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Mortality and injuries of haddock, cod and saithe escaping through codend meshes and sorting grids

By

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Abstract

Mortalities and injuries of the gadoids haddock (*Melanogrammus aeglefinus* L.), cod (*Gadus morhua* L.) and saithe (*Pollachius virens* L.) were studied after codend and grid escapement in two full scale trials in 2000 and 2001 in the Barents Sea. The escaped fish were sampled using small meshed cages. Trawl caught controls were sampled by removing the cod end and attaching the cage directly to the cod end extension. In the 2001 trial, control fish were sampled in fish traps in addition. Acoustic closing and releasing devices were used to time the sampling. Survival rates of cod and saithe escaping through codend and sorting grid were 100%. Mortality of haddock were 26.2 to 50.4% (codend escapees), 1.6 to 20% (grid escapees), 4.1 to 26.5% (trawl caught controls) and 0% (trap caught controls). The haddock mortality and injuries decreased with increasing fish length in all groups, with a mortality peek of the mesh escapees with girth approximately the mesh size circumference. Cod and saithe had significantly less skin and fin injuries than haddock, and in general, frequency of skin injuries increased towards the tail. Grid escaped gadoids had significantly less skin and fin damages than the mesh and control groups.

Introduction

For the efficient management of any fishery, the overall mortality associated with the exploited fish population needs to be considered. If this is not done, stock size estimates will be biased, with the degree of inaccuracy depending on the scale of the unknown mortality (Alverson *et al*., 2000). In trawl fisheries, most fish selection takes place through the meshes of the codend (Wileman *et al*., 1996) or, where appropriate, the bars of sorting grids (Larsen and Isaksen, 1993). The selective devices select out small fish, which are usually of less value or illegal to catch, and it is of vital importance for the fish stock that fish which escape from fishing gear should survive.

Studies of cod (*Gadus morhua* L.) and saithe (*Pollachius virens* L.) escaping through codend meshes and sorting grids have shown little or no mortality (Vinogradov, 1960; Engås *et al*., 1989; Engås *et al*., 1990; Soldal *et al*., 1991; Main and Sangster, 1991; Jacobsen *et al*., 1992; DeAlteris and Reifsteck, 1993; Jacobsen, 1994; Suuronen *et al*., 1995). Haddock tend to be more vulnerable, but experimental results have been highly variable, with survival rates ranging from 0 to 100%.

Most studies have found mortality rates in haddock that range from 0 to 30% (Main & Sangster, 1991; Sangster and Lehmann, 1993 and 1994; Lowry and Sangster, 1996; Sangster *et al*., 1996). Soldal *et al*. (1991) and Wileman *et al*. (1999) found mortality of mesh and grid haddock escapees to be less than 10%, and Jacobsen (1994) observed 15% mortality. Survival rates increase with fish length, and increasing mesh size and square-mesh codends therefore increase the potential survival of haddock and whiting (Main & Sangster, 1990 and 1991; Lowry *et al*., 1996; Sangster *et al*, 1996). Smaller fish were found to have more scale damage than bigger fish and the scale damage was greater towards the tail.

Most mortality occurred during the first 24 hours after escape, and declined with time (Lowry *et al*., 1996; Main & Sangster, 1991; Sangster *et al*., 1996). Sangster *et al*. (1996) also observed that the smaller escapees died sooner than the larger individuals. Physical injuries such as scale loss and sores can lead to stress and disturbed osmotic balance (Eddy, 1981; Sangster & Lehmann, 1993; Smith, 1993), and exhausted fish in the trawl mouth are likely to be hit and injured by a trawl. Substantial scale loss can lead to disturbance in osmotic balance and be a cause of death (Engås *et al*., 1989; Engås *et al*., 1990; Smith, 1993). Stress can be a vital factor, as described by Jonsson

(1994), who observed 40% mortality of the haddock that remained in a tank after he had captured haddock from the tank with a dip net. Intensive exercise, leading to exhaustion, can cause mortality (Wood *et al*., 1983), probably by intracellular acidosis. Having escaped from a trawl, fish may be more vulnerable to predation if they are injured and/or exhausted. However, one experiment could not demonstrate that cod escaping from a trawl suffered a greater risk of predation (Løkkeborg & Soldal, 1995).

Breen *et al*. (1998) and Wileman *et al*. (1999) showed that the survival of individual fish may be affected by the length of time spent in the codend cover during sampling, exposed to continous waterflow. The smallest individuals may not be able to maintain their position in the cover. In previous experiments that used codend covers to sample escaped haddock, mortality was probably overestimated.

Gadoid survival in bottom trawl fisheries was studied by Norwegian marine scientists in the late 80s and early 90s. Ten years later, fishermen and their organisations criticised the experiments for not beeing carried out on fishing grounds where several vessels were present, and it could therefore be asked if the mortalities of fish that passed through sorting grids several times might have been higher. It was also claimed that the experimental hauls were not of commercial length and with normal catch sizes. Furthermore, in previous experiments, except for the experiments of Wileman *et al*. (1999), fish were sampled only at the beginning of the trawl hauls, which could have biased mortality estimates.

For this reason, a new set of experiments was carried out in 2000 and 2001. With the technique used in this study, the sampling period can be controlled by closing and releasing the sampling cages from the trawl by means of acoustic releases. Sampling periods lasted from 5 to 15 minutes after one hour of towing.

Data were collected and analysed with the aim of studying:

- Mortality and injuries of gadoid that had escaped through the codend meshes and bars of a sorting grid in the Barents Sea bottom trawl fisheries.
- Relationships between fish size, mortality and injuries.

Materials and methods

Three commercial trawlers were chartered to trawl within a specified area for a week before the experiments started. Around 70 hauls were made each year. Trial 1 was carried out from 3rd to 23rd of August 2000 and trial 2 from 9th to 31st of August 2001. Both trials took place in the Barents Sea off the Varanger Peninsula.

The commercial trawlers were all rigged with single trawl gears and Sort-X sorting grids. The nominal mesh size in the codends was 135 mm and bar spacing in the grids was 55 mm.

The codend used for survival experiments was made of 2×5mm braided Magnet-PE twine. 20 meshes in a row were measured with a mesh gauge. Measurements ranged from 133 mm to 145 mm with an average of 138 mm (SE = 0.7 mm). The overall length of the codend was 9.4 m and the width 31 meshes (selvedges included).

A standard Sort-X sorting grid, mandatory in Norwegian waters north of 62°N, was used in experiments in which grid escapees were sampled.

