditional trawl net had more external injuries related to the trawl gear than haddock caught with the T90 gear ($p < 0.05$). The gaping frequency for cod caught with the traditional trawl net tended to be higher than cod caught with the T90 gear, but the difference was not significant ($p = 0.07$). No other differences in fish quality between fish caught in the trawl nets were observed.

Keywords Cod · Fish quality · Fish size · Haddock · Trawling · T90 codend

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Introduction

Seafood products have often suffered from an inherent loss of quality caused by the fishing gear, retrieval from the water, and handling on deck. Due to the nature of the industry, it is rather difficult to industrialise the production to provide for more gentle fish handling routines. In addition, seafood is often stored onboard for a comparatively long storage time until it can be landed and delivered to the fish processors or consumers. In 2003, approximately 8,000 metric tons (4% of the total catch volume) of Atlantic cod landed in Norway had suffered serious physical damage, with the result that 1,900 metric tons were down-graded, losing economic value (F. Gregersen, unpublished data 2005). Increasing the utilisation of each catch while also concurrently raising the quality of the catch will result in higher prices for the products and contribute to more sustainable fisheries in the present situation, whereas focus is currently being directed towards a better exploitation of the resources. New technologies which improve quality may further contribute to moving the industry towards quality, rather than quantity only.

Only a few attempts have been made to alter the trawl gear to improve the quality of the catch. The focus has been on the codend, with particular attention being directed towards reducing the turbulence that is seen in full-scale usage. Recent investigations have demonstrated that a drastic reduction in the movements of the codend can be achieved just by turning the direction of the netting 90° (T90) in relation to how it is normally used in traditional trawl assembly (U. J. Hansen, unpublished data 2004; Fig. 1). This effect is due to changes in the configuration of the knots in the netting—the knots are further apart with the 90° shift in direction than in netting stretched in the normal direction. In effect, a T90 codend has a much larger

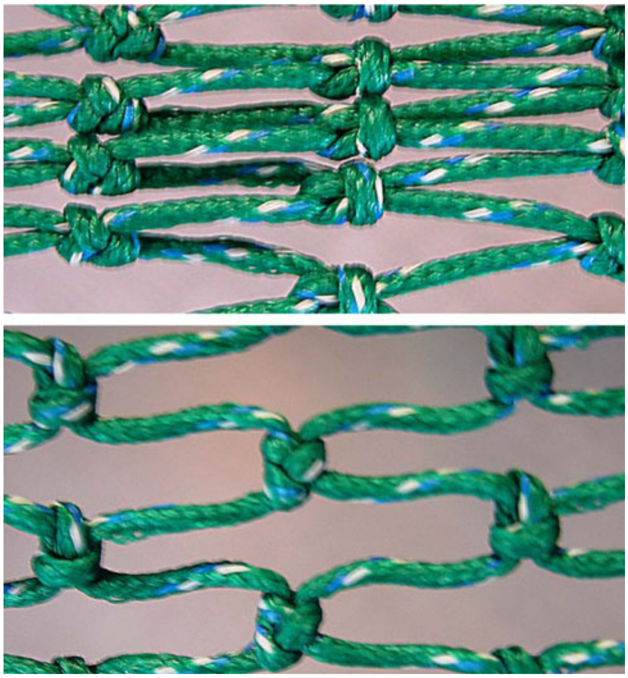

Fig. 1 Trawl netting stretched in the direction of normal use (*top*) and turned 90° (*bottom*)

cross-sectional area, and it is practically free of all movement. Theoretically, these features increase the possibility improving the catch quality.

A typical processing line onboard a present-day trawler comprises the following unit operations: (1) the trawl net is pulled up a steep trawl slip, then over another upper edge before the catch is gathered into the trawl deck; (2) the nets are emptied in a tank; (3) the gills are cut, with subsequent bleeding, gutting, deheading and packing. Although not widely studied, it has nevertheless been shown that catching methods and subsequent onboard handling may affect fish quality [1–8]. The fish are often exhausted, injured or killed as a result of inadequate catching methods, transfer from sea-to-vessel methods, or on-deck handling routines.

The hauling process can damage a substantial part of the catch because of the pressure on the codend when it is being hauled towards the boat. In many cases, the cause of death is anoxia where fish are left in the open air on the deck. The catching process leads to elevated levels of plasma cortisol [9, 10], glucose [11], lactate, [11–14] haematocrit, Na^+, K^+, and Cl^-, whereas blood pH decreases [11]. The more strenuous the stress-related activity the fish are subjected to, the more rapid the muscle ATP depletion [7, 10] and severe muscle activity causes early rigor mortis onset [10, 14]. Cole et al. [7] showed that in terms of low initial flesh pH (7.1), high blood lactate and depleted ATP stores, handlining of blue cod *Parapercis colias* was the most fatiguing capture method when compared with commercial potting, modified potting and rested harvested fish. Chopin et al. [15] showed that stress during capture may vary between different gear types. Auclair [2] evaluated the effects of the gillnet and trawl in the cod fishery and found that gillnetted fish were of a lower quality than trawl-caught fish. This author also found that the bacterial contamination increased with increased fishing times, namely, 4, 12, 24 and 48 h, with significant differences after 24 h for both fishing methods. The use of the gillnet also caused flesh discoloration due to bleeding, and fish were lost to predators and parasites. Chopin et al. [15] showed that the severity and degree of injuries increased with the time of entrapment for trammel net-caught sea bream. The quality of Atlantic cod caught by otter trawl was investigated by Botta and Bonnell [5], who concluded that the initial quality of the cod was usually very good and that the reduction of the quality was a result of catch volumes being too large (>5 tons during a single tow), delayed bleeding (>1 h), storage method and time (>6 days).

Adequate bleeding is considered to be necessary for a good product quality. Botta et al. [16] studied different bleeding/gutting procedures on the sensory quality of fresh raw Atlantic cod caught by a trawler (2–3 h tow lengths; catch amounts 2.3–13.6 tons) and showed that time before gutting (>1 h) was more important than the bleeding/gutting methods. Similar results were obtained by Kelly [17] and Valdimarsson et al. [3]. Wagner [18] evaluated the external appearance and consistency of cod caught using trawls and found that the quality was reduced with increased hauling time and number of fish in the trawl net. Botta et al. [4] compared the effect of season and catching method (gillnet, handline, longline and trap) on the quality of cod and showed that the catching method had an impact on fillet colour, discoloration, bruising and overall quality grades of cod. They concluded that the catching methods had a greater impact than season on the quality of fresh cod. Furthermore, muscle pH is lower and the condition factor is generally higher in fish caught by gillnet compared with fish caught by longline [19]. Hattula et al. [6] studied the effect of gillnetting, poundnetting and trawling on the mortality and quality of herring. Mortality increased when the trawling time increased from 2 to 5 h. Rigor mortis started earlier, and the nucleotide decomposition proceeded further in gillnet-caught fish than in fish caught by the other methods, indicating a loss of freshness due to stress in the catching process. Özyurt et al. [8] showed that quality and shelf life of pike perch (*Sander lucioperca*) were affected by catching methods, with the acceptable shelf life being 7 days longer for pike perch caught by longline and harpoon than gillnetted fish.