Two sets of cover nets were used. One was attached to the front of the codend, covering the entire codend used in trials where codend escapees and control fish were collected (Figure 1 B and C), while another enclosed the sorting grid (Figure 1 A).

Two acoustic releases (AR 661 B2S from Oceano technologies) were mounted on the cover net in front of the cage. The first one was triggered to close the aft end of the cage and the second to release the cage from the trawl and close the cage in front.

The “FOCUS” - a towed underwater vehicle fitted with an underwater SIT camera was used to observe the trawl and cages during towing. In order to observe the cages after release in trial 1, an underwater camera connected to a video recorder was rigged on the lower end of a metal bar and lowered to the cage. In trial 2, a remote operated vehicle (ROV) was used (Super C’cat).

A current meter that measured current speed in cm/s every 5 min was anchored close to the cages in trial 2.

A total of nine cages were used to collect fish during each research period. In the first trial, they were cylindrical; 5 m long, 2 m in diameter, constructed of 25 mm plastic tubing. In the second trial the cages were square, 5 m long, 2 m wide and 2 m high, constructed of 70 mm aluminium tubing. The cages were constructed of knotted square mesh net with mesh size 50 mm (stretched mesh), and twine diameter 1.8 mm Polyethylene (PE). The rear end of the cage (the closing net) consisted of 19.6 mm (stretched mesh) Polyamide (PA) net.

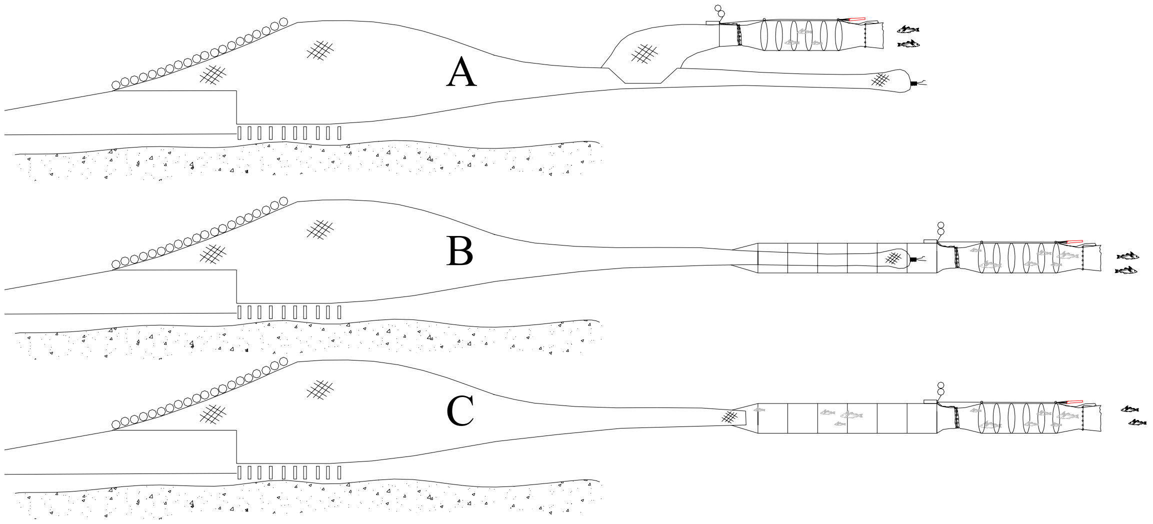

Figure 1 Cover nets and cages; A: Sampling of grid escapees, B: Sampling of mesh escapees, and C: Sampling of control fish where codend has been removed.

The nine cages were systematically rigged in three sets consisting of three hauls in order to minimize possible dependent variation in fish density. Fish were sampled from grid and mesh escapees plus a control haul, for which the codend was removed. Towing speed was 3.5 – 4 knots.

After rigging the cover net and cage the trawler started trawling and towed for approximately one hour with the cage open at the rear, letting all fish pass through. Then a signal was sent to the first release unit, which released a sea anchor connected to the rear end of the cage and closed it. The cage was then monitored by FOCUS and when a sufficient number of fish (100-200 individuals) was estimated to have entered the cage (after five to ten minutes), a signal was sent to the second acoustic release, which released floats and the cage from the cover net. The floats rose to the surface, maintaining tension on the front end of the cage and keeping it closed (see Figure 2 for chronological order for grid-cage release).

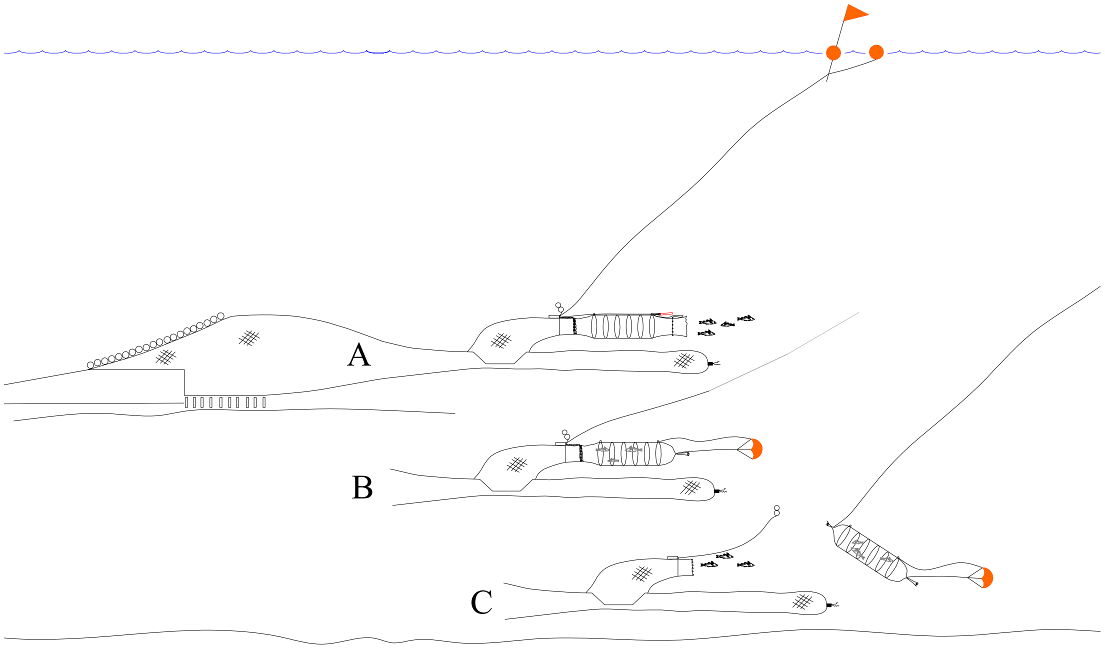

Figure 2 A: Towed with cage open, cover net encloses the Sort-X grid, B: Sea anchor released by acoustic release closes the cage and fish sampling begins, C: Cage released and closed in front by acoustic release.