The objectives of this study were to compare a T90 codend and a traditional trawl net in terms of fish injuries, fish size, handling stress and fillet quality and to obtain more knowledge about how trawling impacts cod and haddock quality.

Materials and methods

Fishing gear

Cod and haddock were captured using a traditional and the novel 'T90' codends by a typical North Atlantic factory trawler (M/T J. Bergvoll, length 57 m, BT 1499, HP 3900) in November 2004. The vessel was selected due to its ability to operate two trawls simultaneously. This was ideal for the aim of the study since the simultaneous use of the two trawls would exclude a number of variables and make the assessments more directly comparable.

The trawls used were identical traditional cod trawls, but fitted with different codends. They were of the type Alfredo no. 5 (Refa-Frøystad Group, Tromsø, Norway) that is standardly used by several trawlers in the North Atlantic. The codend on one side was a standard codend and on the other side, it was of the new (T90) design (Figs. 1, 2). Both trawls were fitted with the sorting grid which is specified by the Norwegian authorities in the Technical Regulations for the whitefish fishery in the Barents Sea (SDBS website: http://www.lovdata.no/for/sf/fi/xi-20000310-0271.html).

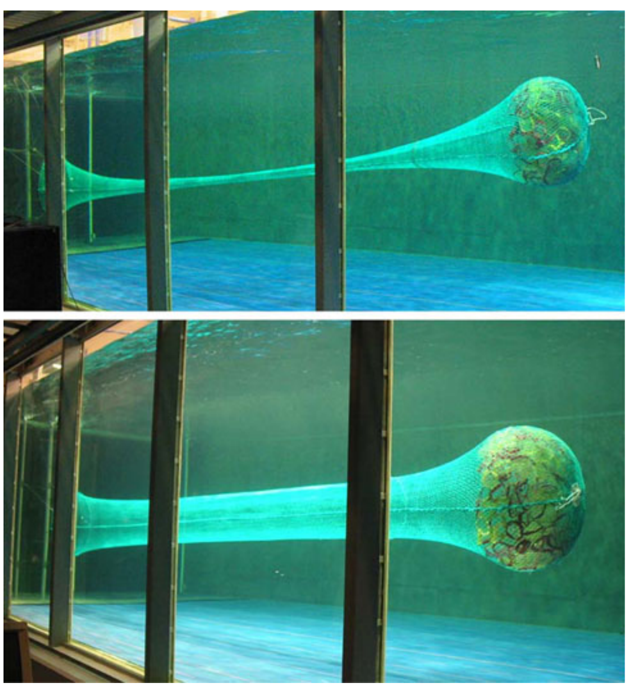

Fig. 2 Two models of codends made from normal netting (*top*) and T90 (*bottom*) demonstrate the difference due to the two configurations. Photographs were taken in the flume tanks of SINTEF Fisheries and Aquaculture in Hirtshals, Denmark

The sorting grids (flexigrids) were mounted as a whole unit between the belly of the trawl and the extension piece in front of the codend. The standard codend had an extension piece and codend made from standard diamond mesh materials, while the T90 codend differed by having a large part made from netting turned 90° (Fig. 3). Normally, a joining ratio of 2:3 is recommended to join the turned meshes from the T90 material to the standard diamond mesh. Because the aforementioned regulation specifies the use of selection grids in cod trawls and also specifies the number of meshes in the circumference, the joining ratio in this case was a compromise—104 meshes were joined to 80 in the case of the T90. The extension piece and codend were made from 6- and 8-mm double-braided polyamide, respectively. The rear-most 4.8 m of the T90 codend was made from knotless netting in an attempt to create the best conditions for the preservation of fish quality. Knotless netting has a much smoother inside surface than double-braided knotted netting. It should be mentioned that the T90 concept does not apply to knotless netting. Both trawls were fitted with the usual top and bottom side chafers. The nets were closed by weaving the top and bottom panel meshes together with a cod line, which results in a long transversal knot that has been seen in model tests to further reduce the movements of the catch. The trawls were both fitted with acoustic monitoring instruments to measure the distance between the doors and the filling rate of the codends.

Fish capture

Seventeen hauls were conducted during the period 20–24 November 2004 in the Nordkapp Bank in the Barents Sea (71°N/24–27°E). The bank is located north of the coast of Finnmark in northern Norway. A trawl was badly damaged in one haul, and that haul was not included in further analyses. The total catch for the 16 valid hauls was 47.6 metric tons, with an average catch of 2.98 tons (range 1.06–4.85 tons) per haul (= 2 codends). During the trials, effort was made to standardise the hauling conditions, but factors such as the bottom conditions or the weather conditions occasionally prevented us from fulfilling this criterion. The mean haul duration was 5 h (range 2.5–6.0 h), and the towing speed was kept close to 4.0 knots. The fishing was conducted at depths between 238 and 370 m. Data for each haul, including catch amount, are given in Table 1.

Processing line

The processing line onboard consisted of the following operations: (1) the trawl net with the fish were hauled up on deck; (2) the nets were emptied in a tank without water;

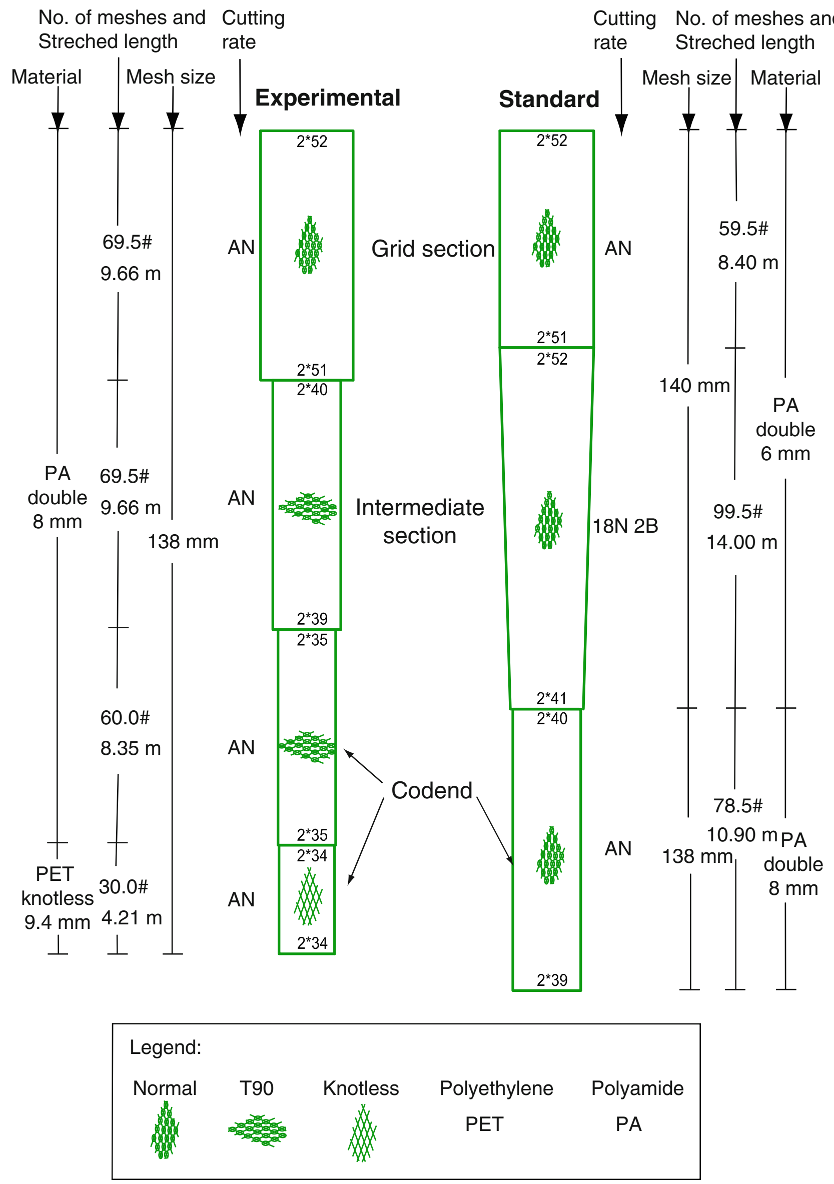

Fig. 3 Specifications for the two different codends, including information on the material, number of meshes and stretched length, mesh size and cutting rate

(2) the throats of the fish were cut (within 2 h) and the fish were placed in a tank without water prior to being gutted, deheaded, frozen in blocks and stored in a freezing room at −21°C. Total processing time from the time the catch was brought onboard until the fish were packed before freezing was typically around 2.5 h.

Fish sampling

Immediately after the catch, cod and haddock were collected from the codends while still on deck. Due to the tight schedule, it was not always possible to make all assessments of the fish from every haul. A selection of the assessments of the fish was conducted from a random selection of the hauls. Fish were selected at random, and the number of mortalities, visual assessment of external damage, and fish size were determined. Mortality rates were assessed for both species from Haul 8 and 11 (cod, $n = 83$; haddock, $n = 84$). Visual assessments of external damage were done on cod ($n = 520$) and haddock ($n = 481$) from eight hauls (Hauls 1, 3, 4, 5, 7, 8, 11 and 13). To evaluate the fish size, we measured the length of individual cod ($n = 3{,}803$) and haddock ($n = 5{,}165$) from eight different hauls (Hauls 4, 5, 7, 8, 11, 12, 13 and 15).

The fish were subsequently collected from the processing line after the throats were cut, and measurements of initial white muscle pH, body temperature, weight, fork length and rigor status were conducted on cod (weight 2.4 ± 0.1 kg, fork length 61 ± 1 cm; $n = 102$) and haddock (weight 1.7 ± 0.1 kg, fork length 50 ± 1 cm; $n = 97$) from five different hauls (Hauls 1, 3, 7, 12 and 15), approximately within 60 min after the fish were landed on deck.

Table 1 Catching data for each haul, fishing conditions and catch amounts for traditional and T90 codend trawl nets

Haul no.	Date November 2004	Haul duration (h)	Wind speed (m/s)	Fishing depth (m)	T90 (kg fish)	Traditional trawl net (kg fish)	Catch difference T90 vs. trad. (kg)	Total catch (kg)
1	20	5	12	296–270	765	497	268	1,262
2	20	6	6	265–240	2,018	1,688	330	3,706
3	21	5.5	6	238–241	2,847	2,006	841	4,853
4	21	5	6	284–258	1,793	1,990	−197	3,783
5	21	3	5	256–275	1,799	1,923	−124	3,722
6	21	5	10	277–243	2,114	2,044	70	4,158
7	22	5	10	252–256	1,799	1,760	39	3,559
8	22	5	8	280–283	1,261	1,955	−694	3,216
9	22	5	8	292–283	–	–	–	–
10	23	2.5	10	254–245	596	573	23	1,169
11	23	5	6	240–320	1,068	1,059	9	2,127
12	23	5	12	370–358	1,993	1,989	4	3,982
13	23	5	7	339–347	1,532	1,541	−9	3,073
14	23	5.5	8	308–309	1,015	1,850	−835	2,865
15	24	5.5	13	365–311	1,236	1,408	−172	2,644
16	24	5	18	342–250	1,279	1,176	103	2,455
17	24	5	25	250–260	572	483	89	1,055
Total					23,687	23,942	−255	47,629

Cod ($n = 40$) and haddock ($n = 40$) from Haul 8 were collected at random from the processing line before the fish were frozen. The fish were packed in Styrofoam boxes, frozen onboard (−21°C), transported to our laboratory and stored at −21°C for 8–9 days. The fish were then thawed at 2–4°C in a cold room for 2 days and filleted (skin-on) by hand, following which muscle pH, fillet colour and visual assessments of blood spots and gaping were carried out (day 10 and 11 postmortem for haddock and cod, respectively).

Table 2 Scoring system used for visual evaluation of injuries on whole fish onboard

Parameter	Score	Description
Gear injuries	0	No visible marks
	1	Visible marks on the surface of the fish
Scale-loss	0	No scale-loss
	1	Some scale-loss of part of the fish (<50%)
	2	Whole fish has lots of scale-loss (>50%)
Pressure injuries	0	No injuries
	1	Some minor injuries on part of the fish (<2)
	2	Whole fish has injuries (>2)
Bruises (discoloration on the skin)	0	No discolorations
	1	Some minor discoloration on parts of the fish
	2	Whole fish has lots of discoloration

Analyses

The mortality rate was estimated by cessation of gill movements and by gently touching the mid-line and the tail immediately after the catch landed onboard to see if the fish responded. Visual assessments of injuries on whole fish were conducted using a scoring system for different parameters: gear injuries, scale loss, pressure injuries and bruises (skin discolorations). A score was devised ranging from 0 up to 2 based on descriptive terms for each parameter (Table 2).