In the first experiment, the auxiliary vessel then raised the cages to a depth of 40-50 m and anchored them on the fishing grounds. An active radar sonde was mounted on the marking buoy in order to track the cages during the next few days. Immediately after the cages were anchored they were inspected by the underwater camera in order to estimate the quantity of fish and check that they were properly closed. The cages were subsequently inspected every second day until they were recovered after seven days in the sea. A likely explanation of the high mortality in trial 1 was thought to be strong currents in the water. In trial 2, it was therefore decided to release the cages close to a fjord, tow them further into a sheltered area and anchor them on the bottom. The auxiliary vessel fetched the buoys after releasing the cages from the trawl, slipped a 10 kg weight down the rope to prevent the cages from lifting from the bottom and to ensure that the front opening had closed. The cages were then towed slowly (≤ 1 knot) for 50 to 85 min to the site where they were anchored and observed with the ROV to check the quantity of fish, their condition and cage closing. A second control group of trap-caught fish was included in trial 2. Three fish traps were set out and baited with mackerel. After the traps were closed, they were left on the sea-bed for six to seven days before they were taken up for observations. Live and dead fish in the cages and the fish traps were registered. The fish were measured (total length) to the nearest cm and the extent of injuries of living individuals was recorded. Each flank was divided into 7 areas and 10 fins were also defined as registration units. In trial1, fin injuries (cleft in fins), fin damage (bare fin rays), bleeding (blood visible but epidermis not ruptured), wounds (epidermis ruptured) and infections (purulence visible) were recorded. Fin injuries of all the cod and saithe were noted and skin injuries recorded.

In trial 2, bleeding (blood visible but epidermis not ruptured), wounds (epidermis ruptured) and scale loss were classified as small (<1 cm^2), medium (1-4 cm^2) and large (>4 cm^2). Clefts in fins, bleeding and bare fin-rays were registrated. After length measurement and injury registration all the fish were counted.

Data analysis

For length-dependent analyses, fish were divided into 5 cm length intervals. To test for differences in the length distributions of live and dead fish and for the General Linear Models analysis (GLM) (see below), true length was used at 1 cm intervals.

Total mortality was calculated as the percentages of each species found dead in each cage, and the percentages of dead fish in each length interval was calculated. When length-dependent mortality from more than one cage was calculated, the mean value was weighted by the total number of fish in each length class.

To test the number of skin injuries in each category, the General Linear Model (GLM) of the SAS software was used. Small, medium and large skin and fin injuries were tested against cage groups (mesh, grid, control), fish length (not grouped), flank areas (Figure 3, from snout to tail, 7 areas divided vertically), fin placement (dorsal, ventral and caudal) and between left and right sides.

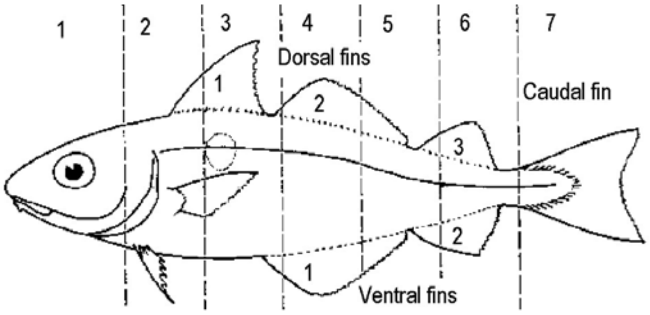

Figure 3 The flank was divided into 7 vertical sections for injury analysis. Dorsal and ventral fins were numbered as shown in the figure.

Results

Catch composition and mortality – trial 1

The total number of fish caught in trial 1 was 864. Of these, 685 were haddock, 94 cod and 83 saithe. No mortality was found among cod and saithe, but haddock mortality ranged from 1.6 to 50.4% (Table 1).

Cages no. 2 (mesh), 7 (grid) and 8 (mesh) were badly closed and therefore excluded from the survival analysis. The remaining valid mesh cage had the highest mortality rate of all cages and rejection of the other cages leads to high degree of uncertainty due to the lack of sufficient comparative data.

The observed mortality of haddock disregarding cages 2, 7 and 8, and irrespective of length, was 50.4% of mesh-selected fish, 12.1% of grid-selected fish and 9.2% of the controls. Percentages are weighted by the total number of haddock in cages.

Table 1 Cages in trial 1, number of fish and mortality arranged by type of experiment (mesh, grid, control).

Cage		Haddock			Cod	Saithe	Remarks
		Number		Mortality	Number		
No.	Type	Total	Dead	%			
2	Mesh	45	4	8.9	15	10	Excluded
5	Mesh	139	70	50.4	15	4	
8	Mesh	33	8	24.2	2	19	Excluded
1	Grid	64	1	1.6	4	8	
6	Grid	85	17	20.0	16	36	
7	Grid	40	4	10.0	16	0	Excluded
3	Control	194	23	11.9	20	3	
4	Control	74	3	4.1	3	0	
9	Control	133	11	8.3	3	3	

Mortality in all control cages was length dependent and mortality rates are merged in the figures (Figure 4). In cage 1 (grid), there was only one dead fish and mortality in that cage shows therefore significant difference from all others. In neither of the grid cages (cages 6 and 7) was haddock mortality length related, and these two cages are merged in Figure 4.