The body temperature was measured in the white muscle between the mid-line and the dorsal fin, and in filleted fish the temperature was measured in the flesh. A Testo 110 thermometer (Lenzkirch, Germany) was used. The pH was measured directly in the white muscle between the mid-line and the dorsal fin using a shielded glass electrode (WTW SenTix 41) connected to a portable pH meter (model WTW 315i; WTW, Weilheim, Germany). During the measurements, the instrument was frequently calibrated using pH 4.01 and pH 7.00 buffers. Frequent cleaning of electrodes was needed to obtain consistent results.

The rigor mortis progression during ice storage was determined using the Rigor Status Method [0 = pre- or postrigor; 1 = rigor onset (first sign of stiffness, for instance, in the neck or tail region); 2 = rigor (a larger area is clearly in rigor); 3 = whole fish in rigor; 4 = stronger rigor; 5 = very strong rigor (the fish is extremely stiff, rod-like)] [20]. Evaluation was done by touching the fish to evaluate muscle tension and by carefully lifting the fish a few centimetres above the ice to judge the degree of stiffness of the fish.

The gaping frequency was subjectively assessed using a score of 0 to 5 according to the number of slits in the fillet [21]. Visual assessments of the number of fillet blood spots according to a subjective scoring system from 0 to 2 was used, where 0 = no blood spots, 1 = 1–4 small spots and 2 = large blood spots or several small (>4).

The colour (L^*, a^* and b^*, International Commission of Illumination (CIE) 1976 colour space; hue; chroma] of the flesh was measured using the Minolta Chroma Meter CR-200 (Minolta, Osaka, Japan). The instrument readings cover an area of 8 mm in diameter. The hue angle (0°/360° = red hue, 240° = blue hue) and chroma (colour intensity or saturation) were calculated as: hue $= 360 - \tan^{-1}(b^*/a^*)$ where $a^* < 0$ and $b^* < 0$, and as chroma $= (a^{*2} + b^{*2})^{1/2}$. The measurements were carried out on the white muscle between the mid-line and the second dorsal fin at three different locations along the fillet. The instrument was calibrated using a standard white plate.

Statistics

To test significance on the effect of trawl gear and haul number on the different parameters (pH, temperature, weight, length, L^*, a^*, b^*, hue and chroma), a two-way analysis of variance (ANOVA) was used. A one-way ANOVA was used to test significance between the two trawl gears and between different catch amounts. For the non-parametric results (mortality, injuries, gaping and blood spots) the Mann–Whitney test was used. Significant differences were defined as $p < 0.05$. All values are reported as mean values ± standard error of means (SEM).

Results

Catch amount and fish size

During the trip a total of 47,600 kg of gutted fish was landed from 16 different hauls (Table 1). The two codends contributed the same amount of total catch, namely, 24 tons fish from each trawl gear. The average length of cod and haddock from the various hauls is given in Fig. 4. In terms of fish length between fish caught in the two trawl nets, cod from Hauls 4, 7, 8 and 13 and haddock from Hauls 5 and 7 were significantly different. In total, cod and haddock caught with the T90 codend were on average 1.5 and 0.5 cm longer (fork length), respectively, than cod and haddock caught with the traditional codend ($p < 0.05$).

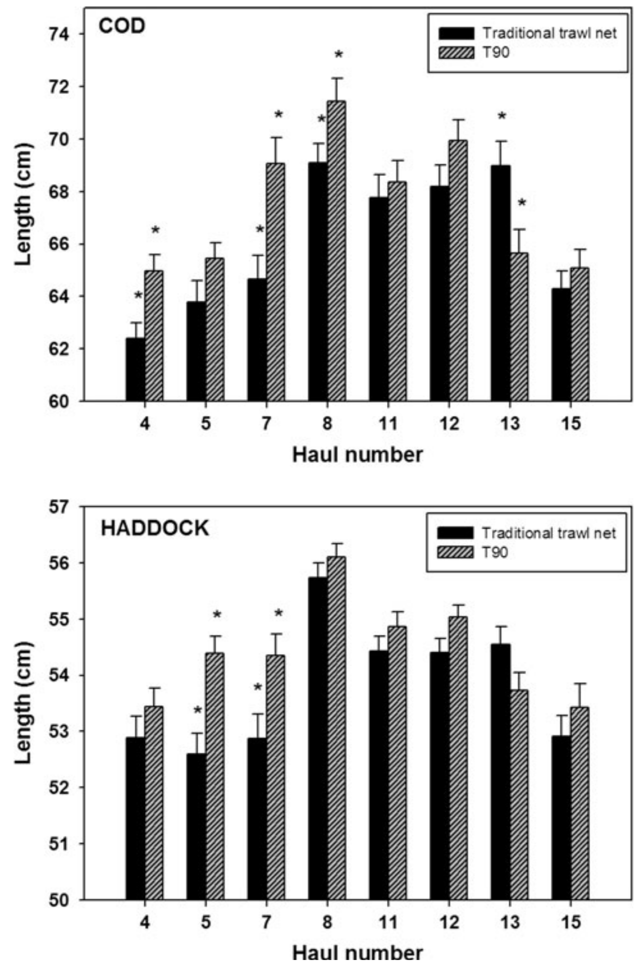

Fig. 4 Fork lengths of cod and haddock from the two trawl nets. *Significant difference between the trawl nets. Mean ± standard error of the mean (SEM) ($n = 122$–530)

Mortality and injuries

The mortality of cod caught by the two trawl nets, evaluated immediately after the catches were brought onboard, was 2.4%, with no significant difference between the nets. For haddock caught by T90 and traditional trawl nets, the mortality was 7.1 and 14.3%, respectively, but the difference was not significant. In both nets, haddock had a higher mortality rate than cod ($p = 0.03$).