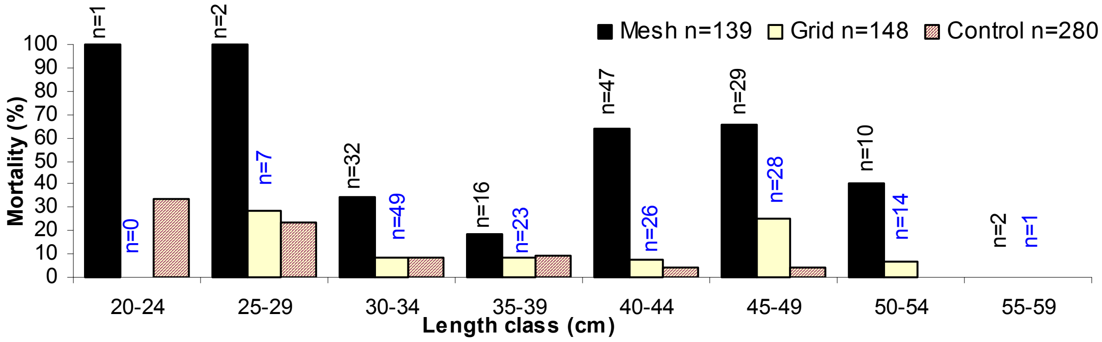

Figure 4 Mortality by length groups from valid cages; one mesh cage (solid bars), two grid cages (open bars) and three control cages (striped bars). Total number of haddock in each length class is given as n.

Mesh-selected fish suffered higher mortality than the other groups (Wilkoxon rank test, P<0.01). The mortality in the control groups was not significantly different from that of the grid-selected fish ($P>0.1$). Mortality rate was inversely proportional to fish length in the mesh group ($r^2=0.48$, $P<0.05$) and the control group ($r^2=0.81$, $P<0.005$). In the grid group, there was no correlation between length and mortality ($r^2=0.025$, $P>0.25$). A tendency to a peak in mortality could be observed in mesh and grid groups in the length interval 40 to 54 cm.

The length of the cod ranged from 30 to 59 cm in all valid cage groups ($n = 61$). Mean length in all groups combined was 44.1 cm, (SD = 5.9). In all cage groups combined, length of saithe ranged from 32 to 50 cm ($n = 54$), with a mean length of 38.6 cm, (SD = 4.9).

Catch composition and mortality – trial 2

A total of 8663 fish were caught in trial 2 (excluding fish from fish traps). Of these, 7442 were haddock, 999 cod, and 222 saithe. Four cages were excluded from analysis since many fish were observed slipping out of it, or because it did not contain sufficient fish. There were only one remaining cage containing grid escapees, and although the diver closed it, it had been open for part of the sampling period, with an outer diameter of the opening estimated to be about 30 cm. The net lay partly under the cage at the anchoring site, preventing escapes.

A total of 62 haddock, 25 saithe and 6 cod were caught in the fish traps. Of those, one saithe was found dead, whose death was caused by a parasite.

Table 2 Cages in trial 2, number of fish and mortality arranged by type of experiment (mesh, grid, control).

		Haddock			Cod		Saithe		
Cage no.	Cage group	Total	Dead	Mortality (%)	Total	Dead	Total	Dead	Remarks
2	Mesh	1700	546	32.1	320	0	56	0	
5	Mesh								Excluded
8	Mesh	2470	646	26.2	139	0	14	0	
1	Grid								Excluded
6	Grid	887	34	3.8	31	0	54	0	
7	Grid	4	0	0.0	2	0	6	0	Excluded
3	Control	601	129	21.5	404	1	30	0	
4	Control								Excluded
9	Control	1780	471	26.5	103	0	68	1	

Mortality rates of haddock, disregarding invalid cages cages, and irrespective of length, was 28.6% of mesh-selected fish, 3.8% of grid-selected fish and 25.2% of controls. Percentages are weighted by the total number of fish in the cages. Cod and saithe in the mesh and grid groups suffered no mortality. No relation was found between sampling period and mortality.

The mean length of dead haddock was significantly lower than that of live fish in all cages. Total average lengths did not differ between cage groups (P>0.05). There were significant differences between the length distributions of live and dead haddock in all cages (Kolmogorov-Smirnov test for goodness of fit, P<0.01). The length of haddock in the fish traps ranged from 25 to 49 cm, with an average length of 33.1 cm (SD = 5.1). The age-analysed haddock were predominantly two and three years old, and the age barrier were at approximately 34 cm.

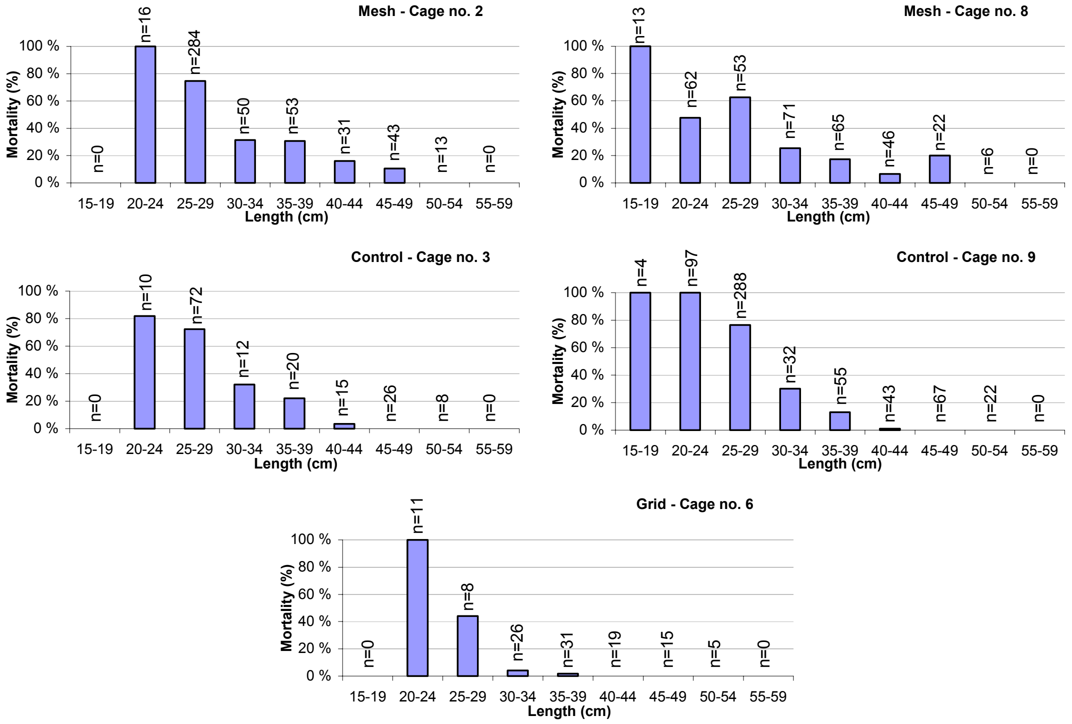

Figure 5 Mortality of haddock by length groups; n denotes total number of haddock in length group in each cage.

Length-related mortality was registered in all cages (Figure 5), P<0.005 in all cases. Cage no. 2 (mesh) had significantly higher mortality than any other cage and cage no. 6 (grid) had significantly lower mortality than the other cages. There was no significant difference in size-related mortality between control cages nor between control groups and cage no. 8 (mesh).

Cod and saithe

The length of the cod ranged from 18 to 63 cm in all cage groups (n = 360). The length of the 6 cod caught in the fish traps was from 26 to 52 cm. In all cage groups combined (n = 168), the length of the saithe ranged from 21 to 45 cm. In the fish traps, the length ranged from 18 to 38 cm.

Fish injuries – trial 1

Table 3 P-values from General Linear Model analysis. Bleeding, infections and fin injuries are categorized as small (S), medium (M) and large (L), non-significant values are denoted NS (α=0.05).

Test variables	Skin injuries			Fin injuries		
	Bleedings	Wounds	Infections	Fin damage	Bleedings	Infections
Cage group	NS	<0.05	NS	<0.01	<0.01	<0.01
Length	NS	NS	NS	NS	NS	NS
Cage*Length	NS	<0.05	NS	NS	NS	NS

All fin injuries and skin wounds differed between cage groups, among which mesh-selected fish showed the highest values and grid selected the lowest (Table 3 and Table 4). No relationship was found between length and injuries when cage groups were pooled. There were intercage differences in skin wounds, but no length relationship was found when individual cage groups were tested. The left and right sides of the haddock showed no differences when tested for injuries.

Table 4 Number and percentages of haddock with one or more recorded skin and fin injuries.

Cage group		Skin injuries			Fin injuries		
		Bleedings	Wounds	Infections	Fin damage	Bleedings	Infections
Mesh	n	17	6	0	41	35	20
n=41	%	*42*	*15*	*0*	*100*	*83*	*49*
Grid	n	42	6	5	71	46	22
n=103	%	*40*	*6*	*5*	*65*	*44*	*21*
Control	n	50	9	5	118	94	58
n=123	%	*40*	*7*	*4*	*96*	*76*	*46*

Skin injuries

There was no difference in number of the most common injury, skin bleeding, between cages. Approximately 40% of the haddock suffered skin bleeding.

Mesh-selected haddock had the highest mean number of wounds (P<0.05). 15% of mesh-selected haddock had one or more wounds, compared to 6% of grid-selected haddock and 7% of the haddock from control cages. Differences in skin infection between cages were not significant. The number of bleeding and wounds sites increased from snout to tail flank areas in all cage groups, with the highest mean number in flank areas 5 and 6. Skin infection differed significantly by flank area. Infections in grid-selected haddock were found only in flank areas 6 and 7 (five fish infected), but in haddock from control cages, the number of infections rose from flank area 3 to flank area 6 (five fish infected). Despite having the highest number of wounds, haddock from the mesh cage had no infections.

Fin injuries

Grid-selected haddock had significantly lowest frequency (65%) of fin damage, and 95% of the control haddock had one or more fin damages. Mesh-selected haddock displayed the highest frequency of fin bleeding, and grid-selected the lowest. 63% of mesh-selected haddock had more than one fin bleeding, while 20% of control and 16% of grid-selected haddock had more than one fin bleeding. Grid-selected haddock had the lowest rate of fin infections. 79% of grid-selected haddock had no infections at all, while 51% of mesh-selected and 54% of the control haddock had no infections. The dorsal and caudal fins in all cage categories were the most liable to suffer fin damage, while ventral fins had the lowest frequency in all cases. The frequency of damage in all fins but the rear ventral fin was highest in mesh-selected haddock, and lowest in all fins in grid selected fish. The caudal fin was most exposed to fin bleedings in all categories, with mesh-selected fish the most exposed and grid-selected the least. Approximately half of the mesh-selected (47%) and control (46%) haddock had infections in the caudal fin, which was the most exposed, compared to 21% of grid selected haddock.

Fish injuries - trial 2

Haddock

Table 5 P-values form General Linear Models analysis, bleedings, wounds and scale losses are categorised as small (S), medium (M) and large (L), not significant values are denoted NS (α=0.05).

Test variables	Skin injuries									Fin injuries							
	Bleeding			Wounds			Scaleloss			Bleeding			Wounds			Fin split	Fin rot
	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L		
Cage group	NS	NS	NS	NS	NS	<0.01	NS	NS	NS	<0.05	NS	NS	<0.05	NS	NS	NS	<0.05
Length	NS	NS	NS	<0.05	NS	<0.01	NS	<0.01	NS	NS	NS	NS	NS	NS	<0.01	<0.05	NS
Cage*Length	NS	NS	NS	<0.01	NS	<0.01	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Inter-cage variations were found for skin wounds, fin bleedings, fin wounds and fin rot, where grid-selected fish had the lowest rates of injuries in all cases (Table 5). Skin bleedings, skin wounds, scale loss, large fin wounds and fin split were related to the length of the fish for some of the sizes of injuries. Skin wounds showed significant effect of length interaction by cage group. The wounds of control haddock were not related to size. The prevalence of injuries is presented in Table 6.

Table 6 Numbers and percentages (italic) of haddock with one or more recorded skin or fin injuries.

Cage group		Skin injuries									Fin injuries							
		Bleedings			Wounds			Scale loss			Bleedings			Wounds			Fin split	Fin rot
		S	M	L	S	M	L	S	M	L	S	M	L	S	M	L		
Mesh	n	105	20	7	17	4	7	150	50	9	167	4	0	33	8	7	165	77
n=185	%	*57*	*11*	*4*	*9*	*2*	*4*	*81*	*27*	*5*	*90*	*2*	*0*	*18*	*4*	*4*	*89*	*42*
Grid	n	49	6	2	1	1	2	84	34	11	76	4	0	7	7	1	93	31
n=94	%	*52*	*6*	*2*	*1*	*1*	*2*	*89*	*36*	*12*	*81*	*4*	*0*	*7*	*7*	*1*	*99*	*33*
Control	n	86	30	9	15	6	3	125	48	14	143	16	1	37	7	12	155	70
n=161	%	*53*	*19*	*6*	*9*	*4*	*2*	*78*	*30*	*9*	*89*	*10*	*1*	*23*	*4*	*7*	*96*	*43*

No difference in injuries were found between the left and right flanks of the fish.