More than 94% of both species exhibited various extents of scale loss, and 20–30% of the fish had some kind of injuries caused by the fishing gear (Table 3). Bruises were found on approximately 20% of both cod and haddock, while pressure injuries were found on 3–5 and 9% of the

Table 3 Mean cod and haddock mortalities and injuries as percentages of the whole catch with T90 and traditional trawl nets

Parameter	Cod		Haddock	
	T90	Traditional	T90	Traditional
Mortality	2.3 ± 2.3*	2.5 ± 2.5*	7.1 ± 4.0*	14.3 ± 5.5*
Gear injuries	28.3 ± 2.7	21.0 ± 2.6	21.8 ± 2.6[A]	30.9 ± 3.0[B]
Scale loss	96.3 ± 1.1	94.4 ± 1.5	98.4 ± 0.8	99.1 ± 0.6
Pressure injuries	5.5 ± 1.4*	3.2 ± 1.1*	8.5 ± 1.8*	8.6 ± 1.8*
Bruises	21.3 ± 2.5	16.5 ± 2.4	19.8 ± 2.5	23.6 ± 2.8

Values are given at the mean ± standard error of the mean (SEM); $n = 40$–43 (mortality), $n = 233$–272 (injuries)

Different letters (A, B) denote significant differences between the trawl nets

* Significant differences between the species ($p < 0.05$)

total catch of cod and haddock, respectively. Haddock were found to have a significantly higher scale-loss scores and a higher degree of pressure injuries than cod. Moreover, haddock caught with the traditional trawl net exhibited more gear injuries than haddock caught with the T90 trawl ($p < 0.05$; Fig. 5). There were no significant differences between the two trawl nets in terms of external damages of cod caught. Catch amount had a significant impact on the degree of injuries (Table 4). When the catch amounts were >2,000 kg, cod showed a higher degree of pressure injuries and bruises, while gear injuries were lower ($p < 0.05$). The relationship between catch amount and injuries were not so pronounced for haddock. At catch amounts >2,000 kg, haddock had more pressure injuries ($p < 0.05$), while gear injuries and scale-loss were higher when the catch amount was <2,000 kg ($p < 0.05$). No relationship between catch amounts and bruises were observed for haddock. A general observation was that haddock was more vulnerable to catch handling than cod, as both the mortality and some of the injuries were higher for haddock than cod ($p < 0.05$).

Initial muscle-pH and rigor mortis

The mean white muscle pH of cod and haddock from all the hauls and from the two trawl nets were 7.3 ± 0.2 and 6.8 ± 0.2, respectively. There was no significant difference between the trawl nets, but for cod the initial muscle pH showed significant difference between some of the hauls (Table 5). Cod from Haul 3 had significantly lower initial pH value compared with cod from Haul 12 and 15. However, there were significant differences between the species and initial muscle pH ($p < 0.001$). The mean body temperature ranged from 6.0 to 7.5°C according to sea temperatures (Table 5).

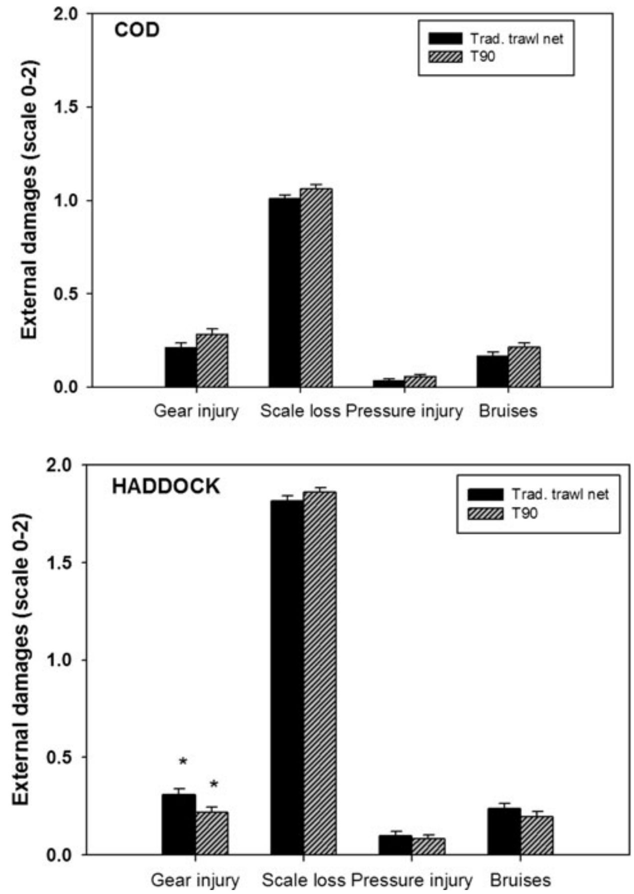

Fig. 5 Effect of using T90 and traditional trawl nets to catch fish on external damage (gear injuries, scale-loss, pressure injuries and bruises) of cod and haddock. *Significant difference between the two trawl nets ($p < 0.05$). Mean ± SEM ($n = 233$–272)

Rigor mortis assessments for both species are shown in Fig. 6. Rigor onset started within 5 h after catching. Firm rigor (score >2) was evident in 63% of the fish after 10 h postharvest; after 20 h postharvest, 100% of both species were in peak rigor. No significant differences in the rate of rigor development were observed between the two trawl nets. Haddock seemed to enter rigor a little later than cod, but rigor peaked at the same time in both fish. None of the dead fish showed visible signs of rigor when the catch was brought on board.

Fillet quality

After 10 days (haddock) and 11 days (cod) postmortem, the ultimate pH values for cod (pH 6.9 ± 0.2) and haddock (pH 6.5 ± 0.1) were significantly different ($p < 0.05$) (Table 6). The mean gaping score for both species was low (Table 6), and there was no difference between the two trawl nets for both species. However, the gaping score for cod fillets caught with the traditional trawl net tended to be

Table 4 Mean cod and haddock injuries as percentages of catch

Parameter	Cod catch (kg)			Haddock catch (kg)		
	<1,000	1,000–2,000	>2,000	<1,000	1,000–2,000	>2,000
n	59	380	81	41	355	85
Gear injuries	28.8 ± 0.1^{A}	27.1 ± 0.0^{A}	11.1 ± 0.0^{B}	17.1 ± 6.0^{AB}	30.7 ± 2.5^{A}	11.8 ± 3.5^{B}
Scale-loss	91.5 ± 0.0	95.8 ± 0.0	96.3 ± 0.0	100 ± 0.0^{A}	99.7 ± 0.3^{A}	94.1 ± 2.6^{B}
Pressure injuries	6.8 ± 0.0^{A}	1.8 ± 0.0^{A}	14.8 ± 0.0^{B}	12.2 ± 5.2^{A}	3.9 ± 1.0^{A}	25.9 ± 4.8^{A}
Bruises	33.9 ± 0.0^{A}	14.0 ± 0.0^{B}	32.1 ± 0.0^{A}	26.8 ± 7.0	19.4 ± 2.1	28.2 ± 4.9

Values are given at the mean ± SEM

Different letters (A, B) denote significant differences between the catch amount for each species ($p < 0.05$)