Skin injuries

No significant relationship between cage groups was found in skin bleedings. The wounds, which were mostly small (<1 cm^2), did not differ between cage groups. Less than 5% of the haddock in grid cages had skin wounds, compared to 14% of mesh-selected fish and 12% of the controls. Scale losses were quite common; 87 to 90% of haddock in the various groups had lost scales. Difference between flank areas were significant. Numbers of scale losses fell significantly with increasing length.No difference was found between cage groups.

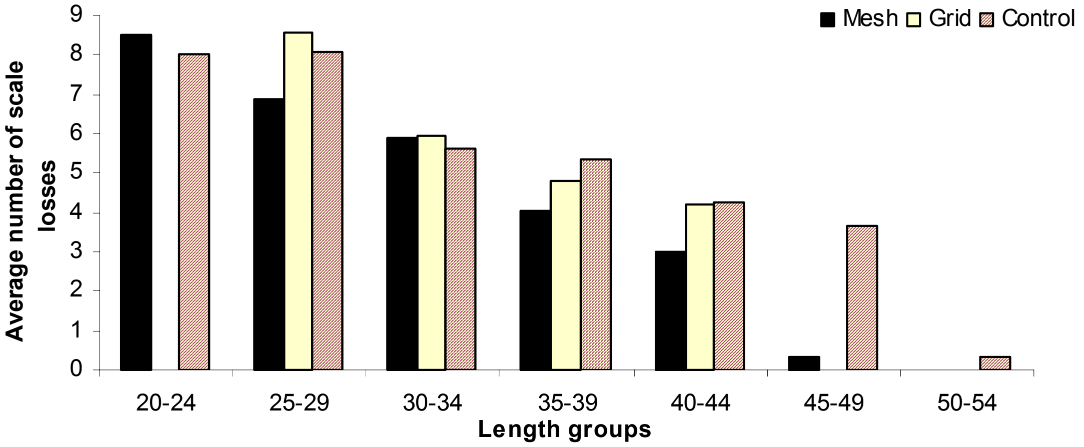

Figure 6 Number of scale losses by length.

The highest rate of bleedings was in flank area 6 in all cage groups; control haddock had the highest rate and grid-selected fish the lowest. The number of wounds did not differ between flank area and the distribution of wounds in terms of flank areas did not differ between cage groups. In all three cage groups, flank areas 4, 5 and 6 had most scale losses.

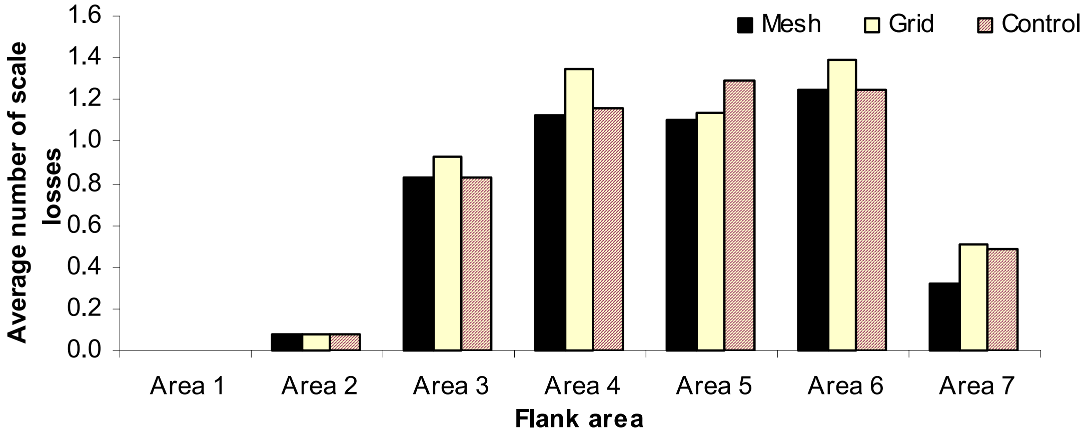

Figure 7 Number of scale losses by flank area

No difference in bleedings between length classes was found. Nor was there any length-related difference between cage groups (Table 5). Number of wounds in the mesh and grid groups showed a length relationship, while the controls did not (Table 5). However, only four haddock from the control group had wounds.

Fin injuries

All fin injuries except fin split differed among the cage groups, and grid-selected haddock had the lowest rate in all cases.

Only fin wounds showed a different pattern of distribution between cages. Grid-selected fish had the fewest wounds, and then only on the caudal fin. No wounds were found on ventral fins. The highest frequencies of fin bleedings were on the foremost dorsal fin and caudal fin in all cage groups, and mesh-selected haddock had the highest frequency of bleedings in all fins. The haddock's caudal fin was most liable to suffer splitting, where 92% of grid-selected fish, 83% of the controls and 76% of the mesh-selected haddock showed clefts. The second most exposed fin was the rear dorsal fin. The frequency of fin rot was highest in the caudal fin. Less fin rot was found in grid-selected haddock.

A decreasing trend in the number of fin splits and fin wounds occurred with increasing fish length.

Cod

Numbers of skin and fin bleedings differed among cage groups. The lowest values were found in the grid cage (Table 7 and Table 8). No length dependence was found in skin bleeding independent of cage groups, but the number of bleedings decreased with in line with fish length in both grid and control groups ($P<0.01$). Skin wounds were length-related, but only two fish from the grid group (35 and 36 cm) and one from the mesh group (42 cm) displayed wounds. A length-related relationship was found in small and total scale losses in all cage groups taken together. The only group that did not show a length relationship in scale losses was the mesh group (P>0.1). Small fin bleedings differed among cage groups. 67% of the control cod suffered small fin bleeding, compared to 65% of mesh-selected and 32% of the grid-selected fish. Medium-sized fin bleedings were length related. Four cod from the control group in the size interval 41 - 54 cm had medium-sized fin bleedings. No fin wounds were found in the cod. The frequency of fin splits was inversely related to fish length when tested independent of cage. Control and mesh-selected fish showed a length-dependent relationship (P<0.01) while grid-selected fish did not (P>0.5). Fin rot differed neither between cage groups nor length groups.

Table 7 P-values of relationships between cage groups (mesh, grid, control), fish length and interactions between cage groups and fish length. Non-significant values are denoted as NS (α = 0.05) and no observed injuries as -.