Table 5 Pooled initial cod and haddock white muscle pH and body temperatures from five different hauls

Haul	Catch amount (kg)	*n*	Initial muscle pH	Body temperature (°C)
Cod				
1	1,262	6	7.2 ± 0.0^{AB}*	6.8 ± 0.1^{A}
3	4,853	35	7.2 ± 0.0^{A}*	7.5 ± 0.0^{B}
7	3,559	21	7.2 ± 0.0^{AB}*	6.6 ± 0.0^{A}
12	3,982	20	7.3 ± 0.0^{B}*	6.0 ± 0.1^{C}
15	2,644	20	7.3 ± 0.0^{B}*	6.6 ± 0.0^{A}
Haddock				
1	1,262	34	6.8 ± 0.0*	7.0 ± 0.1^{A}
3	4,853	4	6.7 ± 0.1*	7.3 ± 0.1^{A}
7	3,559	19	6.8 ± 0.0*	6.7 ± 0.1^{B}
12	3,982	20	6.9 ± 0.0*	6.2 ± 0.1^{C}
15	2,644	20	6.8 ± 0.0*	6.6 ± 0.1^{B}

The measurements were carried out within 60 min after the catch was brought on deck

Mean ± SEM. Since there were no significant differences between the two trawl nets, the data were pooled. Different letters (A, B) denote significant differences between the haul numbers

* Significant differences between the species ($p < 0.05$)

higher than for cod caught with the T90 gear, but the difference were not significant ($p = 0.07$). Blood spots were observed in 33 and 28% of cod and haddock fillets, respectively, with a score <0.6 for both species (Table 6). Again, no differences between the two trawl nets for either species nor between the species were observed ($p > 0.05$).

The L^*, a^*, b^*, hue and chroma values measured on fillets of cod and haddock are shown in Table 7. There were no significant differences between the two trawl nets for either species, and the data were therefore pooled. However, there was a difference between the species in the lightness (L^* value) of the fillets ($p < 0.05$), with the haddock being darker than the cod.

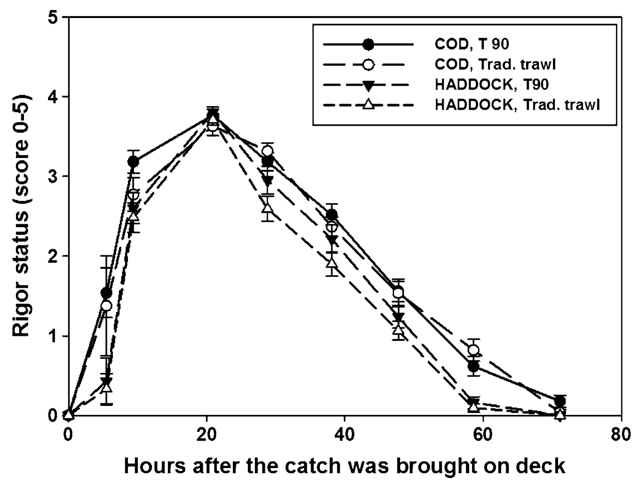

Fig. 6 Development of rigor mortis of cod ($n = 102$) and haddock ($n = 97$) caught with T90 and traditional trawl nets. Data from five different hauls are pooled. Mean ± SEM

Table 6 Gaping, blood spots and ultimate pH in thawed fillets of cod and haddock caught with T90 and traditional trawl nets

Quality parameter	T90	Traditional trawl net
Cod		
Gaping (score 0–5)	0.1 ± 0.1	0.4 ± 0.2
Blood spots (score 0–2)	0.6 ± 0.2	0.4 ± 0.1
Ultimate pH	6.9 ± 0.0*	6.9 ± 0.0*
Haddock		
Gaping (score 0–5)	0.5 ± 0.2	0.7 ± 0.2
Blood spots (score 0–2)	0.3 ± 0.1	0.3 ± 0.1
Ultimate pH	6.5 ± 0.0*	6.5 ± 0.0*

The fish were evaluated after 10 days (haddock) and 11 days (cod) postmortem

Values are given as the mean ± SEM, ($n = 20$)

* Significant differences between species ($p < 0.05$). No significant differences between the trawl nets were found

Table 7 Cod and haddock fillet colour as L^*, a^*, b^*, hue and chroma values after 10 days (haddock) and 11 days (cod) postmortem

Colour	Cod	Haddock
L^*	50.2 ± 0.4*	48.5 ± 0.3*
a^*	−1.4 ± 0.1	−1.4 ± 0.0
b^*	−3.3 ± 0.2	−2.9 ± 0.2
Hue	295.4 ± 1.4	298.1 ± 1.6
Chroma	3.6 ± 0.2	3.3 ± 0.2

Values are given as the mean ± SEM ($n = 40$. As there were no significant differences between the two trawl nets or both fish species, the data were pooled

* Significant differences between species ($p < 0.05$)

Discussion

Even if the size of the fish did not differ much between the two trawl nets, the T90 caught significantly slightly larger fish than the traditional trawl net for both species (Fig. 4). It was not possible to clarify whether this difference was due to better selectivity, possibly as a result of more open meshes and a larger cross-sectional area in the T90 codend (Fig. 1), which have been documented in the Baltic cod fishery [22, 23].

According to the impact of the trawl gears on injuries, the T90 caused fewer gear injuries to haddock. The positive properties of the T90, with its larger cross-section, reduced flow and turbulence, appeared to reduce the damage on the more delicate fish species—in this case, haddock. Similar effects were not seen for cod. This is not in accordance to unpublished results of U.J. Hansen, L.H. Knudsen, P. Nielsen and E.M. Andersen (1996) who reported that cod caught with a T90 codend had 28% fewer injuries than cod caught with a traditional trawl net. It can be argued that the reduced movement of codend is not a direct measurement of the ability to preserve fish quality and reduce injuries. However, there is strong evidence from studies on the survival of fish after escape from the trawl that the fish are more damaged from rubbing against the netting in the trawl than from the act of penetrating the netting and escapement [24, 25]. The damage is seen as pressure marks and other bruises to the flesh as well as damage to the skin, especially in the head and tail regions. A possible explanation for these observations is that the fish are thrown around in the incessant turbulent flow inside the codend and are scraped against the knots in the net.

Nevertheless, regardless of codends, trawling had negative impacts on injuries on both fish species; in particular, various degrees of scale loss were observed on almost all fish. The mortality rate was different between cod and haddock, with haddock having the highest mortality rate (Table 3). This is in accordance to McCracken [26], who found a greater mortality among haddock than Atlantic cod when both were captured by otter trawl for tagging purposes and towed for approximately 30 min at speeds between 140 and 200 cm/s. Beamish [13] found that the mortality varied from 2 to 42% in haddock caught by otter trawl during a 30-min tow and a recovery period for 12 h. The majority of deaths occurred during the first hour after catch.

It is possible that a number of other factors affected the fish quality, positively or negatively, in our experiment and thereby diminished the effect of the different codends. Such factors could include the selectivity devises (flexigrids), the codend attachments (protection bags) and the thick twines used in the trawl nets.

The proportion of injured fish was in some cases higher when the catch size was larger (Table 4). However, the catches in this were rather small (Table 1). Wagner [18] reported that in his study the quality of the cod, expressed as external appearance and consistency, deteriorated as trawling time and catch size increased, while Hattula et al. [6] did not find any effect of catch size (100–3,500 kg) on the quality of herring. However, in both of these studies, the shorter the duration of the trawling, the larger the proportion of fish alive after being caught. Botta and Bonnell [5] showed that the reduction in the quality of Atlantic cod caught by otter trawl was primarily due to external factors, such as delayed bleeding, storage method and time as well as catch size. Catching more than 5 tons per haul decreased the overall grade of the cod.

The initial pH of cod was comparatively high considering the presumed handling stress the fish were subjected to during the catching process (Table 5). The differences observed between three of the hauls were probably due to catch amount in the hauls ($p = 0.03$). The haul with the cod with the lowest initial muscle pH had the highest catch amount, 2.8 tons. The initial pH of haddock was lower than that of cod, with no difference between trawl nets, hauls or catch amounts. Our results therefore indicate that haddock is more susceptible to handling stress than cod. Low pH at the time of killing is widely recognised as an indicator of handling stress, as reported in salmon [27], eel [28] and turbot [29]. Typical initial muscle pH values reported for exhausted cod is about 7.0 [30–32], which is lower than that reported for our cod, namely, pH 7.2–7.3 (Table 5). Surprisingly, this means that the cod in our experiment were just partially affected by capture stress. In previous studies, initial pH values for rested harvested farmed cod were reported to vary between 7.3 [30], 7.4 [32] and 7.9 [31].

Rigor mortis is highly influenced by the ATP-content in the muscle, and below a critical level, actin and myosin make an irreversible bond and muscle enters rigor mortis [33]. None of the fish showed visible signs of rigor when the catch was brought onboard, indicating that the fish had not died early during the 5-h trawling event. Rigor mortis onset occurred 5 h after catching, with no significant differences between trawl nets or fish species (Fig. 6). Since the initial pH value differed between the species, a difference in the development of rigor mortis could be expected between the species, with cod entering rigor later than haddock. However, we have no plausible explanation for this incidence. The early rigor mortis onset indicated that the trawled fish were exhausted, or nearly so, due to struggling and handling during the dragging and emptying of the trawl net. Maximum rigor was attained after 21 h, which is in accordance with Kristoffersen et al. [31], who found that cod exposed to preslaughter handling stress reached maximum rigor after 20–24 h. Hattula et al. [6] did not find any correlation between trawling time and rigor index in herring trawled for 2 and 4–5 h, but they did find that herring caught with gillnet developed rigor mortis earlier than herring caught with trawling or poundnetting. Gillnetted pike perch (*Sander lucioperca*) also developed rigor mortis earlier than fish caught by longline and harpoon [8].

The ultimate pHs in cod and haddock were significantly different (Table 6). These results are in accordance with those of Love [34], who found a higher ultimate pH in wild-caught cod (pH 6.7) than in haddock (pH 6.4–6.6). Hultmann and Rustad [35] reported a similar ultimate pH value for cod caught in November in northern Norway.

The mean gaping score for both species was low, and no effects of the two trawl nets were found (Table 6). These results are in line with those of Fletcher et al. [36] who found no effects of exercise on the tendency of gaping of king salmon. However, Jerrett et al. [37] doubted the usefulness of using gaping scores as an indicator of the propensity of the flesh to gape. Love [34] found that the connective tissue of cod is stronger at high postmortem pH values (pH > 6.6) than at lower pH values. Below pH 6.6, the muscle tends to gape more. In comparison, the ultimate pH values for our cod and haddock were 6.9 and 6.5, respectively.

There were some small blood spots in the cod and haddock fillets (Table 6), but no significant effects of the two trawl nets were observed. Our findings, with a low score for blood spots, indicate that the fillets were only slightly influenced by the catching and handling processes. Botta et al. [4] compared the gillnet, handline, longline and trap and reported that the method of catching significantly ($p \leq 0.001$) affected the colour and discolouration/bruising of Atlantic cod. The colour of our fillets was not different in fish caught in the different trawl nets, except that the cod fillets were lighter than haddock fillets (Table 7).

To conclude, the codend made from T90 netting caught slightly—but significantly—larger cod and haddock than the traditional codend. Haddock caught with traditional trawl net had more gear injuries related to the trawl gear than haddock caught with the T90 gear. No other differences in fish quality between the trawl nets were observed. Regardless of trawl type, most fish exhibited a high degree of external damage, particularly in terms of scale loss. Haddock were more susceptible to suffering damage than cod ($p < 0.001$). We recommend further research to confirm the possibly positive properties of the T90 trawl net. Additional research is also recommended to provide more scientific knowledge about how the trawling process influences the fish quality of other fish species.