Test variables	Skin injuries									Fin injuries							
	Bleedings			Wounds			Scale loss			Bleedings			Wounds			Fin split	Fin rot
	S	M	L	S	M	L	S	M	L	S	M	L	S	M	L		
Cage group	<0.01	NS	-	NS	-	-	NS	NS	-	<0.05	NS	-	-	-	-	NS	NS
Length	NS	NS	-	<0.01	-	-	<0.01	NS	-	NS	<0.05	-	-	-	-	<0.01	NS
Cage*Length	<0.01	NS	-	<0.01	-	-	<0.05	<0.05	-	NS	NS	-	-	-	-	<0.05	NS

Table 8 Numbers and percentages (italic) of fish with one or more recorded injures. Sizes of injuries are denoted as S (small), M (medium) and L (large).

Cage group		Skin injuries									Fin injuries							
		Bleedings			Wounds			Scale loss			Bleedings			Wounds			Fin split	Fin rot
		S	M	L	S	M	L	S	M	L	S	M	L	S	M	L		
Mesh n=71	n	47	5	0	1	0	0	9	0	0	46	0	0	0	0	0	54	4
	%	*66.2*	*7.0*	*0.0*	*1.4*	*0.0*	*0.0*	*12.7*	*0.0*	*0.0*	*64.8*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*76.1*	*5.6*
Grid n=31	n	9	0	0	2	0	0	3	2	0	10	0	0	0	0	0	22	1
	%	*29.0*	*0.0*	*0.0*	*6.5*	*0.0*	*0.0*	*9.7*	*6.5*	*0.0*	*32.3*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*71.0*	*3.2*
Control n=104	n	40	0	0	0	0	0	19	1	0	70	4	0	0	0	0	82	8
	%	*38.5*	*0.0*	*0.0*	*0.0*	*0.0*	*0.0*	*18.3*	*1.0*	*0.0*	*67.3*	*3.8*	*0.0*	*0.0*	*0.0*	*0.0*	*78.8*	*7.7*

The distribution of skin and fin bleedings and skin wounds differed between cage groups. Most skin bleedings in all cage groups were found in flank areas 1 and 2. Two fish from the grid group and one from the mesh group had skin wounds on the head. The most frequent sites of fin bleeding in mesh-selected and control-group cod were on the foremost dorsal fin, but on the foremost ventral fin in grid-selected fish (10 fish). No fin wounds were found in the cod. The distribution of fin bleedings and fin rot did not differ among fins when this was tested with all cage groups pooled. The distributions of scale loss, fin split and fin rot over the flank area and fins did not differ among cage groups. Fin splits differed among fin and were most frequently found on the caudal fin and the rearmost dorsal and ventral fins. There was no trend in the distribution of fin rot by fins or cage groups.

Saithe

Injuries were registered on a total of 17 saithe from mesh cages and 20 from grid cages , but on none from the control cages Only fin bleedings showed differences between cage categories ($\alpha = 0.05$). Twelve saithe (71%) from the mesh group had small fin bleedings, while eight (40%) from the grid cages had this type of injury. Injuries were not length-related.

Skin bleedings, scale losses and fin split differed significantly between flank area and fin location. The four mesh-selected saithe showed bleedings in areas 1 and 2, and the only saithe from the grid group had skin bleeding in area 6. Flank areas 3 - 5 showed the highest frequencies of scale losses in both categories, with mesh-selected fish having 83% and grid-selected fish 74% of scale losses in these areas. No fin splits were found in the caudal fins of mesh-selected saithe and only in one fish out of 20 in saithe from the grid group. These data are limited and definite conclusions cannot be drawn.

Fish traps

Thirty haddock from two fish traps were examined in order to quantify injuries. Fish length ranged from 26 cm to 49 cm (mean length 33 cm). Fewer scale losses, fin bleedings and fin wounds were found in haddock taken in traps than in trawl hauls (pooled data, $P<0.01$). No length relationship was found among registered injuries.

No fin wounds were observed and injuries were predominantly small. Skin bleedings and skin wounds were predominantly on the snout. Scale losses did not differ among areas (GLM test, $P=0.67$). Fin splits were most common on the tail, while fin bleeding and fin rot were more evenly distributed.

Discussion

Experiment procedure

Cage number 6, the only valid grid cage in trial 2, was partly open after anchoring and was therefore closed by a diver before being taken up for observation. The inner diameter of the opening was approximately 25 - 30 cm. If the cage was open while towing, fish may have leaked out, affecting the observed survival rate.

In trial 1, the mesh cages were released and anchored at depths of less than 100 m, except for cage 5, the only valid mesh cage which had 50% haddock mortality. This cage was released at a depth of between 100 and 130 m and then floated up to 50 m depth and anchored. Assuming a similar ability in haddock and cod to resorb gas from the swimbladder, this ascent is close to the tolerance limits of the fish and may have affected the mortality rate. Cod is estimated to need three hours to adapt to a 50% reduction in depth (Harden Jones and Scholes, 1985), and a rapid 70% depth reduction results in ruptured swim bladders (Tytler and Blaxter, 1973). The results obtained by Tytler and Blaxter indicate in fact that haddock have a lower tolerance to pressure reduction, and this may explain the high haddock mortality in this cage. No mortality of cod or saithe was observed.

Due to high turbidity in the sea (visibility approximately 1 m), no observations of behaviour in the cages, number of fish in the cages or of the functionality of the cage mechanism could be made in trial 2.

To close the rear end of the cages, sea anchors, pulling constraining ropes through climb locks were used. Closing frequently and the closure system will have to be improved in future experiments.

Cod and saithe – mortality and injuries

No mortality of cod and saithe was recorded in these experiments in either mesh or grid escapees. These results are in agreement with previous experiments (Vinogradov, 1960; Engås *et al*., 1989; Engås *et al*., 1990; Soldal *et al*., 1991; Main and Sangster, 1991; Jacobsen *et al*., 1992; DeAlteris and Reifsteck, 1993; Jacobsen, 1994; Suuronen *et al*., 1995), and show the high tolerance of these species. The only dead cod and saithe were found in control cages in trial 2. The most likely explanation is that they had been left in the trawl from previous hauls and ended up in the cages during towing of the control cages. The injuries sustained by cod and saithe tended to be less than in haddock, and in all cases, the fewest injuries among the cage groups were seen in the grid group. Many saithe suffered small scale losses, but this did not lead to mortality.

Haddock – mortality and injuries

In both trials, mortality in mesh selected haddock was higher than in grid-selected fish. Overall mortality, disregarding fish length and cage groups, ranged from 1.6 to

50.4%. In trial 1, the mesh-selected fish had the significantly highest mortality rate, with no difference between grid and control cages. In trial 2, there was no statistical difference between mortality in mesh and control cages, but the mortality in the grid cage was significantly lower. The lowest and highest mortalities in our experiments were for grid (1.6%) and mesh (50.4%) escapees in trial 1. Similarly, the lowest and highest mortalities in trial 2 were 3.8% in grid and 32.1% in mesh cages. However, the mortality in the mesh cage in trial 1 may have been caused by rapid pressure reduction, and the survival rate in the grid cage in trial 2 may have been affected by the opening in the cage.

It was evident that injuries were significantly less frequent in grid cages than in control and mesh cages. These results are in agreement with previous experiments (Marteinsson, 1991). One likely explanation is that the grid escapees did not have to pass through the narrow extension between the trawl belly and the codend, since the grid was mounted in front of the extension. Another possible explanation lies in the fact that the sampling cage for the grid escapees was floating above the codend during towing, attached to the cover net above the sorting grid, while the mesh and control cages were towed behind the trawl, with resulting differences in water flow within the cages. The cages attached to the codend cover were also closer to the bottom than the grid cages, and possibly covered by sand and mud clouds from the trawl gear. These clouds may have caused stress and gill irritations.

Most fin injuries were found on the caudal and dorsal fins. In both trials, the injuries were significantly lowest in grid-escaped haddock; only fin split showed no inter-cage variation. In trial 2, rates of fin bleedings and fin wounds were significantly lower in trap-caught controls than trawl-caught haddock, which suggests that the trawling process and/or the sampling technique are likely to be the main causes. Fin injuries were usually small and not length-related, and were thus unlikely as an explanation of the mortality.

There was no mortality of trapped control fish, except for a single dead saithe whose cause of death was probably unrelated to capture or cage captivity. Although the trap-caught haddock had some small injuries, some of them were significantly less serious than those of the trawl-caught groups. These injuries (scale loss, fin bleeding and fin wounds) should therefore be focused on when explaining mortality. Furthermore, since mortality of all trawl-caught haddock in trial 2 was size-related, the injuries most likely to affect mortality are also expected to be size-related. Of the injuries that differed from those of trap- and trawl-caught haddock, only skin injuries were length-related and therefore the most likely physical explanatory factor of mortality. It has nevertheless to be borne in mind that only live haddock, and not dead fish, were examined for injuries.

The haddock mortality in trawl-caught control cages was higher than in earlier experiments in which controls were sampled by barbless hooks (Main and Sangster, 1990; Sangster, 1992; Sangster and Lehmann, 1994; Sangster *et al.*, 1996). It had been expected that the fish in the control groups would suffer the lowest mortality and injury rates since they avoided the mesh and grid escape process. The control groups were not "real" controls, since the fish went through the fishing process, except for escaping from the mesh and grid. Nevertheless, they were important, since the comparison to the other groups showed that escaping through codends and grids is not the main cause of mortality.

Haddock mortality was size-related, and was significantly inversely related to fish length except in the grid cages in trial 1. The causes of mortality, physical or physiological, must therefore be related to the size of the fish. The most likely reason for the size-dependent mortality is the lower swimming capacity of smaller individuals. The smallest haddock have been observed slinging from side to side between the net walls of the trawl when exhausted (Marteinsson, 1991), probably leading to skin damage. Most skin injuries were found on the most flexible region of the body, the rear part. Beating the tail, probably when pressed against net walls of the trawl or cage during trawling, is therefore the most likely cause of the skin injuries. If the injuries had been caused mainly by squeezing through meshes, they would have been predominantly at the broadest body part, while random collisions with the net panels would have led to injuries being more evenly distributed over the flank area. The cages could also have size-related mortality effects since the smallest individuals may not be able to maintain their position in the cage during towing.

In all cages, scale loss and mortality in trial 2 were length-dependent, while there were no length-related injuries in the haddock in trial 1, and length dependency in mortality was not observed in all the cage groups. One possible cause of this difference between trials is the differences in the techniques employed in the two trials, such as the towing of cages to a sheltered area after release from the trawl. The degree of scale loss in trawl-caught haddock in trial 2 was size-related, and differed from that of haddock in fish traps, in which no mortality occurred. Scale loss may therefore be regarded as one explanatory variable of mortality. The results regarding length-related scale loss and mortality of mesh-selected haddock are in agreement with previous experiments (Marteinsson, 1991; Soldal *et al.*, 1991; Sangster and Lehmann, 1994; Sangster *et al.*, 1996; Breen and Sangster, 1997).

A peak in mortality of mesh-escaped haddock was found in length classes whose girth approximated the mesh circumference. The probable girth of a 50 cm haddock is approximately the same as the circumference of a 135 mm mesh (Marteinsson, 1991). The peak in mortality of mesh escapees between 40 and 54 cm in trial 1, and the fact that mesh escapees in trial 2 had highest mortality rates in 40-44 cm and 45-49 length class, indicate that escaping through meshes was a cause of death in individuals whose girth was close to the mesh circumference. The mesh-selected haddock in trial 1 had most skin wounds, and the highest rate of large skin wounds in trial 2. The wounds were size-related, with the highest values recorded in the 45-49 cm length class. The observation that the skin wounds of haddock in mesh cages were more frequent than in both grid and control cages indicates that the wounds were obtained by the mesh escapement.

Conclusions

Our experiments indicated that cod and saithe tolerate selection through meshes and grid without their survival being affected. Haddock mortality was higher and size-related, irrespective of the channel of escape and control sampling. Swimming ability is regarded as a critical factor, and the observed mortality could have been caused by fish passing through the trawl or by the sampling procedure. Mesh and grid escapes are not believed to be the main cause of mortality, although mesh escape might have increased mortality in larger haddock whose girth was similar to the circumference of the codend meshes. Scale loss was size-related in the same way as mortality, and could be one of the factors explaining mortality. Since there was no significant difference between the scale loss of mesh-, grid- and trawl-caught control cages, escapes are not believed to have been the main cause of scale loss, but either collisions of exhausted fish with the front part of the trawl or the sampling procedure. In general, grid escapees sustained significantly fewer injuries than mesh escapees and trawl-caught haddock, probably because they avoided having to pass through the extension between trawl and codend. A possible degree of mortality caused by the sampling methods used has been discussed. Before further studies are carried out, it is important to evaluate the possible mortality-inducing effects of the experimental procedure.

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