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References

1. Fraser DI, Weinstein HM, Dyer WJ (1965) Post-mortem glycolytic and associated changes in the muscle of trap- and trawl-caught cod. J Fish Res Board Can 22:83–100
2. Auclair G (1984) Comparative-study of trawl and gillnet effects on the quality of fish. Canadian Institute of Food Science and Technology. Can Inst Food Sci Technol J 17:R25
3. Valdimarsson G, Matthiasson A, Stefansson G (1984) The effect of on board bleeding and gutting on the quality of fresh, quick frozen and salted products. In: Møller A (ed) Fifty years of fisheries research in Iceland. Icelandic Fisheries Laboratory, Reykjavik, pp 61–72
4. Botta JR, Bonnell G, Squires BE (1987) Effect of method of catching and time of season on sensory quality of fresh Atlantic cod (*Gadus morhua*). J Food Sci 52:928–931, 938
5. Botta JR, Bonnell G (1989) Causes of reduced quality of fresh Atlantic cod (*Gadus morhua*) caught by otter trawl. In: Proc World Symp Fishing Gear and Fishing Vessel Design. St. John's, Newfoundland, pp 340–344
6. Hattula T, Luoma T, Kostiainen R, Poutanen J, Kallio M, Suuronen P (1995) Effects of catching method on different quality parameters of Baltic herring (*Clupea harengus* L.). Fish Res 23:209–221
7. Cole RG, Alcock NK, Handley SJ, Grange KR, Black S, Cairney D, Day J, Ford S, Jerrett AR (2003) Selective capture of blue cod (*Parapercis colias*) by potting: behavioural observations and effects of capture method on peri-mortem fatigue. Fish Res 60:381–392
8. Özyurt G, Özogul Y, Özyurt CE, Polat A, Özogul F, Gökbulut C, Ersoy B, Küley E (2007) Determination of the quality parameters of pike perch *Sander lucioperca* caught by gillnet, longline and harpoon in Turkey. Fish Sci 73:412–420
9. Pankhurst NW, Sharples DF (1992) Effects of capture and confinement on plasma cortisol concentrations in the snapper, *Pagrus auratus*. Aust J Mar Freshw Res 43:345–356
10. Lowe TE, Ryder JM, Carragher JF, Wells RMG (1993) Flesh quality in snapper, *Pagrus auratus*, affected by capture stress. J Food Sci 58:770–773, 796
11. Hopkins TE, Cech J Jr (1992) Physiological effects of capturing striped bass in gillnets and fyke traps. Trans Am Fish Soc 121:819–822

12. Parker RR, Black EC, Larkin PA (1959) Fatigue and mortality in troll-caught Pacific Salmon (*Oncorhynshus*). J Fish Res Board Can 16:429–448
13. Beamish FWH (1966) Muscular fatigue and mortality in haddock, *Melanogrammus aeglefinus*, caught by otter trawl. J Fish Res Board Can 23:1507–1521
14. Korhonen RW, Lanier TC, Giesbrecht F (1990) An evaluation of simple methods for following rigor development in fish. J Food Sci 55:2
15. Chopin FS, Arimoto T, Inoue Y (1996) A comparison of the stress response and mortality of sea bream *Pagrus major* captured by hook and line and trammel net. Fish Res 28:277–289
16. Botta JR, Squires BE, Johnson J (1986) Effect of bleeding/gutting procedures on the sensory quality of fresh raw Atlantic cod (*Gadus morhua*). Can Inst Food Sci Technol J 19:186–190
17. Kelly TR (1969) Discolouration in sea-frozen fish fillets. In: Kreuzer R (ed) Freezing and irradiation of fish. Fishing News (Books), London, pp 64–67
18. Wagner H (1978) Einfluss der Schleppzeiten und Steertfüllung auf die Qualität des Fisches (in German). Seewirtschaft 10:399–400
19. Esaiassen M, Nilsen H, Joensen S, Skjerdal T, Carlehøg M, Eilertsen G, Gundersen B, Elvevoll E (2004) Effects of catching methods on quality changes during storage of cod (*Gadus morhua*). Food Sci Technol/LWT 37:643–648
20. Erikson U (2000) Rigor measurements. In: Kestin SC, Warris PD (eds) Farmed fish quality. Blackwell, Cornwall, pp 283–295
21. Andersen UB, Strømsnes AN, Steinsholt K, Thomassen MS (1994) Fillet gaping in farmed Atlantic salmon (*Salmo salar*). Norwegian J Agric Sci 8:165–179
22. Moderhak W (1997) Determination of selectivity of cod codends made of netting turned through 90 degree. Bull Sea Fish Inst 140:3–14
23. Moderhak W (1999) Investigations of the selectivity of cod (*Gadus morhua*) codends with meshes turned through 90 degree. Bull Sea Fish Inst 146:39–55
24. Main J, Sangster GI (1990) An assessment of the scale damage to and survival rates of young gadoid fish escaping from the cod-end of a demersal trawl. Scottish Fish Res Rep No 46/90. Fisheries Research Services, Aberdeen
25. Lehman KM, Sangster GI (1994) Assessment of the survival of fish escaping from commercial fishing gears. EC Contract Final Report No TE 3.741
26. McCracken FD (1956) Cod and haddock tagging off Lockeport. N S J Fish Res Board Can 64:10–15
27. Sigholt T, Erikson U, Rustad T, Johansen S, Nordtvedt TS, Seland A (1997) Handling stress and storage temperature affect meat quality of farmed-raised Atlantic salmon (*Salmo salar*). J Food Sci 62:898–905
28. Morzel M, Van De Vis H (2003) Effect of the slaughter method on the quality of raw and smoked eels (*Anguilla anguilla* L.). Aquac Res 34:1–11
29. Morzel M, Sohier D, Van De Vis H (2003) Evaluation of slaughtering methods for turbot with respect to animal welfare and flesh quality. J Sci Food Agric 83:19–28
30. Stien LH, Hirmas E, Bjørnevik M, Karlsen Ø, Nordtvedt R, Røra AMB, Sunde J, Kiessling A (2005) The effects of stress and storage temperature on the colour and texture of pre-rigor filleted farmed cod (*Gadus morhua* L.). Aquac Res 36:1197–1206
31. Kristoffersen S, Tobiassen T, Steinsund V, Olsen RL (2006) Slaughter stress, postmortem muscle pH and rigor development in farmed cod (*Gadus morhua* L.). J Food Sci Technol 41:861–864
32. Misimi E, Erikson U, Digre H, Skavhaug A, Mathiassen JR (2008) Computer vision-based evaluation of pre- and post rigor changes in size and shape of Atlantic cod (*Gadus morhua*) and Atlantic salmon (S*almo salar*) fillets during rigor mortis and ice storage: effects of perimortem handling stress. J Food Sci 73:E57–E68
33. Iwamoto M, Yamanaka H, Watabe S, Hashimoto K (1987) Effect of storage temperature on rigor-mortis and ATP degradation in plaice *Paralichthys olivaceus* muscle. J Food Sci 52:1514–1517
34. Love RM (1979) The post mortem pH of cod and haddock muscle and its seasonal variation. J Sci Food Agric 30:433–438
35. Hultmann L, Rustad T (2002) Textural changes during iced storage of salmon (*Salmo salar*) and cod (*Gadus morhua*). J Aquat Food Prod Technol 11:105–123
36. Fletcher GC, Hallett IC, Jerret AR (1997) Changes in the fine structure of the myocommata-muscle fibre junction related to gaping in rested and exercised muscle from king salmon (*Oncorhynchus tshawytscha*). Food Sci Technol/LWT 30:246–252
37. Jerrett AR, Stevens J, Holland AJ (1996) Tensile properties of white muscle in rested and exhausted Chinook salmon (*Oncorhynchus tshawytscha*). J Food Sci 61:527–532